

PRO-CON DEBATE

MODERATOR:

Sulpicio G. Soriano

Where should we operate on the preterm neonate?

The case for operating in the NICU

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Introduction

For some years now, there has been a controversy concerning the best site to perform operations in sick and unstable neonates (1–3). The challenge still remains for a surgical team to perform a matched control study as this has not been achieved to date. Series reported in the literature tend to identify two separate populations; one of larger infants, more easily transportable, less sick, with less respiratory compromise versus a smaller, sicker group with a higher prevalence of more difficult ventilation (1,3,4).

Both sides of the debate seek to advocate that their approach is ultimately in the best interests of the infants but, understandably, each approach this with differing emphases.

The pro-operating room (OR) camp maintains that the key elements are surgical team efficiency, housed in operating environments with which they are familiar, with all their usual equipment and disposables to hand. It may also be presumed that the operating department environment also promotes a more aseptic environment.

Summary

The ideal venue for neonatal surgical procedures has been the subject of a contentious debate between the leading pediatric hospitals throughout the world. Bias toward the location of neonatal surgery tends to be based on institutional practices. The following opposing viewpoints from two leading pediatric institutions in the United Kingdom and the United States highlight the relevant issues.

The cogency of this argument thus hinges on the assumption that what is best for the surgical team must, ultimately, be best for the infant.

The other side would argue that the best approach is to view this more directly from the point of view of the sick infants and then seek to address how any possible deterioration of these patients can be minimized by ensuring that unnecessary transfers are avoided and that there is no hiatus in the continuity of care these infants receive from their intensive care teams. It also challenges the notion that intensive care units are in any way inferior microbiological environments compared with the combination of operating departments and the inside of transport vehicles.

The argument for operating in the neonatal intensive care unit (NICU) thus hinges on addressing what is best for the infant by the strategy of putting it at the center of considerations and then seeing how this can be achieved through the flexibility, innovation, and organization of surgical teams.

Although surgical ligation of persistent ductus arteriosus (PDA) in the NICU has been a long-standing and

widely reported procedure (5,6), perhaps it is time to consider extending this facility to infants with other conditions.

Risks of transport

With the advances seen in neonatal and pediatric intensive care transportation, there is a tendency to believe that they have become so refined that the safety concerns and physiologic deterioration historically associated with such transfers have become so minimized that they can be discounted. However, this is not borne out by recent evidence (7–9).

Just because it is possible to do these transports, even in very sick patients on extracorporeal circuits, and because most services have become better at doing them, it does not mean to say that they are risk-free. The corollary is that it would be better, if possible, to avoid them if they are not strictly necessary.

The conventional model of neonatal surgery requires the baby to be transferred to the tertiary surgical unit, irrespective of the respiratory and cardiovascular challenges, and the need to move serially between different set-ups of ventilators and monitoring for transport between NICU, the OR and then either to a local NICU or back to the referring NICU. This entails transport in a road vehicle for journeys possibly up to two hours and by air if ground transport times are longer, dependent on geography and various national practices.

Data indicating that outcomes are worse if infants with necrotizing enterocolitis are transferred for surgery, rather than operated on in the NICU, may be dismissed as being rather historical (3) but very recent data from Michigan examining transports of very low birth weight (VLBW) infants, that is, <1500 g, using a previously validated transport risk index of physiologic stability ('TRIPS'(10)), confirm the previous historical findings of real deterioration in these infants (7). This latter study identified that increased transport times of only greater than 15 min were associated with increased morbidity. The causes for this deterioration in TRIPS were the most common changes in temperature but also deterioration in cardiorespiratory parameters. Another recent study from the USA examining a national database of over 67 000 VLBW infants showed a nearly doubled increased incidence of intraventricular hemorrhages (IVH) in those infants subject to interhospital transports, and the severity of these IVHs in the transported cohort was significantly greater (8).

In a study looking at the critical incidents occurring in a regional neonatal transport service and measures taken to reduce these over a 6-year period, the best that could be achieved was to reduce the incidence of adverse

events from 34 to 18% (9). While this represents a real and laudable reduction, the residual rate is nonetheless indicating that modern transports are still incident-prone. This should not be surprising. Where it may be difficult enough to maintain stability in the sickest patient on an intensive care unit (ICU), it will not be any easier to achieve this in a moving vehicle. Moving the patient from bed to stretcher-incubator to OR, then back to stretcher-incubator and back to an ICU bed, quite obviously presents multiple opportunities for dislodgment of cannulae, tubes, drains, etc. To this must be added the inertial effects on the circulation of vehicular motion and the challenges of maintaining the correct body temperature.

Additionally, one has to consider immediate postoperative instability caused by the release of inflammatory factors from compromised intestinal mucosa, fluid shifts, the effects of lung compression during tracheo-esophageal fistula repair or ligation of PDA or the more recently recognized postligation cardiac syndrome (PCLS) after PDA closure (11). This latter condition is associated with the early requirement for expert analysis of the postligation echocardiogram in guiding the need for fluid and inotrope administration. If the cardiac output is refractory to inotropes, then it is entirely possible that the infant is demonstrating relative cortisol deficiency and hydrocortisone therapy may be indicated (12,13). It is difficult to see how such standards of care can be achieved while the infant is being transported back from the OR to the referring NICU.

One may make the point that irrespective of the exact final location of surgery, many infants have to be moved anyway; for example, in the situation where VLBW infants have to be moved to other NICUs to either just to receive higher specification care or for surgical expertise. The logic is poor, however; if it can be accepted that transporting infants is not risk-free and has been shown quite recently to be associated with physiological deteriorations (7), then compounding this by adding a supplementary transport purely for surgery in an OR and then returning the infant to an NICU immediately thereafter, that is, two additional transports, one with an immediately postoperative infant, cannot be advocated as a strategy of negligible risk.

Infection

A legitimate concern when operating outside the OR environment is the possible effects on wound infections. One of the hospital design features common to both OR and critical care areas is highly specified controlled and filtered air changes. Hospital design requirements for environmental ventilation, in terms of air changes

per hour as a means of infection control are much the same in the USA, the UK, and Australia (14). Both operating rooms and critical care areas have higher flows than other clinical areas and have high efficiency particulate air filtration (HEPA) and positive pressurization. Air changes per hour ($AC\ h^{-1}$) for critical care areas are recommended at 12–15 $AC\ h^{-1}$ and for operation rooms at 20 $AC\ h^{-1}$ (14,15). However, there are no such precautions for the environments involved in the transport of patients; hospital corridors and transport vehicles. Even when infants are placed in warm incubators, radiant heat losses to neighboring cooler structures can still occur and briefly moving outdoors when embarking into vehicles will exacerbate the problem. Areas such as critical care units and operating departments with higher air changes are inevitably prone to increase wind chill effects on small, preterm infants, particularly with open body cavities so, in either environment, active measures to prevent infant hypothermia must be undertaken.

Some data exist on the incidence of infection when performing surgery in the NICU. In a small series in Ireland reporting 27 thoracic or abdominal procedures undertaken in the NICU, there was no identifiable surgical-related morbidity and, in particular, no wound infections (16). A larger series from the Netherlands, reporting on 45 infants having a mix of abdominal and ductal surgery, found no evidence of infection directly attributable to the surgical procedure (17).

In a large, 10-year series of 312 infants operated on in the NICU noted that there was no increased risk of wound infections or positive blood cultures (4).

However, such data have to be interpreted in the knowledge that, in these studies, there were no matched control groups.

Continuity of intensive care

A number of treatments underway in the NICU may have to be interrupted if the infants move. This could include oscillatory or other sophisticated ventilation that cannot be reproduced on a transport ventilator, nitric oxide, dialysis, or hemofiltration.

However, if it is decided not to move the infant, but to move the surgical team, there is nothing to disrupt the detailed knowledge of the case held by the neonatal intensive care staff. On the other hand, if the baby is transferred, all this background has to be handed on to OR staff whose involvement in this child will be relatively fleeting and perhaps less responsive to any nuanced change in parameters that would be otherwise identified by staff more used to the patient (1,2,4).

Convenience and 'preferences'

One of the human factors that need to be addressed is the fact that the surgical team may not be as familiar with the NICU environment as their normal OR. However, it can also be appreciated that this is in effect a self-fulfilling scenario that can be changed by an attitudinal switch and by doing more operations in the NICU, so gaining greater familiarity and ownership of that environment. For example, in a series from Philadelphia concerning 72 patients with persistent ductus not only did the surgical team perform surgery outside their OR in the NICU of their own institution but, expressly to avoid transferring these neonates, they also travelled to other institutions' NICUs, one of which was 75 miles from their tertiary base (6). The outcomes appeared no different whether the operation was performed 'in-house' or in another institution and, in qualitative terms, demonstrated additional beneficial aspects for the families involved. Additionally, regarding the more objective outcome of mortality, subsequent deaths in these infants (seven infants of 72 operated overall) all occurred more than 96 h after surgery and were attributed to respiratory failure, intraventricular hemorrhage, and generalized sepsis, rather than the surgery *per se*.

While there is an undoubted 'lack of convenience for the surgical team' in operating in the NICU, this should be offset against the elimination of the various adverse factors that are inherent for the infant in the transfer process (2).

Some changes obviously need to be made in surgical practice; for example, the use of headlights as opposed to reliance on overhead OR lights (16). For anesthesiologists, unfamiliarity with NICU ventilators may present a challenge but this can be overcome with organizational preparedness (outlined below). The unavailability of inhalational anesthesia may be a challenge, but most anesthesiologists can easily switch to intravenous anesthesia. Some units advocate that if the baby is not yet already intubated on the NICU, then this can be performed by the local NICU team prior to the arrival of the surgical team and equally, the NICU team can extubate the baby when most appropriate rather than this being attempted immediately postprocedure, thus removing yet another time-pressure on the surgical team (4). In some respects, therefore, the surgical team's 'convenience' can be enhanced.

In a 10-year study of their practice in operating in the NICU on 312 'general' surgical neonates with quite a wide spectrum of disorders, Hall *et al.* (4) noted an growing acceptance of operating in the NICU among surgeons, anesthesiologists, and OR staff, and this even

evolved to a preference for the NICU model among practitioners in that unit. However, they also found an emerging consensus that for the more complex operations on term or near-term infants who were not previously ventilated, these would be better operated on in the OR.

There was also recognition that when operating in the NICU, there was a degree of disruption for the general running of the NICU and for the other families in the NICU.

Organizational considerations

In a 7-year review of their practice of operating in the NICU, Arbell and colleagues analyzed the care given to infants under 1000 g at the time of surgery for bowel perforations, all with the evidence of hemodynamic compromise. Anesthesia was performed by both anesthesiology and neonatology staff drawn from the local teams and working in tandem. When compared against data in the contemporaneous literature for infants with similar pathologies operated in ORs, the survival outcome results of this group operated in the NICU were certainly no worse regarding the operation itself at 24 h or 30-day postprocedure (2). This would indicate that operating in the NICU, when all logistical preparations have been thought through, is at least as safe as the practice of transferring these sick and potentially unstable infants to and from tertiary surgical centers.

The point was also made in an earlier series from Australia, that as far as possible, the whole team that would be expected to work together in the OR, should remain the same when in the NICU (6). Not only does this preserve the integrity of the team and could be expected to reduce human-factor errors, it defrays the aspect of working in a less familiar environment.

Thorough briefing of both the OR and the neonatal teams, establishing clear expectations on both sides, should be undertaken, protocols written for future reference and clear operational plans made that also encompass local radiology and the local blood bank (18,19).

It is clear that suitable equipment must be organized (4,16). This would include heating lamps, open incubators with radiant warmers and mattress heaters, and surgical and anesthetic equipment. Although overhead heaters will have to be turned off or swung away during the actual procedure to avoid thermal injury to the surgeons' heads, the mattress heating can be retained and warm air heaters used just as in the OR.

Dependent on local practices, orientation for the visiting anesthesiologists on NICU ventilators should be undertaken – or the presence of a NICU respiratory technician should be ensured during the procedure.

The anesthetic technique has to become intravenous rather than inhalational, partly due to space but also due to lack of appropriate scavenging in the NICU (16).

One of logistical benefits and efficiencies is the fact that the surgical team can go to the infant when it suits their operating schedule, obviating the difficulties associated with the transfer model where either a late arrival of the patient will delay the surgical program, or an inappropriately early arrival of a sick infant will cause distraction and disruption to the receiving and holding area, be that the operating department, the recovery area, or other critical care facility (16).

The question then arises concerning the distance a surgical team could or should travel to perform surgery. One team reports traveling as far as 75 miles in which to perform PDA ligation (6), but in view of scant data in this regard, it is impossible to be prescriptive. Viewed pragmatically, the relative logistic advantages of performing the procedure in the NICU but according to the surgical team's program will be eroded progressively as the time to travel between centers increases. Perhaps the overriding consideration is ensuring that the infant is operated in a NICU with optimal facilities and staffing to deal with its pathophysiology. Often therefore these types of facilities, namely tertiary NICU and neonatal surgical teams, will most commonly coincide, if not on the same campus, then in the same city. It is debatable at which point the logistic economic and logistic impact on the surgical team eventually outweigh the potential benefit to the infant in not being moved and this will hinge on factors such as distance, time and local organizational factors such as reliable availability of vehicles at all times. It will work best when the team can leave promptly, have the NICU environment prepared and 'ready-to-go' and, once the procedure completed, able to return without delay. This offsets the logistic inefficiencies of the delivery of the infant by a NICU team either too early or too late in the surgical program. If carried out in a practised, time-efficient manner then, quite apart from the debate about the demerits of moving sick infants, no more personnel is required to bring this about, other than the transport vehicle and driver, and thus should be independent of any consideration about size of the surgical unit overall.

In their 10-year experience of operating in the NICU, Hall *et al.* (4) have identified a number of challenges and their solutions. Environmental factors are space, lighting, anesthetic access, temperature control, equipment, and unit disruption. The solutions found were protected environment with mobile screens; surgical head-light; sterile, and transparent drapes to visualize the child; thermal mattress and warmed air system; and

fully stocked surgical, and anesthetic equipment and disposables (i.e., duplicated from OR). Regarding human factors, there had to be a consensus that operating on the NICU is in the best interest of the infant; neonatologist and anesthesiologist working closely before, during, and after the case; and, for team working, careful preparation and team briefing.

Conclusions

Disadvantages of surgery on the NICU

The clearest challenge for the surgical team is to overcome unfamiliarity with the NICU environment. This entails ensuring that there is reliable availability of the necessary equipment, instruments, and disposables that surgeons and anesthesiologists will require. Additionally, steps must be taken by both neonatal and surgical teams to ensure that workable space is made available to the surgical team so that their ability to give quality care to the infant is not compromised.

Where necessary, anesthesiologists must be given the opportunity to be trained on the NICU ventilators so that necessary adjustments can be made promptly as the patient's condition requires. For those services more dependent on respiratory technicians, it is clear that these personnel should be available for the duration of the procedure.

Benefits of surgery on the NICU

These benefits are principally for the infant but that should be the objective of all the teams concerned. This

rather places the onus on the surgical and neonatal teams to rise to this challenge and find ways in which this objective can be met.

Consequently, these infants can continue to receive their on-going sophisticated intensive care with minimal disruption, without exposure to the inherent risks of transport and, never having had to leave to continuity of care they are receiving from their neonatal medical and nursing staff, they can be immediately returned to the care of these personnel once the procedure is completed (1–4,6,11,16,17,19).

Are there any 'absolutes'?

Clearly, there is little point in undertaking surgery in the NICU where necessary bulky or overtly impractical ancillary equipment precludes this. This would include procedures entailing cardiopulmonary bypass, laser work or where intraoperative diagnostic imaging such as radiological screening or magnetic resonance is needed and probably would include laparoscopic, thoracoscopic, and endoscopic procedures or where particular patient positioning is required (4).

By contrast, some procedures are currently commonly performed in the NICU or PICU; exploration and closure of postoperative sternotomies, ligation of PDAs and particularly ligation or partial occlusion of arterio-pulmonary shunts on extracorporeal circuits, and there are circumstances when a patient is precariously maintained on high-frequency oscillatory ventilation that some may regard as an 'absolute'.

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The case for operating in the OR

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Introduction

Neonates who require surgery are at high risk for morbidity and mortality. Consequently, neonatal intensive care unit (NICU) patients who undergo surgical and/or diagnostic procedures present the greatest challenge for the pediatric anesthesiologist. The National Surgical Quality Improvement Program for Improving Neonatal Surgical Care (NSQIP) data for 2011 disclosed 2938 neonatal surgical cases in 43 US children's hospitals (20). Newborn surgeries performed in the United States range from elective operations on full-term newborns to emergent procedures on preterm neonates. The goal of any pediatric anesthesiologist managing these patients should be to provide the safest and most effective perioperative care and to strive to minimize any contribution to their morbidity and mortality. Often times, NICU patients requiring surgical intervention have their procedures performed at the NICU bedside. The presumed reasoning for bedside surgery is to minimize adverse events associated with transport to the operating room (OR), thus providing the most favorable medical care to the patient. This may not be the best practice.

Our review will focus on the advantages of the OR setting to perform surgery on neonates as opposed to performing them in the NICU. Significant issues include the decision regarding procedure location, the precise nature of the procedure under consideration, the urgency of the situation, the resources available in each location, and the personal preferences of the surgeon, anesthesiologist, and neonatologist.

Direct comparisons between the performance of neonatal surgery in NICU or OR have not been rigorously examined for many reasons. Practices vary among institutions regarding the location of neonatal surgical procedures. An analogy can be surmised by the contrasting management strategies of newborns with congenital dia-

phragmatic hernia (CDH) at Boston Children's Hospital and The Hospital for Sick Children in Toronto. Despite very different management strategies implemented by these two major children's hospitals, survival rates at the two institutions are nearly identical (21,22). However, the most apparent distinction between the two institutions is the transport of the patient from the NICU to the OR. Transporting critically ill newborns within an institution can be fraught with difficulty and risks, but it can be, and is being, routinely performed safely. It is even reported that several hospital systems around the globe can safely execute interhospital transport of patients on extracorporeal membrane oxygenation (ECMO) support over very long distances (23,24). At our own institution, a large percentage of neonates on ECMO or high-frequency modes of mechanical ventilation have been transported without undue risk throughout the hospital for over a decade. An unpublished institutional review of more than 900 such intrahospital transports did not reveal any adverse events such as line dislodgement, extubation, or requirement for additional emergency resources en route.

Personnel

Just as surgeons specialize in particular areas such as general surgery, urology, otorhinolaryngology, cardiac surgery, etc., so do the OR nurses and the pediatric anesthesiologists who work at major children's hospitals. In general, the nurses and pediatric anesthesiologists are not as limited to a given area of specialization as the surgeons are; but nurses and anesthesiologists often develop expertise in one or more surgical subspecialty areas. Due to the logistics of operating suites, there are experts from many different backgrounds available to offer consultation or assistance at any given time. As anesthesiologists, we are also accustomed to seeking and

offering advice to colleagues for various technical or complex issues. This support can include instructing a trainee in regional anesthesia/analgesia, vascular access, airway management, patient positioning, ventilator adjustment, or even trouble shooting unexplained alarms while the attending anesthesiologist of record devotes her/his attention to the overall care of the patient.

In addition to providing skilled help with challenging technical issues that arise in the care of critically ill newborns, anesthesia colleagues that are in close proximity in the OR suite may act as 'another pair of eyes and hands' during a complex case. Their availability can be indispensable during a very stressful situation when tunnel vision can come into play when dealing with critical issues. Even having a colleague available to simply help in evaluating laboratory results obtained during the case can be quite beneficial. Such collaboration is not unique to our specialty in the operating room environment. Operating room nurses often consult more experienced colleagues for assistance in patient care or to offer advice on the use of equipment such as laparoscopes, specialized surgical instruments, and equipment or even placement of a bladder catheter in a very tiny patient. Even the surgeon, the person ultimately responsible for scheduling and performing the procedure, benefits from the proximity of other surgical colleagues in the OR suite.

For the OR to work efficiently and safely, we rely on the availability of other ancillary care providers such as OR assistants, patient care technicians, pharmacists, and others. Surgical cases would not go forward as we are accustomed without their assistance. As pediatric anesthesiologists, we rely on the expert help of the anesthesia technicians in every case. These integral members of the anesthesia team not only assist in preparing the OR prior to a case, such as performing the anesthesia machine safety check-out, but they are also available to immediately provide additional airway equipment, invasive monitoring devices, anesthetic adjuncts, and transport monitors for use at the conclusion of a case. Their skill in assisting the anesthesiologist in the OR is essential to conduct a safe anesthetic. In addition to anesthesia technicians, OR pharmacists play a unique role in the delivery of peri-anesthetic care. Although the system of drug delivery and accounting in the OR is structured differently among institutions, the OR pharmacist's niche is central to the smooth functioning of the OR system. They are a valuable resource for specific drug indications and dosages. Consider the time it takes to go from the anesthesiologist's decision to administer a particular medication that is not immediately available in the OR, such as an infusion of a vasoactive or hemo-

static medication or a solution with a nonstandard glucose concentration, to the delivery of that medication to the patient. The turnaround time for such medications is remarkably brief due to the training and skill of the OR pharmacist.

It goes without saying that the personnel involved in the care of the patient in the NICU are essential to the patient's overall wellbeing and are debatably the best resource regarding the patient's history and care. So, when surgeries are carried out in the OR, these valuable individuals and their knowledge and expertise are not immediately available. In order for cases to be performed with the greatest possible safety, there must be a complete and thorough transfer of pertinent information between the NICU team and the OR team prior to departure from the NICU. Once this handoff is thoroughly completed, we feel that communication between the OR and NICU teams can and should be able to continue on an as needed basis. In our institution, the NICU nurses and physicians carry phones and we are easily able to call with questions as they arise during the case. Our NICU population includes patients cared for in extramural NICUs, located in separate hospitals. When these patients come to our ORs, the primary RN accompanies the patient and is invited to stay in the OR for the entire procedure. Such open and available communication is vital to the success of caring for surgical neonates in the OR.

Equipment

Equipment availability and staff knowledge of its use are also vital to the success of neonatal surgery. For our purposes, the term equipment refers to everything available and needed to perform surgical procedures exclusive of personnel. When surgery is performed out of the OR environment and in the NICU, equipment issues can arise. We use the example of ECMO cannulation at our institution to demonstrate some pitfalls as it is a procedure that is nearly always performed at the bedside and many of the patients for whom this intervention is needed are newborns. The exceptions are ECMO cases performed in the cardiac OR's where separation from bypass cannot be accomplished and the patient is brought to the cardiac intensive care unit (CICU) on extracorporeal support. The process has evolved and improved with time and experience. Despite this, there are many occasions when a member of the ECMO cannulation team is urgently dispatched from the ICU bedside to the OR for additional equipment, such as another cannula, additional suture material, etc. Once the cannulae are in place, radiographic confirmation is carried out via portable CXR, not fluoroscopy, which is available in the OR. This technique can lead to a delay

in repositioning access if needed. We can only infer that such pitfalls will only be magnified in cases where a given procedure is carried out less frequently in the ICU. Just as additional medical and nursing expertise is available to procedures conducted in the OR, it seems obvious that additional equipment that the surgeon or anesthesiologist will unexpectedly need is immediately available in the OR, but not in the ICU.

Considering logistics, the physical layout in the ICU is less conducive to straightforward anesthetic care as it is in the OR. In the OR, the surgeon, nurses, and anesthesiologist discuss the layout of the room, plans for patient positioning, and changes in location or position of the OR table prior to the procedure. In the NICU, there is, of course, no OR table; the patient's bed becomes the OR table, a use for which it was not originally designed. While many ICU beds may have height adjustments, they cannot be moved in any other ways. In addition, there are many neonatal beds that have overhead clearance limits due to heat sources attached to the top of the bed. With this bed setup, it is easy to infer that intraprocedure X-rays in the NICU are much more problematic than in the OR. Also, taking X-rays while the newborn is within a sterile field in a NICU bed is not routine for technicians, adding another layer of complexity and breakdown in sterility.

In the NICU, sterility can be assured at the start of a procedure with proper skin decontamination as is performed in the operating room; however, maintaining this condition can be challenging in ways not seen in the OR. A matter as simple as draping the patient is no longer routine when the patient is in a NICU incubator. Further difficulties with the maintenance of a sterile operating field and sterile instruments will occur with any of the instruments is dropped or considered nonsterile for any reason. In the OR, there are small autoclaves located throughout the suite. Instruments deemed nonsterile are regularly 'Flashed', cooled and returned to the surgical team in short order. This, of course, cannot occur when the procedure is taking place in the NICU.

Another obstacle in the NICU is that physical access to the patient. Access is greatly limited compared with the operating room, and this can contribute to sterility issues as well as issues associated with being out of routine. The anesthesiologist is often at the side of the patient or a corner of the NICU bed, as opposed to the head of the bed, and must struggle with the various drapes, shelves, infusion pumps, and other barriers that are part of the NICU bed spaces and surgical setup. There is a logical reason for the design of the NICU in this fashion as there are different priorities for the NICU team on a daily basis. For example, venous

access in the NICU compared with the OR is inherently different. In the interest of minimizing breaking into a line in the NICU, there are many, many permanent connections. These connections are often to infusion pumps and some of these connections are used for intermittent administration of medications by the nursing staff. In contrast, in the OR, the pediatric anesthesiologists will assure themselves that all connections of intravenous lines are exactly tailored to their needs. Total parenteral nutrition lines are untangled and often isolated, and dedicated venous access for the rapid administration of (resuscitation) medications is assured. For safety and by training, the pediatric anesthesiologist must have a secure line for the administration of what the anesthesiologist wishes to administer, if nothing else is assured. Details matter in the anesthetic care of all children, but are of the utmost importance with these tiny, critically ill patients and the details are different in the NICU.

The ventilators are also different in the NICU. It is often the case that the ventilators on the anesthesia machine are inadequate to provide equivalent mechanical ventilation to these newborns. Neonatal intensive care unit ventilators are specifically designed for use in term and preterm newborns and their function and form is slightly different from that of the standard anesthesia machine. Due to this difference, pediatric anesthesiologists must often ask the respiratory therapists (RT) in the NICU for assistance with the ventilator equipment. It is necessary to have the RT readily available in the NICU for ventilator management during bedside procedures. If the procedure is to take place in the OR and the anesthesiologist deems the NICU ventilator more appropriate for the patient than the OR ventilator, then it is possible to have the RT to prepare the same ventilator for us in the OR. While patients requiring high-frequency oscillatory ventilation (HFOV) do require a hiatus from their ventilator on transport, they can be temporarily managed by manual ventilation that aims to mimic the HFOV during the transport process. If the patient is not on HFOV, it is possible to transport with a battery-powered NICU ventilator. The RTs act as an indispensable resource and can also review changes we may undertake in the OR during the procedure if we are not as adept at using the NICU technology. As safety factor in our institution, the RT leaves a contact phone number for us to call with questions. In addition, the patient's nurse accompanies the anesthesia team to the OR to assist in transport and that nurse also leaves a contact phone number for routine questions or emergent inquiries.

Another significant equipment-related issue that will occur with greater frequency over time is the increased

use of minimally invasive procedures in the newborn. These techniques have been used in older, larger children for some time and with recent advances in technology, formerly open procedures are being accomplished in smaller, younger children. As, on occasion, even an operating room will become too crowded in cases with minimally invasive procedures require cumbersome equipment and viewing screens that can even crowd ORs designed to accommodate them. Not only will minimally invasive surgeries impose nearly impossible space and infrastructure requirements on the NICU, cases involving any endoscopies, (such as airway, pulmonary or GI) will similarly be performed much more safely, thoroughly, and efficiently in the OR. Endoscopies are often part of a surgical procedure and the ability to record both still and moving images is an important part of these procedures. This capacity is not available in distant locations such as the NICU.

'NOW' and 'STAT'

For better or worse, OR staff are involved in patient resuscitation more often and for different reasons than caregivers in any other location of the hospital. At our institution, when the overhead paging system announces 'now' or 'stat' or if someone in an OR hits the STAT button, the response is both immediate and well attended. Whether the problem stems from the loss of an airway, cardiovascular compromise or something less urgent, there is plenty of expert help for any problem that may face the anesthesiology team and it is available immediately regardless of the reason. Also, there is no uncertainty about roles in response to an OR emergency. By convention, the attending anesthesiologist and surgeon in the respective OR quickly inform those who have arrived about the pertinent issues and direct the responding team in whatever is needed. There is no delay in action and additional equipment and/or expertise is brought to bear as needed in the OR. Newborn medicine nurses and doctors are certainly expert in the resuscitation of their patients, but resuscitation from surgical or anesthetic difficulties can be different from resuscitation in the delivery room or NICU. When emergency issues arise in the NICU during neonatal surgery, there may be unnecessary delays as the anesthesiologist and newborn medicine caregivers are not as used to collaborating on such issues and may have alternate approaches. For example, if resuscitation medications are needed, there may be delays as the doses and timing are debated. Even the rate at which medications are pushed or infused may be drastically different. As anesthesiologists, we are used to drawing up and pushing medications routinely, and we have a sense of urgency for many medications that doctors in other

fields do not; it is often custom for doctors to order a medication and have a nurse administer them which may cause what we perceive as a slight delay in treatment.

Intangibles

If the advantages of undertaking neonatal surgery and anesthesia in the OR versus the NICU remain difficult to quantify, the intangibles are even more so. Human nature makes it so that we are all more comfortable, and therefore, at our best, when we are at 'home' in a familiar environment. For surgeons, OR nurses, and anesthesiologists, 'home' is the OR. With regard to perioperative care, anesthesiologists are nothing if not creatures of habit, compulsive to a fare-thee-well; the pediatric anesthesiologist arguably more so than others in the field. When infrequent procedures are performed outside of our 'home', in the completely different location of the NICU, and with only a handful of the individuals involved being well know to us, it is difficult to imagine that we can easily function at our best. We are aware of this phenomenon and consider its consequences in many circumstances, such as when a new staff anesthesiologist joins our group. Even though they are sufficiently trained in the field, and even aware of our equipment and computer systems, they are given several days of orientation to the operating rooms to become familiar with the details of the physical OR layout as well as procedural and cultural differences. It is valuable time to gain an intangible comfort with their new surroundings. Once orientation is complete, their case assignment is tailored so that they gradually assume care of more and more complex patients and procedures to ensure a safe transition into practice. None of this can occur with the relatively rare procedures performed in the NICU. For the most part, there is no orientation to the NICU and with the rarity of surgical procedures performed on NICU patients, an individual anesthesiologist, surgeon, or OR nurse may be called upon to function in that strange (to them) environment only on occasion. The fact that they are critically ill patients, located distantly from the OR, only compounds the difficulty with ensuring the safest of care. For example, at our institution in the year 2012 there were more than 400 surgeries done on newborns, but with a staff of greater than 100 pediatric anesthesiologists, the chances that any one of us would be a regular member of the perioperative team in the NICU is exceedingly small.

Conclusions

We have no doubt that many types of surgical procedures can be safely and efficiently performed in the

NICU environment, the advantages of the OR location mentioned above notwithstanding. Just as all politics is local, the same may be said about the location of surgery involving NICU patients. We think that all will agree that decisions about the location of surgery on complex neonatal patients should be made after careful deliberation involving all concerned parties, separate from any urgent clinical situation and certainly not ad hoc on a case-by-case basis.

If an institution is contemplating on performing procedures in the NICU, there are several compulsory considerations. Specific procedures should be designated as appropriate for the NICU location. These might include venous access procedures, placement of peritoneal drains, and management of gastroschisis. As the group of surgeons, anesthesiologists, neonatologists, and nurses discusses which specific procedures can be performed in the NICU, measures can be considered that will improve the environment for the 'visiting' surgeons, OR nurses, and anesthesiologists. These include, but are not limited to: the use of screens to isolate the case and minimize disruption on NICU routines outside of the surgical procedure, as well as keeping the number of people near the surgical site to a minimum which enhances sterility and minimizes unneeded interrup-

tions; the use of transparent drapes to facilitate the anesthesiologists access to the newborn; the use of underbody forced air warmers and discontinuing overhead warmers; and provision of adequate lighting for the surgeon. Prior to initiating these cases, the anesthesiologist, neonatologist, and neonatal RN must have a conversation and all be certain of each person's role in the anticipated and unanticipated events that may occur in the perioperative care of the patient. Regardless of the location chosen by the care team for these NICU patients, it is critical that there be ongoing analysis of patient outcomes. This evaluation is essential to assure that neonatal care is not only being conducted safely, but that it continues to improve through thoughtful efforts.

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Conflicts of interest

The authors declare that they have no conflict of interests.

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