Role of a Hybrid Room in Damage Control Surgery

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Dushyant Iyer, Chad G. Ball,
and Scott K. D'Amours

Abstract

Time to hemorrhage control is the key performance indicator of a trauma system. Open and percutaneous techniques represent complementary therapeutic modalities that may both be necessary in achieving expedient hemorrhage control. In most trauma facilities, the operating theater and angiography suite are separate rooms, not infrequently located on different floors or buildings. Transfer between these locations increases time to hemorrhage control and the chances of a patient succumbing to physiological exhaustion. By unifying an operating theater and angiography suite, hybrid rooms offer the potential to minimize time to hemorrhage control through nullifying the dilemma of deciding the optimal location to best manage a patient's ongoing bleeding.

D. Iyer, B.Med., M.D.
Department of Trauma Surgery, Liverpool Hospital, The University of New South Wales, Sydney, Australia

C.G. Ball, M.D., M.Sc., F.R.C.S.C.
Department of Hepatobiliary and Pancreatic Surgery, University of Calgary, Calgary, Canada

Department of Trauma and Acute Care Surgery, University of Calgary, Calgary, Canada

S.K. D'Amours, M.D., C.M., F.R.C.S.C. (✉)
Department of Trauma Surgery and General Surgery, Liverpool Hospital, University of New South Wales, Sydney, Australia
e-mail: Scott.Damours@sswahs.nsw.gov.au

8.1 Time to Hemorrhage Control

Exsanguination is the primary cause of death on the battlefield and the second leading cause of death in civilian trauma [1, 2]. On autopsy, it has been found that many of these patients have technically repairable injuries and may have survived if hemorrhage control was obtained before the onset of irreversible shock [3, 4]. Thus, the emphasis on actively resuscitating and arresting bleeding in the "golden hour" has formed the basis for modern trauma care. Indeed, in recent decades, trauma systems around the world have streamlined prehospital care services to expedite transport to specialized trauma centers by bypassing other hospitals and improved the layout of their units to allow easy access to CT scanners, operating theaters, interventional radiology suites, and intensive care units from their emergency departments.

Recent literature has indicated the importance of time to hemorrhage control as a key performance indicator in the management of trauma patients. One retrospective analysis of hemodynamically unstable patients with severe abdominal injuries found that every 3-minute delay in laparotomy commencement was associated with an approximately 1% increase in mortality. Furthermore, a retrospective study investigating hemodynamically unstable trauma patients that required early therapeutic interventional radiological (IR) procedures found that a delay to

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radiographic vascular occlusion was independently associated with more than a twofold risk of mortality and that for every hour delay, the risk of mortality increased by 47% [5].

Concurrent damage control resuscitation is imperative in extending the window for definitive hemorrhage control. Indeed, the acute coagulopathy of traumatic shock is a well-documented phenomenon that is independently associated with up to a fourfold increase in mortality [6, 7]. Successful damage control resuscitation involving the early administration of tranexamic acid and warmed blood products and the sparing use of crystalloids, potentially guided by viscoelastic tests (thromboelastography (TEG) and rotational thromboelastometry (ROTEM)), may prevent and reverse the lethal triad of hypothermia, acidosis, and coagulopathy.

8.2 Hemorrhage Control

Hemorrhage control may be achieved in an operating theater with open surgical techniques, such as the ligation of bleeding vessels or the application of direct pressure through packing. However, certain anatomical locations of bleeding such as the pelvis, retroperitoneum, and solid organs (e.g., the spleen) may be more expediently controlled through the application of endoluminal techniques in an angiography suite. Indeed, interventional radiology (IR) and the use of catheter-directed angiography, intravascular balloon occlusion, embolization of bleeding vessels, and the deployment of stents to repair damaged vessels have become an imperative component of modern trauma care [8–10].

This is highlighted by the evolution in the management of hemodynamically unstable patients with pelvic fractures. Historically, this cohort of patients has a significant reported mortality that ranges from 10% to 42% [11–13]. Indeed, the surgical exploration and ligation of bleeding pelvic arteries are technically challenging, time consuming, and potentially comorbid. The invasion of the retroperitoneal space and disruption of formed clots have the propensity to exacerbate bleeding. While elegant surgical techniques such as preperitoneal pelvic packing have been developed and used successfully in some centers [14, 15], pelvic angiography and transcatheter arterial embolization (TAE) have been shown to be effective, acute interventions for arterial hemorrhage control [16]. A systematic review of the literature found that the efficacy of rate of emergency TAE in controlling retroperitoneal arterial hemorrhage associated with unstable pelvic fractures found an efficacy rate of 81–100% with a very low rate of associated complications [8].

Given the complementary nature of open and percutaneous techniques, it is often difficult to choose where to transport a bleeding patient for hemorrhage control. Consider, for instance, a prehospital retrieval team en route to your emergency department with a young male involved in a motorcycle collision. The retrieval team informs you that the patient is hemodynamically unstable, has an unstable pelvis on clinical examination, and has a positive FAST scan indicating intraperitoneal free fluid. Such a patient will demand time-critical decisions in regard to diagnoses, resuscitative strategies, and use of techniques to arrest bleeding. Indeed, it is difficult to establish what the most active site of extravasation is and whether the operating theater or the angiography suite is the most optimal location to transport the patient. In most trauma facilities, these destinations are separate geographic rooms, not infrequently located on different floors or buildings. Unfortunately, if the hypothesis defining the most compelling site of extravasation is incorrect and patients require further transportation to an alternate location, the time to hemorrhage control and the chances of a patient dying because of physiologic exhaustion secondary to the lethal triad increase.

This scenario is not uncommon; a retrospective review of persistently hypotensive patients arriving to a Canadian level I trauma center in a 17-year period found that 35 (7%) of these patients required both angiography and an operative interventions for ongoing hemodynamic instability [17]. Interestingly, there was a 90% rate of mortality (<24 h) in patients transferred to the angiography suite after the operating theater.

The authors stated that death in these patients was almost entirely due to ongoing hemorrhage and physiological exhaustion and that transport from one site to another was clearly a significant factor contributing to this poor end result.

8.3 Hybrid Suites

A trauma hybrid operating theater represents a dedicated location where open operative and percutaneous procedures can be performed concurrently with the added benefit of offering rotational computerized imaging and ample space to resuscitate the patient. The term hybrid room is synonymous with a RAPTOR unit (resuscitation with angiography, percutaneous techniques, and operative repair). By uniting an operating theater and an angiography suite, hybrid rooms offer the potential to minimize time to hemorrhage control through nullifying the dilemma of deciding the optimal location to best manage a patient's ongoing bleeding. Additionally, time lost in transit between two locations can be saved when one technique cannot completely control bleeding.

Like many other hospitals with hybrid rooms, the construction of a RAPTOR suite at Liverpool Hospital has been the centerpiece of a broader initiative to improve the delivery of quality trauma care. In preparation for the suite's construction, the center developed a "hot floor" that was connected to the helipad and emergency department by a high-speed elevator system. This floor was designed with broad corridors and configured to contain operating theaters, diagnostic and interventional radiology suites, and the intensive care unit in close proximity to each other. The RAPTOR suite was constructed close to the entrance of the operating theater complex, minimizing its distance to the elevator and intensive care unit.

The RAPTOR suite is essentially a large operating theater configured around a floating radiolucent table that allows for a mobile C-arm to preform rotational angiography. All components apart from the table, including a high-resolution flat screen monitor, are mounted on frames attached to the ceiling. These frames are built for flexible positioning, including the important ability to be stowed away (Fig. 8.1). The components are controlled from a large glass-paneled room adjacent to the suite. Three sets of doors around the suite allow for large numbers of personnel to enter and exit and bring additional equipment such as ultrasound and near-infrared spectroscopy machines without interfering with ongoing procedures.

Recent updates to the suite include an automated positioning program that minimizes human error when moving the robotic C-arm.

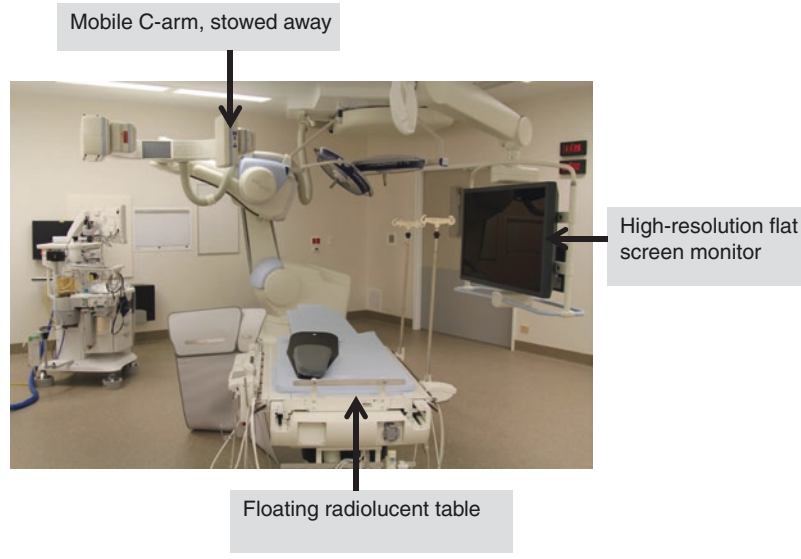

Fig. 8.1 RAPTOR suite at Liverpool Hospital

Wireless ultrasound transducers that connect to monitors via Bluetooth are useful in reducing congestion of valuable floor space and in reducing the potential for personnel to trip. Finally, while the rotational computerized imaging offered by the C-arm is not the same quality as that provided by a formal CT scanner, newer software enables the 3-D fusion of the static images obtained from a CT scanner with the real-time images obtained from rotational computerized imaging.

8.4 Overcoming Challenges Associated with Hybrid Suites

Traditionally, the early management of severely injured trauma patient has been compartmentalized into separate domains: the prehospital phase, the emergency department, the CT scanner, the operating theater, the angiography suite, and the intensive care unit. Each of these domains represents a distinct environment with unique objectives, equipment, and personnel with specific skills sets and team structures. Hybrid suites integrate these compartments and the personnel involved. Needless to say, it is a logistical challenge for the large numbers of clinicians required to effectively operate these suites to balance priorities, make collaborative decisions, and work in close proximity to each other. Furthermore, the team must respond effectively to dynamic information that may arise from real-time radiological and operative findings in the suite.

When conceptualizing their hybrid suite, the Calgary group recognized that with the increased propensity for complex decision-making and technical interventions, there was a greater potential for conflict and miscommunication [18]. Thus, before embarking on construction, the group assembled a multidisciplinary group consisting of architects, builders, clinicians, and allied health staff from emergency medicine, surgery, and anesthesia to optimize the final design of the suite. A plywood mockup of the preliminary model was constructed, and a committee of over 30 persons participated in a series of complex simulation scenarios under direct observation by several video cameras setup around the suite. The video footage, and specifically the movement of personnel, was analyzed to demonstrate high-traffic areas and "bump" points. This analysis led to a number of recommendations that translated in to changes in the suite's design [18].

One difficult issue experienced at Liverpool that is not unique to our hospital remains the high turnover of staff. With trainees regularly rotating through the emergency, surgical, radiology, anesthetic, and intensive care units, it is challenging to maintain a high level of competency with clinicians who may need to utilize the suite. Indeed, there have been instances when patients with injuries that were suitable for treatment in the RAPTOR suite were taken to the operating theater. Retrospective discussions regarding the decision-making process often reveal that the clinicians on site felt more confident in the familiar environment of the operating theater. This issue is being addressed through an increased emphasis on education and training for new clinicians beginning work at our center. We are also in the process of conducting a retrospective review of the use of our hybrid suite with the goal of developing formal criteria that will assist clinicians in identifying when to activate the RAPTOR suite.

Finally, there will always be clinicians who are more comfortable treating traumatically injured patients in the traditional compartmental model of trauma care. Thus, it is imperative to develop a core group of clinicians with a passion for utilizing the hybrid suite to improve the delivery of trauma care. One strategy to reduce the reliance on personnel to operate the suite is to increase the skill set of clinicians that are passionate about traumatology. In the United States, there are surgeons who are completing a secondary vascular fellowship after their trauma fellowship to develop competency in catheter-based hemorrhage control [19]. While, at present, no common standard or credentialing exists for trauma surgeons interested in adding interventional techniques to their skill set, this may be the natural evolution of trauma fellowships [19].

8.5 Future Directions

If these challenges can be successfully addressed, it is exciting to consider the impact that hybrid suites could potentially have on the delivery of quality trauma care. Decades before the construction of the first hybrid suite, Griswold and Drye introduced the concept of saving critical time by bypassing the emergency department and moving patients with suspected cardiac injuries straight to the operating theater for an exploratory thoracotomy [20]. More recently, Martin et al. described a model of care that involves recognizing patients requiring immediate surgery (defined by their own criteria) and transporting them from the prehospital scene directly to a dedicated trauma operating room that is prepared for both resuscitation and surgical intervention [21]. A 10-year retrospective review of their experience demonstrated a remarkable door to intervention time of 13 min in patients requiring emergency surgery with a survival rate that was significantly better than that predicted by TRISS methodology. With access to radiological modalities in the RAPTOR suite, many have suggested that the future role of the omnicapable hybrid theater will be to serve as a "one stop shop" for the unstable trauma patient.

The fundamental barrier preventing this is the resource intensive nature of the RAPTOR suite. As alluded to, the successful operation of this suite requires the rapid mobilization of senior medical, nursing, and allied health staff from several disciplines. Despite the successful experience of Martin et al., only 33% of the patients that met the criteria to bypass the emergency department actually required immediate emergency surgery [21]. Given the relative infancy of hybrid suites in trauma care, as well as the economic and political potential costs of overtriage, more work must be done to define evidence-based criteria to guide the triage of patients to these suites.

Conclusion

Time to hemorrhage control is the crucial factor in the care of the critically ill, hemorrhaging patient. The hybrid suite represents a dedicated location where open and percutaneous procedures can be performed concurrently and thus offers great potential to expedite hemorrhage control. Harnessing the potential of hybrid suites requires a change from the traditionally compartmentalized model of trauma care to one that is more integrated. This transition will require passionate clinicians to broaden their skill set and champion further education and training among their colleagues. Finally, given the resource-intensive nature of hybrid suites, further work must be done to develop formal criteria that will assist clinicians in identifying which patients will benefit from management in this domain.

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