Damage Control Surgery: An Update

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Stefania Cimbanassi and Osvaldo Chiara

6.1 Introduction

Damage control surgery (DCS) represents a staged management approach for those injured patients who present with severe physiological compromise and who require surgical intervention. This strategy focuses on physiological and biochemical stabilization of the patient prior to the comprehensive anatomical and functional repair of all injuries. DCS can be applied across all body cavities as a continuum, according to the degree of physiological derangement [1, 2]. The DCS paradigm is strictly related to the concept of damage control resuscitation, which focuses on initial hypotensive resuscitation and early use of blood products to prevent/correct the lethal triad of acidosis, coagulopathy, and hypothermia [3]. Appropriate selection of patients requiring DCS is critical. It is estimated that 10% of traumatized patients require DCS [3]. However, although this strategy is widely used and has been reported to result in improved survival, up to 50–70% [4] in the severely injured, it is associated with a high incidence of potentially severe complications, hospital readmissions, subsequent surgical procedures, and a reduced quality of life because of the aftermath of the treatment [5]. For these reasons, it is crucial to ensure that DCS is provided to the right patients within the correct scenarios.

S. Cimbanassi (✉)
General Surgery and Trauma Team, Niguarda Hospital, Milan, Italy
e-mail: stefania.cimbanassi@ospedaleniguarda.it

O. Chiara
General Surgery and Trauma Team, Niguarda Hospital, Milan, Italy
Department of Pathophysiology and Transplantation, University of Milan, Milan, Italy
e-mail: osvaldo.chiara@ospedaleniguarda.it

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6.2 Indication for DCS

As general rule, the patient who truly requires DCS is a patient who is more likely to die from an uncorrected shock state than from failure to complete organ repair [6]. It must be noted that not all patients with initial physiological derangement require DCS, if their physiological parameters improve after rapid control of hemorrhage and effective resuscitation, allowing definitive repair of the injuries.

In two content analysis and appropriateness rating studies, Roberts et al. [7, 8] identified the trigger points to dictate DCS with the greatest expected benefit-to harm ratio (Table 6.1). The results of these analyses showed that the presence of physiologic reserve compromise, defined as hypothermia, acidosis, coagulopathy in the pre- or intraoperative setting, represents the indication for DCS in more than 47% of cases.

Table 6.1 Indications for use of damage control surgery in civilian trauma patients [7, 8]

Degree of physiologic insult – Hypothermia (core T < 34 °C), acidosis (pH <7.2), and/or clinical or laboratory coagulopathy in the pre- or intraoperative settings (PT and PTT >1.5 times normal) – Persistent intraoperative cellular shock (VO_2I < 100 mL/min/m^2, lactate >5 mmol/L, pH <7.2, BD >15 mmol/L, core T < 34 °C) – Development of intraoperative ventricular arrhythmias
Amount of resuscitation provided – A large volume of PRBCs (median > 10 U), other blood products, and crystalloids combined (median > 12 L) administered preoperatively or across the pre- and intraoperative settings
Injury patterns – A difficult access major venous injury (intrahepatic, retroperitoneal, or pelvic) – A major liver or combined pancreaticoduodenal injury with hemodynamic instability in the OR – A combined pancreaticoduodenal injury with massive hemorrhage from the head of the pancreas – Devascularization or massive disruption of the duodenum, pancreas, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD – Pulmonary hilum, lung parenchymal injuries – Cardiac injury – Major vascular injuries of the extremities – Complex pelvic injuries – Complex extremities injuries
Inability to control bleeding by conventional methods
Need for staged abdominal or thoracic wall reconstruction – Inability to close the abdominal or thoracic wall without tension because of visceral edema – Signs of an abdominal or thoracic compartment syndrome developed during attempted abdominal or thoracic wall closure
Need to reassess the extent of bowel viability after a period of further resuscitation in the ICU

BD base deficit, *CBD* common bile duct, *ICU* intensive care unit, *OR* operating room, *PRBCs* packed red blood cells, *PT* prothrombin time, *PTT* partial thromboplastin time, VO_2I oxygen consumption index

Additional highly appropriate indications are represented by the need for large-volume fluid resuscitation, both pre- and intraoperatively, because it carries the risks of dilutional coagulopathy, visceral edema, intra-abdominal hypertension, and abdominal compartment syndrome.

The injury patterns which better indicate the appropriateness of DCS are represented by those injuries presenting significant management challenges. These include zone I and III neck injuries with concurrent internal and external hemorrhage; major lung and pulmonary hilum, cardiac, liver and juxtahepatic venous injuries, and combined pancreaticoduodenal injuries; actively bleeding major abdominal, pelvic, and peripheral vascular injuries [9]. These patterns are characteristic of those with competing management priorities, which have the potential for intraoperative exsanguination during attempted definitive repair.

6.3 Steps of Damage Control Surgery

The historical three-step DCS has recently been outlined in five clinical phases, which follow one another as a continuum, from recognition of the unwell patient to definitive repair of the injuries [10].

6.3.1 DCS Part 0: Recognition of Injuries and Goal-Directed Hemostatic Resuscitation Without Delaying Surgery

This step begins on the field, with truncated scene times, after the rapid recognition of the patient needing expeditious transfer to the referral center, and continues in the emergency department (ED), through a rapid assessment of the injuries, and applying the principles of damage control resuscitation (DCR) to minimize blood loss, maximize tissue oxygenation, and optimize the outcome.

In the ED a minimal work-up is required. The cornerstones are extended focused assessment with sonography for trauma (E-FAST), an antero-posterior pelvic plain film, and an antero-posterior chest plain film, in order to identify the most probable site of the hemorrhagic injuries. Whole-body computed tomography (WBCT) in unstable patients not responding to resuscitation efforts is not warranted, so as not to delay access to hemostatic maneuvers. A WBCT scan in the unstable patient could be considered only in a logistically favorable environment and by a well-organized trauma team. Hemorrhagic patients with associated neurological impairment and lateral signs (anisocoria) and those who remain unstable without any evidence of bleeding may represent the exception for CT. In the former case, head CT alone, after the ED work-up, allows rapid recognition of any cerebral injuries potentially amenable to surgery; in the latter case, torso contrast-enhanced CT (CECT) allows detection of other causes of instability (i.e., spinal cord trauma).

The main elements of DCR are:

- **CAB resuscitation** [3]
  Borrowed from the military experience, the aim is to rapidly deal with life-threatening external bleeding using the field-dressing, tourniquet and topical hemostatic agents. When control of catastrophic hemorrhage(s) has been achieved, AB is dealt with along the conventional trauma paradigm.
- **Permissive hypotension**
  A mean arterial pressure (MAP) of 50 mmHg is a well-tolerated strategy that results in less overall blood product and fluid administration, decreased dilutional coagulopathy, and reduced early death [11]. In patients having associated traumatic brain injury, permissive hypotension should last as little as possible. After hemorrhage control a MAP of 85 mmHg is advised.
- **Massive transfusion protocol (MTP) and limitation of crystalloids**
  Early and balanced transfusion of plasma and platelets along with units of red blood cells (i.e., maintaining the plasma:platelet:red blood cell ratio closer to the 1:1:1 ratio of whole blood), while simultaneously minimizing crystalloid use in order to avert or reverse the triad of coagulopathy, acidosis, and hypothermia and decrease endothelial permeability is warranted [12–14].
- **Early use of tranexamic acid (TXA)**
  Tranexamic acid reduces bleeding by inhibiting the enzymatic breakdown of fibrin blood clots (fibrinolysis). The CRASH2 trial [15] showed that in patients with trauma with major extracranial bleeding, early administration (within 3 h of injury) of tranexamic acid reduces bleeding deaths by a third.
- **Pre-hospital and emergency department hemostatic procedures**
  Surgical life-saving maneuvers (i.e., pleural decompression, wound packing, tourniquet, extraperitoneal pelvic packing [16]), angioembolization [17], use of resuscitative endovascular balloon occlusion of the aorta (REBOA) [18] represent the strategies to obtain expeditious bleeding control.

6.3.2 DCS Part 1: Abbreviated Surgery, Prioritizing Physiology over Anatomy

During this phase, truncated surgery is used to rapidly control exsanguinating hemorrhage, massive air leak, and/or gross contamination [7]. Additional surgery has to be performed only once the physiological reserve has been restored. Historically introduced for abdominal trauma [19], nowadays damage control techniques are generally accepted throughout all body regions (Table 6.2) [20–29], although liver and major abdominopelvic vascular injuries still remain the main indications for DCS.

6.3.2.1 Operating Room Set-Up

The operating room must be set up properly. Room temperature should be kept between 70 °F and 80 °F (21–26 °C) and equipped with all devices and technology which can be useful in DCS, such as rapid infuser with warming of infusions, blood saver equipment, instruments for abdominal and chest surgery, vascular clamps, laparotomy pads, stapler for intestinal resection, temporary vascular shunts.

Table 6.2 Damage control surgery across body cavities [19–31]

Body region	DCS Intervention	Description
Head/spine	ICP monitoring	A probe is positioned, usually intraparenchymal, to monitor intracranial pressure
	Decompressive craniectomy	A large bone flap is removed to release brain swelling. Focal injuries are evacuated and hemostasis achieved. Dura is always closed primarily
	Spine decompression and stabilization	Epidural hematoma is evacuated, posterior fixation/instrumentation performed
Maxillofacial	Airway management	Orotracheal intubation, cricothyroidotomy, or surgical tracheotomy are performed
	Bleeding control	Nasal or oral packing is used to control bleeding, angioembolization or selective ligation of the external carotid artery may be used to control life-threatening hemorrhages
Neck	Airway management	Orotracheal intubation, cricothyroidotomy, or surgical tracheotomy are performed. Direct intubation through the airway injury may be performed in cases of open wound
	Bleeding control	Packing, Foley catheter through the wound, bone wax may be used to control hemorrhage, angioembolization controls bleeding in zone III

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Thorax	Cardiorraphy	Interrupted stiches are placed after temporary hemorrhage control with stapler or Foley catheter inserted into the bleeding wound tract
	Pneumonorrhaphy	After small injured vessels and bronchi within the parenchyma of a superficial pulmonary laceration are selectively ligated, the edges are approximated
	Pulmonary tractotomy	The lung bridging a pulmonary parenchymal wound is divided using a GIA 55/75 vascular stapler or between two long vascular clamps and then small injured parenchymal vessels and bronchi lying underneath are selectively ligated
	Pulmonary wedge resection	A GIA 55/75 or TA 30/60/90 vascular stapler is used to resect a peripheral portion of a pulmonary lobe or segment of lung
	Rapid, simultaneously stapled pneumonectomy	A TA 90/55 vascular stapler is placed across the pulmonary hilar structures and fired, resulting in an *en masse* simultaneous division of the mainstem bronchus and pulmonary vessels
	Intraluminal drainage of the proximal esophagus and wide drainage of the pleural space	The esophagus above or at the site of an esophageal injury is drained with a nasogastric tube connected to low suction while the pleural space is widely drained with thoracostomy tubes
	Therapeutic mediastinal and/or pleural space packing	Compressive gauze packing is applied to the mediastinal and/or pleural surface to tamponade venous and/or coagulopathic hemorrhage at least until the first reoperation (which frequently occurs within 24–48 h)
	Temporary thoracic closure	The thoracotomy incision is temporarily closed *en masse* using a heavy, nonabsorbable, running suture or with towel clips, a patch or silo/Bogota bag, or a modified Barker's vacuum pack or commercial negative-pressure wound therapy device

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Abdomen	Packing	Compressive gauze packing is placed above and below the liver and spleen, and in the paracolic gutters. The interposition of a plastic sheet is not warranted
	Balloon catheter tamponade	For penetrating liver injuries, A Foley, Fogarty, Sengstaken-Blakemore, or improvised balloon catheter (created using a red rubber catheter and Penrose drain) is inserted into a bleeding wound tract. The balloon of the catheter is then inflated with sterile water and repositioned until adequate hemostasis is achieved
	REBOA	A REBOA device is inflated in zone I (supradiaphragmatic) to control bleeding from parenchymal injuries. The aortic occlusion may be complete, partial, intermittent, depending on the patient's physiologic derangement
	Staged pancreaticoduodenectomy	Major vascular hemorrhage is controlled and, where necessary (sometimes this has already been done by the inciting trauma), the duodenum distal to the pylorus, common bile duct, pancreas distal to the injury, and distal duodenum or jejunum are transected; and the right upper quadrant and peripancreatic space are widely drained
	Bilateral externalized ureteral stenting and diversion	When neither transurethral or suprapubic drainage effectively evacuates urine from the injured bladder, J-stents are passed up each ureteral orifice and then externalized to divert the urinary output of both kidneys until definitive repair of the bladder is possible
	Bilateral internal iliac artery ligation	Both internal iliac arteries are ligated using heavy, permanent sutures during laparotomy
	Interventional radiology	Angioembolization may be used to control residual bleeding or in cases of challenging bleeding control
	TAC/open abdominal management	The abdomen is temporarily closed using a Barker's vacuum pack, commercial negative-pressure peritoneal therapy device

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Pelvis	EPP	After a 6- to 8-cm midline incision is made extending from the pubic symphysis cephalad (dividing the midline abdominal fascia) and the preperitoneal space is opened using digital dissection (where necessary), laparotomy pads are placed on either side of the bladder, the fascia is closed with a heavy suture, and the skin is closed with staples
	Interventional radiology	Angioembolization is useful to control bleeding if the patient remains unstable despite external mechanical compression or after EPP
	ExFx	Anterior ExFx can be placed into the iliac crest or supra-acetabular area. In unstable patients, the iliac crest route is faster, the pins can by placed without fluoroscopic guidance. The C-clamp is indicated in the presence of ligamentous VS injuries through the sacroiliac joint, VS injuries with "zone 1" sacral body fractures and APC3 equivalent injuries with vertical instability
Extremities	ExFx	External fixation, especially in the setting of bilateral femoral fractures in patients with multiple injuries, should be considered
	Temporary intravascular shunt	After an embolectomy and administration of local intravascular heparinized saline, the defect in the injured artery and/or vein is bridged with vascular shunt or with a piece of an intravenous line or nasogastric/chest tube (cut to length such that it overlaps within the vessel by approximately 2 cm and secured into place with a heavy silk tie on either end). The shunt is left in place until at least the first reoperation (which frequently occurs within 24–48 h)
	Interventional radiology	Angiography may facilitate endovascular repair of particularly anatomically challenging injuries

APC3 anterior posterior compression type III, *EPP* extraperitoneal pelvic packing, *ExFx* external fixators, *ICP* intracranial pressure, *REBOA* resuscitative endovascular balloon occlusion of the aorta, *TAC* temporary abdominal closure, *VS* vertical shear

6.3.2.2 Patient Position

For torso procedures the patient lays supine in a cruciform position with both arms abducted, prepped from chin to middle thighs and laterally down to the table. This preparation of the field allows surgical incisions of the neck, the chest (antero-lateral thoracotomy, sternotomy, tube thoracostomy), laparotomy, and femoral vessels at the groin. The patient is instrumented with electrocardiogram, arterial and venous lines, urinary catheter and gastric tube, while resuscitation and control of hemorrhage are ongoing: the instrumentation of the patient should not interfere and delay surgical control of the source of bleeding.

6.3.2.3 Surgical Incisions for Torso Injuries

The abdomen is explored through a midline incision extended from xiphoid to pubis. The incision is limited to the area around the umbilicus in the presence of pelvic fracture because separation of the muscles at the midline causes further opening of the pelvic bones, with worsening of retroperitoneal hematoma. The midline incision of the abdomen allows optimal exposure and can be extended subcostally to improve the view of difficult areas, such as the suprahepatic-caval junction. In the case of thoracic DCS, the thorax is entered through an anterolateral thoracotomy in the left fifth intercostal space, with the possibility to extend the incision contralaterally (clam-shell thoracotomy). Neck DCS is approached through a standard incision along the sternocleidomastoid muscle, with the head slightly rotated contralaterally.

6.3.2.4 Hemorrhage Control

For abdominal DCS, the steps of laparotomy are as follows:

1. Incision at the midline
2. Removal of large clots and release of tamponade
3. Packing of all four quadrants
4. Rapid control of major vascular bleeding, achieving proximal and distal control of vessels.

Adequate packing should provide a good degree of hemorrhage control for venous and solid organ bleeding (Fig. 6.1).

The technique to perform adequate packing is:

1. Retract the anterior abdominal wall
2. Hand over organ to protect it
3. Take down the falciform ligament
4. Pack above and below the liver and spleen
5. Sweep small bowel and colon medially to pack the paracolic gutters and base of mesentery
6. Sweep bowel cephalad to pack the pelvis.

Radiopaque pads only are to be used and an accurate count by scrub nurse must be done. The use of plastic sheets between solid organ parenchyma and pads is not warranted. Attention must be paid not to either overpack, which may worsen diaphragmatic excursions and compression of the inferior vena cava, or underpack, which may be not effective. If the patient remains profoundly unstable after packing, aortic inflow at the diaphragmatic hiatus should be obtained. This can be achieved with manual occlusion, vascular clamp or with REBOA placed in zone I. Once clamped, time should be noted as severe ischemia will develop unless aortic outflow is restored. For major vascular injuries, DCS options are either ligation or placement of temporary vascular shunts in critical arteries. Ligation of almost any major vein is usually a survivable procedure, if required.

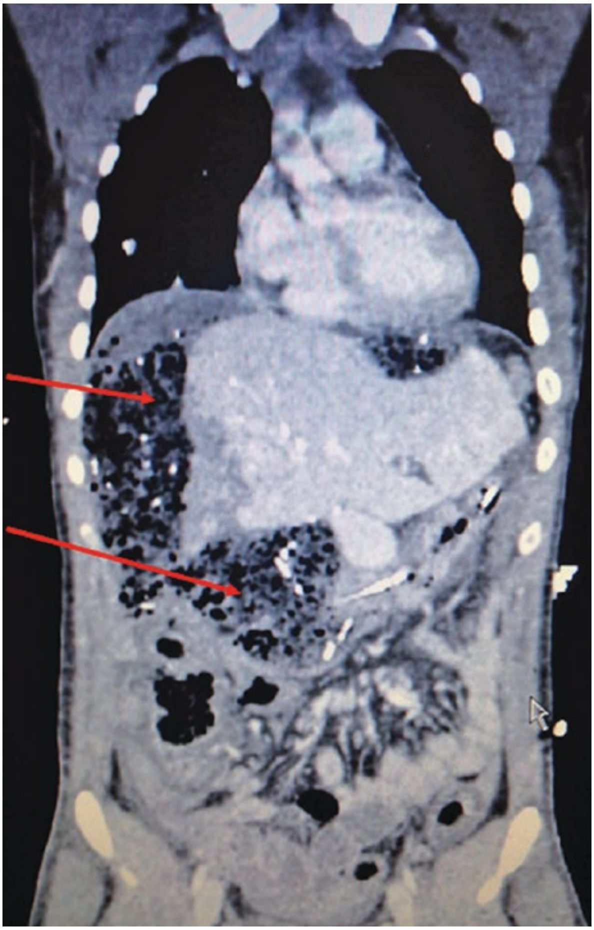

Fig. 6.1 Computed tomography scan after abdominal packing for a liver trauma (*red arrows*, laparotomy pads for packing)

Once the patient has been stabilized the surgeon may address the injuries:

1. Removing the packs one quadrant at a time, starting from the remote area of suspected injury
2. Inspecting for active bleeding (expendable organs such as the spleen and, to some extent, the kidney should be removed), bowel, diaphragm, and bladder injuries.

6.3.2.5 Contamination Control

Spillage of biliary and pancreatic juice, intestinal content and urine can be addressed after hemorrhage control:

1. Biliopancreatic injuries, in a vast majority, can be managed initially with closed-suction drainage, until ultimate repair or resection can be undertaken later.

Drains are brought out through the flank, if possible laterally to the external edge of the rectus muscle, and intra-abdominal packs are carefully placed so as not to cause kinking of these tubes.
2. All bowels must be inspected completely. Spillage control may be achieved with simple suture, clamps, skin staples, or resection leaving the stump abandoned.
3. Bladder injuries can be rapidly oversewn, and ureteral injuries are amenable to either ligation or exteriorization. Temporary nephrostomy may be required to relieve the renal obstruction as a result of ureteral ligation.

DCS Part 1 cannot be considered completed until all surgical bleedings are arrested. Interventional radiology techniques are useful to halt uncontrolled bleeding in complex hepatic, retroperitoneal, and pelvic injuries that are not amenable to surgical control or would require lengthy surgical exploration in the setting of coagulopathy. Endovascular procedures may be performed using either mobile imaging or a hybrid operating room.

6.3.3 DCS Part 2: Dynamic Intraoperative Reassessment of Physiology

A continuous reassessment of the patient's metabolic derangement is mandatory during DCS Part 1. Although it has commonly been suggested that prolonged operation should be avoided in severely injured patients, recent indications for use of DCS in civilian trauma [7] suggest that if patients are not already in physiological extremis, it may be appropriate to complete a definitive operation as long as they demonstrate an adequate response to resuscitation. If not, the surgical intervention is truncated and a temporary closure of the body cavity performed. Options for effective temporary closure are well described for the abdomen (temporary abdominal closure), ranging from simple skin-only closure to industry-made devices (i.e., negative pressure wound therapy) [30].

6.3.4 DCS Part 3: Continued Physiological Restoration in the Intensive Care Unit

The goal of this phase is to restore the physiological reserve to allow within 24–36 h the take-back to the operating room for definitive repair of the injuries and abdominal closure. Acidosis and coagulopathy must be corrected with an aggressive strategy, and the patient rewarmed and re-evaluated with a tertiary survey. Unplanned reoperation before physiological restoration may be necessary in the event of:

– a patient with ongoing transfusion requirements or persistent acidosis despite normalized clotting and core temperature; missed surgical bleeding or visceral injury must be suspected;

– onset of abdominal compartment syndrome, defined as sustained intra-abdominal pressure (IAP) >20 mmHg in the presence of new single or multiple organ system failure.

6.3.5 DCS Part 4: Definitive Reconstruction

At this stage, all packs are irrigated copiously and removed carefully to avoid further visceral damage or rebleeding. If a persisting bleeding is encountered the definitive repairs must be delayed and repacking performed to avoid recurrent physiological deterioration. After successful depacking, a complete re-examination of the cavity should occur, paying particular attention to previous repairs made during DCS Part 1. A plain film of the body cavity must be obtained not to miss retained pads. In the abdomen, gastrointestinal continuity is re-established, a stoma is formed if necessary, and solid organ debridement is performed as needed. Formal abdominal closure without tension is attempted. Nevertheless, if the peak airway pressure increases by >10 cmH_2O or IAP is higher than 15 mmHg the fascia should be left open and the temporary abdominal closure device replaced. In this case the aim is to achieve a fascial closure within 7 days to avoid complications such as enteroatmospheric fistula [31].

6.4 Damage Control for Extra-Abdominal Injuries

6.4.1 DCS for Neurosurgical Injuries [20, 21]

Principles are the early monitoring of intracranial pressure, the arrest of intracranial bleeding, the evacuation of intracranial hematomas, and the limiting of contamination of compound wounds of the head by early surgical debridement. The dura is always closed primarily and the scalp is preferably closed over the dura so that the risk of intracranial infection is minimized. The bone flap must be removed after hematoma evacuation if there is a risk of brain swelling. Application of damage control principles to the spine varies depending on the pattern of injury to the bony structures and extent of spinal cord involvement, according to the postulate that primary mechanical spinal cord injury initiates a series of secondary injury events that exacerbate spinal cord damage. The steps are to evacuate epidural hematoma, to stabilize major fracture(s)/reduce dislocated joint(s) with posterior fixation and instrumentation within 24 h, and to decontaminate open wound(s). Scheduled surgery for a 360° fusion should be done within 3 days if an anterior decompression is indicated for neurological or biomechanical reasons.

6.4.2 DCS for Maxillo-Facial Injuries [22]

Critical hemorrhage from bone fractures and soft tissue injuries and airway compromise can be challenging in maxillo-facial injuries. The airway can be controlled with orotracheal intubation, but a surgical airway may be the only chance (cricothyroidotomy, tracheostomy). Bleeding is addressed in emergency with oral and nasal packing and, in critical conditions, ligation of the external carotid artery/ies is an option. Bone fractures are temporarily stabilized with external fixation or handmade interdental splints. After damage control, a contrast-enhanced CT scan is obtained to detect residual bleeding, and angioembolization will definitely control ongoing hemorrhage. Definitive reconstruction of maxillo-facial injuries will be performed after few days, when the tissue edema has regressed and physiology is restored.

6.4.3 DCS for Neck Injuries [23]

Because of the peculiar anatomy of the neck, DCS must guarantee airway control, hemorrhage control and control of potential contamination from the airway and digestive tract. For the purposes of initial assessment and management planning, the neck is divided into three zones:

- ***Zone I***
  Zone I extends between the clavicle/suprasternal notch and the cricoid cartilage (including the thoracic inlet). Surgical access to this zone may require thoracotomy or sternotomy. Major arteries and veins, trachea and nerves, esophagus, lower thyroid and parathyroid glands and thymus are located in this zone.
- ***Zone II***
  Zone II lies between horizontal lines drawn at the level of the cricoid cartilage and the angle of the mandible. It contains the internal and external carotid arteries, jugular veins, pharynx, larynx, esophagus, recurrent laryngeal nerves, spinal cord, trachea, upper thyroid and parathyroid glands.
- ***Zone III***
  Zone III extends between the angle of the mandible and base of skull. It contains the extracranial internal carotid and vertebral arteries, jugular veins, cranial nerves IX–XII and sympathetic nerve trunk.

The surgical approach is usually made through a standard incision along the sternocleidomastoid muscle, with the head slightly rotated contralaterally. Hemorrhage may be controlled with packing, a Foley catheter, or bone wax. Angiography may represent the only effective strategy to control ominous bleeding in zone III.

6.4.4 DCS for Thoracic Injuries [24–26]

Since some intrathoracic injuries require definitive repair while others can be temporized, the approach to thoracic DCS should be to perform procedures that are technically faster and simpler for definitive repair and to perform maneuvers to temporize those injuries that do not require immediate repair in the patient in extremis. The standard approach is through a left anterolateral thoracotomy extending from the sternum to the stretcher laterally, below the nipple at the fifth intercostal space, with the aims to release pericardial tamponade, to control intrathoracic bleeding, massive air embolism or bronchopleural fistula, to permit open cardiac massage and to allow for cross-clamping of the descending thoracic aorta. The patient is supine, with both arms out. If deflation of the left lung is needed, a bronchial blocker or advancement of the endotracheal tube into the right main stem is easier than trying to place a double-lumen endotracheal tube. Clam-shell thoracotomy should be performed to gain access to mediastinal structures or to control contralateral injuries. Median sternotomy or supraclavicular extension or both may be required to provide proximal vascular control in subclavian artery injuries; the “trap door” incision has been abandoned, due to the significant associated morbidity. Successful hemostasis may be achieved by packing around the apex, diaphragm and vertebrae. Moreover, packing should be carefully considered, because the presence of bulky gauzes may induce increased intrathoracic pressures, with potential cardiopulmonary collapse, desaturation and ventilation disorders. In this case, a temporary thoracic closure may be achieved with a Bogota bag, without exerting undue intrathoracic pressure.

6.4.5 DCS for Orthopedic Injuries [27]

Damage control orthopedics is the current treatment of choice for the severely injured patient, especially those with unstable pelvic ring injuries associated with hemodynamic instability and proximal long bone fractures. Timely control of bleeding in pelvis fractures should use damage control principles, such as packing and adjunctive measures such as REBOA. Provisional fracture stabilization is obtained by closed reduction with binder or sheet and external fixator of any fractured pelvis with increased pelvic volume. After damage control of the pelvis, a contrast-enhanced CT scan is obtained to detect occult bleeding and angioembolization, if needed, is the treatment of choice. Blood loss from long bone fractures can be reduced by temporary splinting followed by external fixation in emergency, as a bridge to definitive stabilization.

6.4.6 DCS for Extremity Vascular Injuries [28, 29]

Complex vascular injuries of the extremity accompanied by skeletal fractures or soft tissue destruction still result in a rate of limb loss of up to 20%. Tourniquets may prevent exsanguination, as can ligation, balloon occlusion or clamping of an injured blood vessel, but irreversible tissue loss may occur if such measures are maintained while other injuries are treated. Complex repairs, including end-to-end anastomosis, saphenous vein grafts and vascular prosthesis transplantation, are time-consuming. Temporary intravascular shunts in such cases have the potential advantage of facilitating rapid control of hemorrhage and restoration of distal flow while permitting deferment of definitive repairs to higher echelons of care where greater resources and expertise will be available. Commercially available shunts (the Javid, Sundt, Argyle and Pruitt-Inahara carotid shunts) or self-made tubes (i.v. lines, feeding tubes, chest tubes) may be used, depending in the vessel diameter. The shunt size should be the largest diameter that fits comfortably into the injured vessel. Once obtained proximal and distal vascular control a Fogarty is passed to remove intraluminal thrombi, the shunt distal edge is inserted first and back-flow appreciated; the proximal edge is inserted after heparinized saline; the shunt is secured as close to the vessel edge as possible. The flow through the shunt should be regularly monitored by palpating distal pulses or by Doppler ultrasound. A temporary arterial shunt could maintain patency with adequate distal perfusion for up to 24 h without systemic anticoagulation. Primary amputation should be considered for mangled extremities which threaten life and when patient survival may be jeopardized by limb salvage efforts.

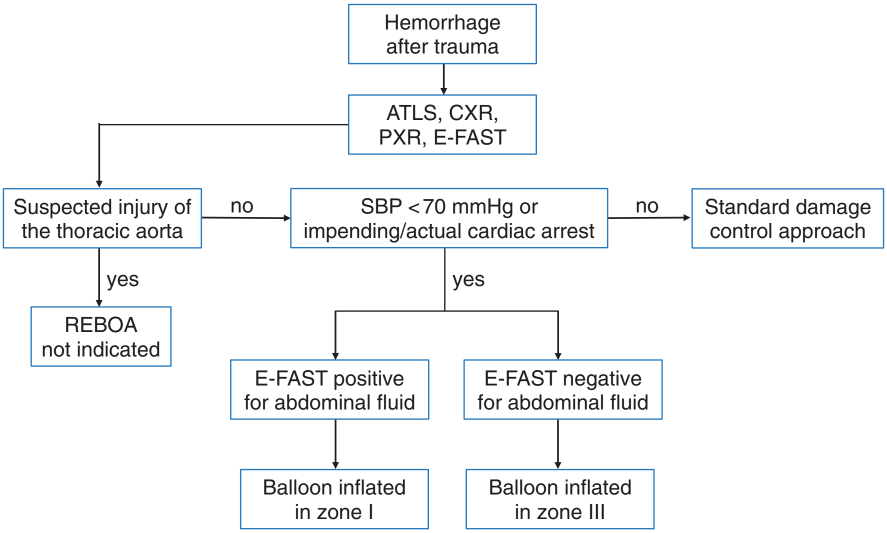

Fig. 6.2 Algorithm for the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in hemorrhagic trauma patient. *ATLS* advanced trauma life support, *CXR* chest x-ray, *PXR* pelvis x-ray, *E-FAST* extended focused assessment with sonography for trauma, *SBP* systolic blood pressure

6.5 Resuscitative Endovascular Balloon for the Occlusion of the Aorta

The resuscitative endovascular balloon for the occlusion of the aorta (REBOA) has been introduced in recent years as a technique for limitation or cessation of blood flow through the thoracic or abdominal aorta in patients with non-compressible torso hemorrhages [32]. This technique for temporary control of bleeding should be applied as a bridge to more definitive damage control procedures in very sick patients (Fig. 6.2).

6.5.1 Technique of Insertion

REBOA can be inserted via the common femoral artery either percutaneously, with or without ultrasound guidance, or through a surgical cutdown. The balloon is inflated in aortic zone I (from the left subclavian artery origin to the celiac axis), in patients with positive E-FAST for abdominal fluid, with the aim of stopping bleeding from the abdomen, pelvis and lower extremities. Ischemia of this large part of the body is poorly tolerated and the occlusion should not be kept for more than 15 min. In hemorrhagic patients with negative E-FAST and x-ray of the pelvis showing unstable pelvic fractures, the REBOA is inflated in aortic zone III (below the renal arteries) to stop retroperitoneal bleeding. The aortic occlusion in zone III can be maintained for 20 min. In both zones I and III occlusion time can be prolonged if the balloon is partially inflated, but the evidence is still limited. Modern catheters allow proximal pressure recording from the tip and the inflation can be adjusted to maintain the desired pressure in the aorta above the balloon without the need for a complete vascular occlusion.

6.5.2 Complications

The use of REBOA is associated with a high incidence of complications, up to 20%. The most important problems with this technique are injuries to the femoral artery requiring surgical reconstruction, and limb ischemia provoked by distal dissection or embolization, with sometimes a need for amputation. Injury of the thoracic and abdominal aorta have been described due to dissection or perforation of the wall during progression of the catheter, and aortic rupture caused by hyperinflation of the balloon. The complication rate is reduced if a low diameter catheter (7–8 Fr) with atraumatic tip is used.

6.5.3 Evidence

The application of REBOA for temporary control of torso hemorrhage is a controversial issue. After initial enthusiasm, many concerns have been expressed for the high rate of complications, on the one hand, and the uncertain results, on the other. A review of the literature suggests that REBOA can be associated with a survival benefit in patients with impending or actual cardiac arrest from hemorrhagic shock, when compared to resuscitative thoracotomy [33]. Conversely, when REBOA was compared with standard damage control procedures (abdominal or pelvic packing) in less severe conditions of hemorrhagic shock, no clear survival improvement was observed [34].

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