

and subcellular mechanisms triggered by profound shock, exsanguination, acidosis, hypothermia, and coagulopathy. Delays in the decision to perform damage control contribute to a higher morbidity and mortality. Therefore, damage control is a vital part of the management of the multiply injured patient and should be performed before metabolic exhaustion.

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Damage Control: Beyond the Limits of the Abdominal Cavity. A Review

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Learning Objectives: 1) To understand the concept of damage control surgery. 2) To review the pathophysiology after major trauma. 3) To understand the indications for damage control surgery. 4) To understand the decision-making, procedures used, and timing involved in planning damage control procedures.

Abstract

The end point of any operation is the restoration of disrupted anatomy, and often technically impressive repairs accomplished after hours of surgery do not restore the physiology. Damage control is a concept in which the initial surgery becomes part of the resuscitation process rather than part of the curative process. The surgery is aimed at limitation of further physiologic insults, bleeding, and contamination. Once this limitation has been achieved, the patient's ongoing surgery is abbreviated and resuscitation continues in the intensive care unit. Only when the patient has become physiologically stable is the final therapeutic surgery embarked on. This process serves to limit the physiologic exposure to an unstable environment, allowing better resuscitation and outcome in the critically ill patient.

The concept of damage control was born out of the need to care for hemodynamically unstable patients who have sustained multiple high-energy injuries (including both blunt and penetrating trauma). This is not a modern concept, but its application represents a new paradigm in surgery. Damage control itself produces a whole new set of challenges, complications, and disease syndromes not previously encountered.

The end point of any operation is the restoration of disrupted anatomy and physiology. Technically impressive repairs (usually performed "after hours"), however, often expose the patient to a

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harsh theatre environment that may worsen the physiologic insult. This creates a challenge to balance the metabolic insult of the initial operation against the then concept of early total care.

Damage control surgery (sometimes known as “damage limitation surgery” or “abbreviated laparotomy”) is best defined as creating a suitable anatomical environment yet preventing the patient from progressing to an unsalvageable metabolic state. In many “good surgical” situations, patients are more likely to die from their “metabolic failure” than from failure to complete organ repairs.

Damage control is “a strategy that sacrifices the completeness of immediate repair so as to adequately address the combined physiological impact of trauma and emergency surgery.”⁷¹

The term *damage control* originates from the United States Navy, with reference to “the capacity of a ship to absorb damage and maintain mission integrity.”⁷² This allowed for rapid assessment of the damage, thereafter instituting the best manner of sufficient temporary repair to facilitate expedient return to a controlled environment in port. This analogy of preventing a ship from sinking is even more relevant when one considers the anatomical and physiological damage inflicted on trauma patients.

In the early 19th century, Schroeder³ and Halsted⁴ discussed abbreviated laparotomy, describing planned reexploration for hepatic trauma. At this stage, packing was described with absorbable and nonabsorbable materials, which were sutured in place. The main complications were related to bleeding during removal of these materials. Pringle⁵ subsequently described packing with occlusion of the porta hepatis to control liver bleeding. This continued into World War II, but was abandoned thereafter because of poor results related to complications associated with bleeding, necrosis, and sepsis, when Carmona et al⁶ reported that perihepatic liver packing with planned reoperation was a “valuable adjunct...without incurring increased morbidity or mortality.” This was confirmed when Feliciano et al⁷ and others⁶⁻¹¹ reintroduced packing for control of hepatic hemorrhage in 1978.

In a prospective study, Stone et al¹² demonstrated a decreased mortality of 35% in the packed group, compared with 93% in the conventionally treated group. Seventeen patients were managed with damage control-type procedures, compared with 14 patients treated conventionally during the preceding 3 years. The majority of deaths were a direct result of uncontrolled hemorrhage.

Ivatury et al⁹ did not demonstrate a decrease in mortality from hemorrhage, although sepsis remained an issue. A subset of the patients from this study gained from this approach of packing for tamponade. These were patients who required multiple transfusions and who were hypothermic and acidotic. This technique allowed time for transfer to a tertiary facility or abandonment of the procedure, resuscitation and correction of physiology, and controlled reoperation.^{7,9,10}

The concept has evolved to include nonhepatic strategies, including thoracic injuries, vascular injuries,¹³ complex soft tissue and orthopaedic injuries, and even neck injuries. As shown in Table 1, damage control is traditionally applicable as three or five phases,¹⁴⁻²⁷ although nowadays it is generally regarded as being divided into five phases.¹⁶

Pathophysiology

Elerding et al²⁸ emphasized the importance of preventing hypothermia as a prelude to coagulopathy in severe hepatic injury requiring massive transfusion. Trauma patients often present with hypotension, hypothermia, or both. Severity of initial injury, the harsh prehospital environment, and delay in transport can worsen the hypothermia. Hypothermia, bleeding, and metabolic acidosis further cause progressive coagulation defects, and these are the most important indicators for damage control procedures.

Hemorrhage leads to hypothermia. Impaired tissue perfusion further leads to decreased ability to generate heat at a cellular level. With hypothermia there is a sympathetic α -adrenergic overdrive, peripheral vasoconstriction, and more severe end organ hypoperfusion, resulting in conversion from aerobic to anaerobic metabolism and an ensuing metabolic lactic acidosis.^{29,30}

Hypothermia is further associated with decreased myocardial contractility, increased systemic resistance, increased chances of cardiac arrhythmias, and left shift in the oxygen dissociation curve.³⁰ It further causes abnormalities in both active and slow-phase coagulation cascades. There is also a decrease in the production of thromboxane B₂,³¹ which results in inhibition of platelet aggregation. Even with replacement of platelets, they may remain dysfunctional in hypothermia.

The coagulopathy has two causes. The dilutional component is invariably secondary to aggressive fluid resuscitation, and the second, a “consumptive coagulopathy,” results from the system’s activation as a normal physiologic response. The need to resuscitate appropriately with early replacement of red blood cells and clotting factors cannot be overemphasized. Active measures at warming the patient will limit further insult on the coagulation cascade.

The shock state causes anaerobic metabolism that results in metabolic acidosis. The increased adrenergic response further worsens cellular acidosis by direct effects in the cell. Aortic cross-clamping and vasopressors also contribute to metabolic acidosis. Acidosis causes a decrease in the patient’s response to endogenous and exogenous catecholamines. This is the result of uncoupling of β -adrenergic receptors.

Hirshberg and Mattox¹ described the operating room as “a physiologically unfavorable environment for the severely injured patient (involving) dissipation of body heat and blood loss, massive replacement (and the) result is hypothermia, coagulopathy and metabolic acidosis.” The patient remains cold, becomes acidotic, and bleeds. This “bloody vicious cycle,” the triad of hypothermia, acidosis, and coagulopathy is well described^{7,9,10,13,32} and is seen as the trigger in events leading up to the requirement for damage control. Hypothermia is an independent risk factor,³³ but with a direct correlation to injury severity.³⁴ Mortalities of 100% in trauma patients undergoing laparotomy^{33,35} have been reported, with core temperatures of <32°C.

Table 1. Staged Approach to Damage Control

Three-Stage Approach		Five-Stage Approach	
Stage 1	Patient selection and damage control surgery	Stage 1	Patient selection
		Stage 2	Damage control surgery
Stage 2	Restoration of physiology in ICU	Stage 3	Restoration of the physiology in ICU
Stage 3	Definitive operation with abdominal closure	Stage 4	Definitive surgery
		Stage 5	Abdominal closure

Indications

Traditionally, all methods of surgical control were attempted before progressing to packing as a last desperate measure.^{7,10} In this situation, the decision to institute damage control is invariably made too late.^{8,12} Although no definitive management plan existed, in 1986 Nichols et al³⁶ emphasized the importance of achieving appropriate control of surgical bleeding before closure. Cue et al,³² reviewing packing and staged repair of both hepatic and retroperitoneal injuries, concluded that the procedure was more effective if instituted early, and that patients packed early required an average of six units of packed cells less than those packed after onset of coagulopathy. If effected early enough and adequately, packing will permit the return of the patient to the intensive care unit (ICU) for correction of acidosis, hypothermia, and coagulation abnormalities.⁸ Consequently, there has been a search for early criteria to direct this decision and begin damage control in the resuscitation area.^{6,32} Burch et al¹³ were the first to use temperature and pH as indicators of coagulopathy; base excess and coagulation profile were subsequently added as independent indicators.¹⁴ Length of procedure at this stage averaged 2.9 hours.

Other factors were recognized as predictive, not only for coagulopathy but for damage control itself.^{15, 17-20} In 1998, Moore and colleagues¹⁶ summarized the risk indicators of coagulopathy. Table 2 lists these development predictors for coagulopathy. At the time, the significance of a raised arterial lactate as a measure of anaerobic metabolism at tissue level, a readily available investigation, had not been realized. Only in 1992 did Talbert et al¹⁴ report its use, although as an end point of resuscitation rather than as an indicator for abbreviated surgery. Systemic lactate provides a good indicator of the patient's physiologic insult, and therefore the awareness of the need for early damage control procedures. The inability to clear lactate in 48 hours is associated with increased mortality.³⁷

Damage control is indicated only in a highly select group of patients,¹⁸ and if the previously mentioned indicators are not adhered to, results will be no better than if the patient had undergone a definitive procedure in the first place. Morbidity may, in fact, increase, should inappropriate damage control procedures be instituted too late.

Table 2. Predictive Indicators for Coagulopathy

- Injury severity score >25
- Systolic blood pressure <70 mm Hg
- Temperature <34° C
- pH <7.10

Timing of Reoperation

Previous literature has described time to reoperation for periods between 8 hours and 10 days,^{7, 12,16} generally at the surgeon's discretion. Formal thresholds have now evolved, principally the reversal of hypothermia, acidosis, and the correction of coagulopathy. A lactate level of 4 mmol/L is presently one of the best indicators of the return of tissue perfusion, in conjunction with a base deficit better than -4, and a normalized coagulation profile.

Differentiation between "planned" and "emergency" relook procedures is important. Although the guidelines noted here are appropriate to "planned" procedures, ongoing, uncontrolled surgical bleeding, the development of abdominal compartment syndrome (ACS), or both, may mandate an unscheduled revisit to the abdominal cavity. This may mean emergency return to the operating room, or urgent decompression in the ICU. Other situations may include limb ischemia after arterial ligation or stenting, or closed-loop obstruction following emergency bowel resection. Ideally, however, planned relook, although at the discretion of the surgeon, should be as soon as possible after physiologic parameters have been restored. The planned relook has a significantly lower mortality rate; Hirschberg et al¹⁹ showed that 8 of 52 patients undergoing planned relook died, whereas 13 of 21 patients undergoing emergency relook died.

Complications

The most common condition directly associated with damage control is intraabdominal hypertension. This is easily measured with an indwelling urinary catheter³⁸ in a supine patient, zeroed at the midaxillary line. It should be expressed in millimeters of mercury. The intraabdominal hypertension can be divided into four grades,³⁹ as indicated in Table 3.

Grade	Intraabdominal Pressure Measurement (mm Hg)
0 (Normal)	<12
I	12–15
II	16–20
III	21–25
IV	>25

Abdominal compartment syndrome is not graded, but considered as an "all or nothing" phenomenon. Abdominal compartment syndrome, however, is defined as an intraabdominal pressure >20 mm Hg and /or abdominal perfusion pressure of <60 mm Hg in association with new-onset single or multiple organ failure. Better surveillance will lead to earlier detection and optimize outcome.

There is an associated increase in intraabdominal abscess formation with packing.^{6-10,12,14} The use of antibiotic cover should be considered routinely in these cases. Care should be given to the number of packs used to avoid missed swabs, and it is good clinical practice to obtain radiographs of the abdomen in the operating room to ensure that there are no retained swabs. This is particularly relevant when one considers the urgency of these patients and the involvement of multiple personnel. Some septic complications were directly associated with selective hepatic artery ligation.³²

Managing patients in this fashion also exposes them to complications of an open abdomen. The timing of closure, the best-available technique, and the patients' condition will determine the end results.

The Five-Stage Approach As Performed Today

The principles of the five-stage approach discussed in the next sections are as described by Moore (1998).¹⁶

The Damage Control Laparotomy

Stage 1: Decision to Perform Damage Control. For greatest benefit from this procedure, the decision to proceed to damage control surgery needs to be made as early as possible, before the physiologic derangement has reached the point of no return. This must be during initial planning of the operation or as soon as the operation is started and the injuries have been reassessed. Hirshberg and Mattox¹⁵ emphasize the concept of index of suspicion based on “injury pattern recognition” rather than adherence to physiologic end points, although the two should be used in conjunction with each other, and the index of suspicion immediately confirmed intraoperatively (Table 4).

Table 4. Index of Suspicion for Damage Control
<ul style="list-style-type: none"> • Inability to achieve hemostasis because of coagulopathy • Time-consuming procedure in appropriate patient (usually >90 min) • Inaccessible major venous injury • Associated life-threatening injury in second anatomical location • Planned reassessment of abdominal contents • Inability to approximate sheath because of visceral edema or ACS

Patients who will require operation time in excess of 90 minutes or those requiring multiple interventions should be recognized at this stage, and no attempt at definitive closure should be made.

The indications as described here, in conjunction with a systemic lactate of >5 mmol/L, together with an appropriate injury pattern, should prompt aggressive institution of damage control.

Stage 2: The Operation. During this stage, one aims at quick assessment of the injuries, definitive control of bleeding, control of contamination, and temporary abdominal wall closure. This is done simultaneously with ongoing anesthetic resuscitation. Coordination is essential to optimize outcome. The goals are shown in Table 5.

Table 5. Goals of the Damage Control Operation
<ul style="list-style-type: none"> • Initial control of hemorrhage (resuscitative packing) • Exploration of the abdomen • Control of contamination • Therapeutic packing • Rapid abdominal closure

The abdomen is explored initially, and all blood present is scooped or sucked out. Autotransfusion should be considered. Bleeding is controlled by vessel control (clamping) or initial packing. Packing is not a substitute for the direct control of large bleeding vessels. Aortic cross-clamping or pressure control may make assessment easier. Hemorrhage can then be assessed and dealt with by rapid repair, ligation, or use of stents for temporary control. Balloon catheter tamponade may be relevant for some injuries.

The Pringle maneuver and even total liver isolation may help in

assessing complex liver injuries. Appropriate control of active hepatic bleeding and packing is useful in these cases.¹⁹ A fine line exists between sufficient packing to achieve tamponade and increasing the risk of ACS.

Surgery when dealing with renal and splenic injuries, especially in the face of expanding hematomas, active bleeding, and coagulopathy, has become more aggressive, with nephrectomy or splenectomy being preferred to conservation in the unstable patient with bleeding from these organs. Ureteric injury is either stented, exteriorized, or even ligated in certain instances.

Intestinal spillage is controlled by stapling bowel ends without definitive repair, occlusion with umbilical tape, suture, or towel tag ligation. Proper end-to-end anastomosis and maturation of a stoma is delayed until reoperation. Running suture can be used temporarily in some injuries. Gastric contents must be adequately drained.

Moore et al¹⁶ recommend that up to 30 minutes can be spent continuing active resuscitation, rewarming, and correcting the coagulopathy. The patient’s condition should be reassessed for possible reopening and control of active bleeding before transfer to ICU. This is the time to apply damage control to other anatomical sites. It may also be feasible to consider primary closure.

The abdomen needs to be covered to minimize further heat dissipation and to make packing effective. Preferred wall closure techniques include running nylon skin suture or towel clip closure in situations where the wound edges can be approximated. The sheath should be left strictly alone at this stage.

Towel clip closure has the benefit of rapid application, that is, 1 to 4 minutes.¹³ If applied at 1-cm intervals, there is less chance of visceral herniation, and easy abdominal wall decompression is possible. The sheath is not damaged with this closure technique^{7,10,13,14}; however, towel clips interfere with the radiologic visualization of the abdomen. A running nylon suture for skin closure, therefore, may be an easier alternative under these circumstances.

Packing and aggressive fluid resuscitation may make skin closure difficult. Bogota bag, silo formation, and the Opsite (Smith and Nephew, Andover, Massachusetts) sandwich techniques are alternatives. The Bogota bag makes use of an opened intravenous fluid or urologic irrigation bag sutured to skin edge with a continuous suture. It offers the advantage of allowing inspection of the abdominal contents through the bag. The Opsite sandwich technique requires no suturing. A sheet of Opsite or Steridrape (3M Corporation, St. Paul, Minnesota) is placed on an abdominal swab. Holes may be cut in the drape to assist drainage. The swab is placed into the open abdomen with the drape in contact with bowel. The swab edges are tucked sufficiently far under the wound edges so that visceral herniation does not take place. Suction drains are placed on the swab, and a second drape is then used to close off the wound.

Mesh can also be used as a temporary closure, but thought must be given to the expense involved and time required for suturing the mesh in place.

Stage 3: Restoration of Physiology in the ICU. Patients are then transferred to the ICU for further resuscitation, reversal of acidosis, correction of coagulopathy, and rewarming. With a core temperature <35°C, normal coagulation will not occur, despite aggressive component replacement.³⁵ It is essential to prevent and treat hypothermia. Rewarming is continued throughout patient care. Active anatomical cavity rewarming may be initiated in theatre. In ICU, passive warming techniques including warm air blankets, warmed fluids, and humidified ventilator gases are routinely used. External heaters should also be considered. Other aggressive techniques include continuous arteriovenous rewarming.⁴⁰

Resuscitation should be aimed at restoring the oxygen-carrying capacity, volume, and reestablishing a normal coagulation profile. This requires early transfusion of red blood cells, fresh-frozen

plasma, and minimizing overuse of crystalloids. At this stage, laboratory results of hemoglobin and clotting factors will act as a guide. Hypothermia may lead to erroneous clotting profile results because these tests are designed for optimal results at 37°C. Platelets must be kept above 100,000/mm³ in the presence of active bleeding. Cryoprecipitate should be given if the fibrinogen level is expected to be <1 g/L.³⁰ Vitamin K and calcium gluconate should also be considered. Recombinant activated factor VIIa (rFVIIa) may also have a role in resuscitation,^{41,42} which can be maximized by improved patient monitoring. Although this can be achieved with invasive methods such as pulmonary artery wedge pressure monitoring, which will allow for assessment, for example, of cardiac output and oxygen extraction calculation, other less-invasive techniques are preferable in trauma. Transesophageal ultrasound probes, which measure variations in the descending thoracic aorta between systole and diastole, can be used to derive hemodynamic variables that can guide resuscitation. This device is positional-dependent and may require constant readjustment during patient position change. Other devices include NiCO, which uses CO₂ measurements to estimate cardiac output.

These devices will assist in goal-directed resuscitation and help in reaching the end points of resuscitation. These include a systemic lactate <2.5 mmol/L, base deficit better than -4, a core temperature >35°C, an international normalized ratio less than 1.25 times normal, and a urine output of >1 mL/kg.

The challenge in this period is in recognizing patients with ongoing bleeding that is not the result of a coagulopathic state. This requires clinical acumen aimed at assessment of failure to improve the hemodynamic status and increasing evidence of bleeding from the drains or intraabdominal bleeding. This may occur despite improving the core temperature or even the coagulation. Failure to recognize this will lead to reentry into the vicious cycle.

ACS should also be monitored during this period, as previously discussed. Renal failure occurs when intraabdominal (intravesical) pressures exceed 20 to 25 mm Hg^{38,43} and decompression is urgent.

Patients at this stage are likely to have respiratory complications from the direct chest trauma, the systemic effects of major trauma, and complications of multiple transfusions. Protective lung ventilation should be used early.

Stage 4: Relook or Definitive Surgery. Timing of relook surgery is generally at the surgeon's discretion, although other factors include the reversal of the triad, the availability of resources, and the initial indication for the damage control procedure. Reports have varied from 8 hours to 10 days.^{7,12,16} As soon as the end points of resuscitation (as described here) are met, the patient can be taken for a planned relook. Earlier consideration should be given to patients with vascular injuries that were stented, or those with multiple ligated bowel loops.

Relook on demand will be based on the evidence of overt bleeding, or ongoing occult hypotension despite appropriate measures, and ACS. These patients should be carefully assessed before their condition worsens. The procedure is best done in theatre with an appropriate team and good lighting, but some patients' conditions may mandate that this will be performed in the ICU.

Definitive procedures should be performed prior to pack removal because this may induce bleeding, necessitating repacking, preventing completion of the intended operation. Proper exploration is essential to detect missed injuries.¹⁹

Once surgery is completed, a decision for another "directed relook" may be made. This will determine if a temporary closure is still relevant.

Stage 5: Abdominal Wall Closure. The abdominal wall can be closed as soon as all the definitive operations are completed, packs are removed, and bowel edema has resolved. This can be achieved by a standard continuous abdominal closure in layers. This is the

first time that the sheath should be sutured. However, mobilization of this interstitial fluid may not be complete at this stage and temporary closure may still be necessary. Some cases may still require fluid restriction. Albumin and mannitol may be used to hasten this process, but this is not common practice.

Use of abdominal synthetic mesh for temporary closure may be appropriate; this can be followed with skin graft once granulation tissue is adequate. A suction dressing can increase granulation tissue formation and result in earlier grafting. The patient may require later abdominal wall reconstruction. Abdominal wall separation techniques may also be considered at that stage. When these delayed abdominal wall closure methods are used, patients should be monitored for associated complications, which include formation of enterocutaneous fistulae.

Extremity Injury: Vascular Injuries

The use of shunts has been described regularly,^{19,36,43-49} although it was only in 1994, after Scalea et al⁵⁰ published a case report describing staged procedures for exsanguinating lower limb injury, that the concept of using damage control in extremity injury was formally introduced.

The principles are similar to those described previously, and a similar operative approach is applied.

Stage 1: Indication for Damage Control in the Limbs. This will include patients with the previously mentioned physiologic insults and/or with multiple life-threatening injuries. Mass casualty situations and patients who require transfer to tertiary institutions may also benefit from this approach. Isolated severe complex limb injuries requiring multiple teams may benefit from shunting as well.

Stage 2: The Operation. A higher index of suspicion is required, erring on the side of more aggressive surgery with shunt insertion, ligation, or packing. In making this choice it is important to remember the concept of life over limb, in which ligation with ultimate limb loss may be the only option. Barros D'Sa⁵¹⁻⁵³ cites warm ischemia time as the critical predisposing factor leading to necrosis and renal failure. Shunting, with immediate restoration of flow, avoids this.

The operative technique is ultimately unchanged, although delayed, and principles of vascular repair are maintained. The only variation is the insertion of the shunt, which serves to buy time, allowing adequate resuscitation and maintaining adequate distal perfusion. It must be inserted with care to avoid intimal separation on either proximal or distal limb. The shunt can be secured with clamps, or "vascular keepers," using umbilical tape, ligatures, or a Ramel tourniquet. In case of associated fractured limbs, the shunt should be well secured in a way that it will not dislodge during orthopaedic manipulation. The postoperative challenge is constant clinical assessment for patency on the shunt. On return to the operating room, one is operating on a stable patient, without pressure of time, and with additional expertise available.

Choice of a shunt should be determined by the size of the vessel that requires shunting. Other options available include the Javid, Brenner, and Sundt shunts, although any plastic or silastic tubing is suitable. The use of large-bore intravenous tubing has been described.²⁶

The use of concurrent anticoagulation remains controversial,^{47,54} keeping in mind the appropriate patient might already be coagulopathic. In the absence of contraindications, the use of anticoagulation should be considered. If the shunt is technically correctly placed in animal models, shunt patency can be maintained for at least 24 hours without anticoagulation.⁵⁵

Fasciotomy should be considered mandatory when dealing with combined arterial and venous injuries. When the vein is ligated in the setting of the patient in extremis, fasciotomy at the initial operation is

mandatory to prevent subsequent compartment syndrome and its contribution to further ischemia of the limb. Postoperative bleeding should be managed appropriately with dressing.

Stage 3: Restoration of the Physiology. This remains identical, concentrating on restoration of physiologic parameters prior to return to the operating room for definitive repair. A controversial issue is the length of time that a shunt can be left in situ without further compromising the limb. Essentially, as long as distal perfusion is regularly monitored, there is no urgency to return for definitive repair, although reoperation is recommended as soon as acidosis, hypothermia, and coagulopathy have been corrected. In clinical circumstances, shunts have been left in situ for periods of up to 17 hours with good results.⁴⁷

Stage 4: Relook and Final Vascular Repair. Standard surgical techniques of proximal and distal control, debridement of damaged segment, and insertion of appropriate conduit should be maintained. Conduit should not be left exposed.

Stage 5: Wound Cover. Wound closure is less challenging, with primary closure often feasible. However, split-thickness skin grafts and occasionally tissue transfer techniques are necessary. Associated soft tissue injury will determine the appropriate cover.

Extremity Injury: Orthopaedic Injury

Initial fear of early manipulation of fractured long bones was subsequently replaced by the concept of “early total care” in the 1980s. This change was encouraged by growing knowledge about fat embolism and the advantages of early bone fixation. However, on further analysis, patients with an Injury Severity Score of >18 did not show benefit from this approach, and an increasing understanding of the physiologic insult of prolonged theatre time during definitive orthopaedic management and success with damage control in the abdomen led to the new era of damage control orthopaedics.⁵⁶

Patients with associated severe head injury, significant pulmonary contusions, or severe associated injuries could be compromised by intramedullary reaming of long bones. Studies have shown that reaming is associated with an increase in polymorphonuclear leucocytes, intramedullary pressure, blood loss, and interleukin 6 levels,^{56,57} all of which play a part in adding insult to the systemic effects of trauma.

Controversy still exists about the effects of unreamed nails that can be approached intraarticularly in a retrograde fashion.⁵⁸ The future may lie in nails that can simultaneously irrigate and apply suction to the intramedullary space to reduce the pressure.

Stage 1: Patient Selection. This stage is aimed at recognizing the patient with multiple fractures, or fractures with associated severe injuries to the chest, head, and abdomen. Included in this group will be those with deranged metabolic status. Early recognition is essential!

Stage 2: The Emergency Operation. The plan in the initial management of these patients is to offer a stabilization that is quick and minimizes further insult to the metabolic state. The femur can be managed with external fixation. With proximal fractures, skeletal or skin traction may be appropriate. Other fractures can also undergo external fixation or immobilization. Associated soft tissue injury will require debridement and control of bleeding.

Unstable fracture of the pelvis should be recognized from the beginning. A temporary measure, such as a sheath around the pelvis, C-clamp, or external fixation in theatre may help to stabilize a patient. Care must be taken during removal of the sheath to avoid patient deterioration. Traction may be considered in vertical shear injuries. Where appropriate and the patient’s condition allows it, an angiogram can be used. Very rarely, laparotomy with packing or ligation of internal vessels may be relevant.

Stage 4: Definitive Fixation. Further wound debridement will be carried out as necessary. The external fixation can be converted to an intramedullary nail once the condition has stabilized. This can be delayed to as long as 10 to 14 days after the initial injury.

Stage 5: Wound Cover. Wound management may require myocutaneous or myofacial flaps with skin graft for definitive cover.

Thoracic Injury

The triad of hypothermia, acidosis, and coagulopathy are the best predictors of the need for damage control in the thorax.^{59, 60} A high index of suspicion should be maintained, as for other injuries.

Stage 1: Patient Selection. There are many situations in the chest in which damage control is, in fact, the definitive surgery. However, there are situations, like elsewhere, where control of hemorrhage in a temporizing fashion supersedes all therapeutic surgery. Injury pattern recognition is crucial.

Stage 2: Emergency Operation. Clinical presentation of these patients may even require emergency room thoracotomy. This is more relevant in penetrating than blunt trauma,⁶¹ and will allow for cross-clamping of the aorta, internal massage, control of thoracic bleeding, and temporary control of cardiac injuries. If staples or temporary suture or balloon catheter are used to control cardiac lesions, these will be converted in theatre as part of ongoing operation.

In theatre, thoracic structures are not easily controlled with temporary maneuvers. Rapid and definitive control of hemorrhage and air leaks is required, using abbreviated techniques rather than staged procedures. The heart and great vessels require definitive repair, although packing of the pleural cavity remains an option should diffuse nonsurgical bleeding develop. Packing is easier at the apex of the lung or the deep posterior area. Mediastinal packing may be associated with cardiovascular compromise.

Traditionally, major pulmonary parenchymal and bronchial injuries were treated with lengthy, anatomical resections during which the patient often became coagulopathic with profound shock and, ultimately, demise. Alternatively, patients who presented in extremis were subjected to pneumonectomy, with mortality rates approaching 100%, or formal lobectomy, with a 55% mortality.⁶²

A double-lumen endotracheal tube is ideal, allowing differential ventilation of each lung, and is protective in that bleeding from one side may not spill across to the other. Unfortunately, however, the instability of these patients does not usually allow the use of a double-lumen tube. They may not even have a cleared spinal injury, excluding optimal positioning for some. This may make the operation technically challenging.

To achieve hemostasis, minimize air leak, and avoid air embolism, simpler techniques like pulmonary tractotomy and nonanatomical pulmonary wedge resection may be used.^{59, 61} Tractotomy with a lineal stapler will allow for better control of vessels in the parenchyma, which may be sutured appropriately. When simple pulmonorrhaphy is used, the endotracheal tube should be checked to observe those patients with internal bleeding who may compromise the normal bronchus on the opposite side.

In cases with severe bleeding, visualization can be improved by hilar control. This can be achieved with noncrushing clamps or a Foley’s catheter across the hilum. Some authors have also twisted the hilum through 360° to achieve control, and reassessed it later, once the condition had stabilized.⁶³

Esophageal injuries may require drainage at this stage if repair cannot be achieved within a short period of time.

Chest wall closure may be temporarily achieved with a mass closure technique. This is quick and will control bleeding from the muscle edge. Alternatively, methods similar to those used in the abdomen can be used.

Stages 4 and 5: Definitive Operation and Chest Wall Cover.

Definitive repair will be achieved if not accomplished earlier. Debridement of wall and final closure will be achieved at this stage. Myofascial flaps may be necessary in large wall defects.

Head Injuries

The most critical part of head injury management is the prevention of secondary brain injury.^{64,65} This includes optimizing the mean arterial pressure, hemoglobin level, and oxygenation, at both pulmonary and cerebral level. Intracranial lesions should be dealt with after any drainable lesions are managed appropriately. Care should be aimed at minimizing intracranial pressure using supportive and medical therapy.

Unfortunately, some of these patients in extremis may have not had a computerized tomographic scan assessment of the head injury. In the absence of localizing neurologic symptoms, attention will be given to stabilizing the general condition. Optimizing the general condition of the patient is essential in optimizing outcome of head injury. Patients with severe head injury with evidence of terminal signs may require review of further management in consultation with neurosurgeons.

Craniectomy may be considered to alleviate cerebral swelling, even after drainage of hematomas. Dural cover may be expanded with temporalis fascia or even synthetic dura.⁶⁶

Intracranial pressure monitoring can aid in the management of severe head injury. Coagulation status must be optimized before insertion, to avoid bleeding complications. If indicated, these can be inserted in casualty, theatre, or even in the ICU.

Spinal Injuries

Improvement in resuscitation has increased awareness of associated spinal injuries. In-line immobilization of the spine is critical. Optimizing general condition will also improve outcome of reversible spinal injuries. Once the condition has settled, further examination of the spine and appropriate fixation can be achieved.⁶⁷

In the absence of other priorities, the initial management includes the use of external traction, such as halo traction, and fixation of easily accessible spine (e.g., posterior segments). The more complex repairs are reserved for later.⁶⁸ Debridement of open wounds and antibiotic cover in contaminated spinal injuries form part of initial management. Acute bleeding points should be sought out, and angiography may be used as well.

Eye Injuries

Damage control has been applied in eye management.⁶⁹ Wounds should be debrided, major globe lacerations sutured, and the retinas reattached. Most other injuries can be repaired subsequently when the condition improves. Choroidal hemorrhage is better allowed to settle initially, before reconstructive work is done. If operated early, it may be complicated by severe bleeding.

The Pediatric Patient

Technology in radiology has improved in the past years. The surface area in children allows for its easier use. Care should be given to minimizing unnecessary radiation exposure when ultrasound investigation can suffice. Pediatric surgery has been at the forefront of conservative management in blunt injury.

Immediate exploration is indicated only if profound

hemodynamic instability, continued hemorrhage, hollow viscus perforation, and major pancreatic ductal disruption exist. The majority of these types of cases are treated definitively at the initial operation and rarely require temporizing measures and relook operations.

Although often primarily repaired, packing the liver with or without subsequent embolization may be beneficial. Asensio et al,⁷⁰ in a relatively small study, showed that grade 4 and 5 liver injuries treated with packing and subsequent embolization had survival rates of 92% and 78%, respectively.

A general surgeon may have to deal with the pediatric patient, especially with respect to perihaptic packing and vascular management, including stenting.⁷¹⁻⁷⁴ This may allow for stabilization of a patient and subsequent transfer to a tertiary institution for definitive care.

The role of damage control in pediatric injury needs to be defined further.

Conclusion

Damage control is an operative technique that has been used for almost a century. It has evolved from being performed almost at random, to having reasonably clear indications and defined end points for each stage.

Damage control is gaining momentum in use in areas other than the abdomen and the chest. These include orthopaedic-related, eye, and spinal injury. The most important issue is that other members of the team understand the rationale and participate more constructively in this team approach to patient care.

In a select subgroup of patients, the procedure has been proven to reduce mortality significantly when related to injuries that were previously not survivable.⁷⁵

Level I evidence is still lacking. Given the proven benefits of this concept, it seems unnecessary to perform such a study. We still believe that studies should be dedicated to better definition of indications and toward improving the technical aspects of the procedure.

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