Review Article

Thoracic damage control surgery

Tamas F. Molnar[1,2]

[1]Department of Operational Medicine, Medical Humanities Unit, University of Pécs, Pécs, Hungary; [2]Department Surgery, St Sebastian Thoracic Surgery Unit, Petz A University Teaching Hospital, Győr, Hungary

Correspondence to: Tamas F. Molnar. Magaslati u. 35 II.8, Pécs, Hungary. Email: tfmolnar@gmail.com.

Abstract: Thoracic damage control surgery (TDCS) is a decision making tool and derivate of the damage control concept (DCC), where physiological stabilization has a priority over anatomical reconstruction under the pressure of time. Intrathoracic haemorrhage control and pleural decompression are the two main immediate tasks of TDCS, while definitive procedures follow when the patient is stabilised in 24–48 hours. The focus of the thoracic surgeon is on the prevention of the haemorrhage induced coagulopathy, metabolic acidosis and hypothermy formed triad of death. Surgical haemorrhage control and pleural space decompression are to be performed. The individual patients benefit from TDCS procedures whose condition is too severe for a complex immediate reconstruction (polytrauma). Life threatening chest injuries in multiple/mass casualty scenarios in civilian and military environment alike are triaged and treated accordingly. Onset of acute mismatch between the resources (available hands, OP theaters, resources, hardware) and the needs (number and severity of chest trauma cases), a mindset shift should take place, where time and space the two main limiting factors. Airway obstruction, tension haemo/pneumothorax falls into the preventable death category. Chest drainage and emergency thoracotomy are the two main procedures offered by TDCS. An intervention structured organ/injury specific list of procedures is detailed. This is a mix of emergency surgery and cardiothoracic surgery, where less is more. TDSC is not the Holy Grail found to solve all complex thoracic trauma cases, but is a good tool to increase the chance for survival in challenging, and frequently quite hopeless situations.

Keywords: Chest trauma; thoracic surgery; damage control concept; acute lung injury

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Introduction

Damage control concept in trauma as we understand it now, was born in the mid-1980s and became well established a decade later (1,2). The expression is borrowed from the Navy, describing the emergency procedures during battle, when a seriously destroyed warship was prevented from sinking and kept sailing to make the nearest friendly port, where the necessary repairs can be done. The medical term covered concept was a reaction in trauma surgery to rapid progression in anesthesiology cum intensive therapy and novel surgical technologies promising limitless operation time, space and resources. Pursuing surgical perfection at any price in multi and polytrauma patient resulted in suboptimal outcomes due to the abuse of the biological reserves of the injured patient. Emerging ignorance (hubris of omnipotence) of physiologic limits of patient in extreme was only half of the reasons calling for a mindset change. Accumulated military surgical experiences in asymmetric warfare (3) and changing injury profiles in new types of violence (4) were to be applied in care of terror attack victims (5,6). An increasing number of civilian surgeons had to face mass casualty situations (7,8) challenging received wisdom and well established protocols developed in decades of peace (9). The temporary but drastic disruption of the balance in patient/injured and resources (staff, space, hardware) is threatening with chaos (10). The standard no-compromises surgical attitude of offering everything available to the individual patient and doing it at once which have been dominating our orthodox decision making

needs a rethinking. Thoracic surgery has its own particular tasks in this new situation (11). The recent emergence of the "preventable death issue" debates (12) highlight the importance of the torso and especially chest injuries (13,14).

Both of the individual patient care challenges and organization-rooted problems are calling for remodelling of ruling emergency surgery concepts. Identification of the triad of trauma death: hypothermy, metabolic acidosis and coagulopathy led to a paradigm shift, where function became a priority over anatomical reconstruction. The aim is blocking the domino effect of the hypoperfusion centered element of the lethal triad, where catastrophic bleeding is the trigger. Maximum of overall surgical time between 60 and 90 minutes in damage control surgery defines properly the time frame of the first stage. Following a successful 24–48 hours stabilisation at the ICU (second stage) the definite (reconstructive) surgical procedures complete the protocol (third stage). Damage control surgery allows a patient and/or resource optimised approached in an enormously stressed/hostile environment. The time limits are important but flexible in a degree guidelines rather than being carved into marble rules.

Damage control surgery (DCS) in general can be defined as one is abbreviated, reductive or rudimentary when the standard policy is challenged for some reason. The classic surgical philosophy, in which all of us were trained and socialised, the primary dictum of all surgeons is to provide all what is available by all means for the individual patient. The surgical aim is achieved only when all pathologies are removed and anatomy and functions are reconstructed. While duration of the surgery is important, time is not a decisive factor. However, when an acute mismatch exists between the resources (available hands, OP theaters, resources) and the requirements: number and severity of the cases, a decision must be taken. Therefore the very first decision to make is, to judge if the system is still capable to cope with the situation or it is going to be overflowed (saturated) soon. This is a dynamic process, where regular reevaluation of the picture is needed. It is not only the time/resource which can be short, but experience/knowledge of the actual players also. Patient and system are the two different faces of the same coin.

The key element of damage control is to support the very basic life functions and keep the system under control without attempting to reach a definite solution at any price. This is a sort of surgery, where less is more. There are strict limitations when the rules of DCS are to be implemented. A clear distinction must be made between the standard operational procedures in the torso injuries and DCS. The decision to shift is not for good and forever, as it should be reviewed, according to the actual situation. A standard procedure might need a conversion to DCS if several new heavy cases arrive and acute shortage of tables, anesthesia machines occur. Any particular operation might be converted into a DCS-led procedure, if the anesthetist advises (Decisions over the screen). There are different recommendations and protocols in the literature supporting the decisions, but the threshold values are generally agreed. Significant spontaneous hypotension over 50–60 min, adverse metabolic parameters: hypothermia <35 ℃, acidosis pH <7.15, BE <8 mmol/L coagulopathy PT >15, PTT >42, thrombocyte number <200,000 are the most important basic data. Local policies, schooling, personal experience might add further indicators and there is a range in the recommended numerical data, also. Personal factors, like limited experience might also have a role, as a stabilized patient has better chance at a second look procedure by a more experienced or simply fresh colleague, than what an all in one procedure can offer.

The term—damage control—is a flexible one. A chest drainage in order to decompress the pleural space—might offer a decisive solution also, as not only a diagnostic procedure, but by stabilising the pleural pressures might treat the patient definitely (15). The temporary and sometimes improvised nature of DCS procedures makes documentation extremely important. Documentare necesse est—all of us know it in our clinical practice. It has an extreme importance in DCS, as notes on foreign bodies left behind intentionally, procedures performed and have not been performed are vital. Lack of information kills the very sense of the word.

Damage control surgery is optimization instead of maximisation of surgical aggressivity. It is integral part of the Damage Control Concept, a sort of short term and distilled surgical decision making with well-established and clear mid-term plans.

Definition

Thoracic damage control surgery (TDCS), is a programmed approach of a complex chest problem, rather than a specific set of procedures. It focuses on the chest injured patient rather than the injuries themselves. There is no special technique in TDSC, as all its procedures are well established and integral parts of general thoracic surgery (13,14). Only the luxurious fineties are stripped off from a standard

thoracic surgical case care under the stress of time and circumstances. Maximal utilization of time in diagnosis and intervention typifies TDCS. In the chest cavity there are two substances exposing the injured patient to danger of life: blood and air. Thoracic surgeon performing TDCS has only two enemies to cope with: exsanguination and/or space occupying and lung-compressing events. Just for sake of illustration, the dual dangers in abdominal damage control surgery are haemorrhage and immediate infection exposed by the gastrointestinal tract injury. Of course, contamination should concern thoracic surgeon as well, but the danger is not imminent on the same scale, therefore is not a reason to choose TDCS in itself. Blunt lung parenchyma injury needs similar consideration, as maintainence of ventilation/oxygenisation is relegated to our anesthetist/intensive therapist partners. The two primary aims of TDCS are arrest of haemorrhage and maintaining oxygenisation by relieving intrathoracic positive pressures. Everything else is secondary—if those two functions are reached, than job done. All the operational time you have 60 min but never more than 90 min. One can, of course step over this threshold, but then the report of performing DCTS needs a credible explanation. No question, a chest procedure might be longer and till follow some rules and concepts of DCTS borrowing important features of it, but the red tag of that particular term might be questionable. DCTS is very far from being the Holy Gral offering general solution for all of our problems. The lucky ones can do their job without it. DCTS is just a secret weapon to pull it out from the back of our mindset if needs arise. Hope, the Reader never need it, and the author wrote an unnecessary article. I am afraid, this ideal world is far far away…

Patient pool

Two distinctively different reasons can command decision to turn to TDCS.

The first scenario concerns one patient only, and it can be defined as the story of an individual case (16). Any patient who is too unstable for standard trauma bay evaluation is candidate for TDCS. The decision can be altered during the procedures. Quickly improving general condition of the patient on table, unexpectedly easily manageable local situation might overwrite the original decision, and the plan is converted to a standard procedure. Chest monotrauma is a simpler case. Haemodynamically unstable patient with obvious penetrating injury needs intubation and surgical exploration, the visual impression of the external signs dictates surgical attitude. Stable patient needs physical examination and bloods for labs. An initial chest drainage is to be performed if severe ventilatory impairment (hypoxia) is due to haemo/pneumothorax detected with physical examination. The procedure is followed by chest X-ray and/or CT. The only acceptable exception from the intervention first, image follows rule at patient in danger of tension hamo/pneumothorax is the availability of bedside chest ultrasound (Focused Assessment with Sonography in Trauma: FAST). Stable patient with acceptable oxygenisation needs images first (17,18). Chest injury part of polytrauma is a different piece of cake. Drainage as a primary diagnostic and in the majority of the cases therapeutic procedure precedes imaging in unstable patient (15,19). Sequence of procedures in both of haemodynamically stable and instable patient and is dictated by the particular injury pattern (20,21).

The second scenario refers to a situation when more than some chest injured patients manageable by first come first served rule are reporting at the same time (22). There are two subtypes of the possible event: multi-casualty scenario and mass-casualty scenario.

The two situations differ in their particular capacity/demand ratio. When the hands/resources are sufficiently enough to cope with the needs, a sequential care providing is initiated and the most severe case has an absolute priority. Mass casualty (MASCAL) scenario is different, and a triage system needs to be applied in order to optimise the outcome (23). There is no need for TDCS in haemodynamically stable chest patients in a multi-casualty scenario: a business as usual policy is to be followed. The haemodynamically instable/critical patient with chest injury should be treated as it was advised above, in the individual patient section. TDSC is to be applied only in the MASCAL scenario, where the human and material resources are overflowed, and the system is "saturated". In these extreme situations the triage system must be activated (24).

Chest injury in triage

Triage, allocation or sorting is a system, where the limited medical resources demand prioritization in order to optimise outcome in terms of number of survivors. There are different types of triage. According to the site we can differentiate prehospital and in-hospital triage: i.e., Emergency Department/inpatient (Intensive Care Unit/Department). Incident triage is similar but not equal to battlefield triage, and both have overlappings with

(natural) disaster triage (24). There are (too) many different categorizations in the literature, however the absolute majority of them are common in a 1–4 or 5 grading (Some system separates a T1a „top priority" subgroup). Number 1 is the most serious group, usually colour coded by red, indicating need of immediate medical attention. All significant chest injuries are categorised as T1 or T1a signalling the condition as one of the most serious cases. T1a is to be operated on without extensive investigations, while T1 refers to stable patients with potentially life threatening condition. The high priority of the condition shows also, that at least a part of the cases is a potential survivor (9,25). From a thoracic surgical point, tension haemo/pneumothorax commands immediate intervention (T1a). However, while a chest drain shifts a T1a patient with tension pneumothorax to the most convenient T3 group, a penetrating chest wound causing haemodynamic instability calls for immediate exploratory thoracotomy and occupies an operational table and needs a whole team. Access to the diagnosis/therapy is limited by external factors and determined by the severity of the condition at arrival.

Diagnostics

Diagnosis is based on basic life parameters, visual observation and additional information provided by paramedics, police, etc. FAST is a good adjust, but the 360 degree physical examination of the full nude body has the utmost importance. Chest drain is the main auxiliary weapon of the attending physician. Chest trauma includes the potential of the junctional and thoracoabdominal injuries also. Always consider „what might happen in the other—i.e., the inferior box? Chest X-ray and/or CT are for the stable patient. Any additional examination should have a consequence, hypothetised in advance.

Specific damage control procedures: tips and tricks

Chest drainage (Tube thoracostomy, intercostal catheter)

Do not use the incision made by the injury bought your patient to the hospital: knife, bullet, etc. The standard drainage site is the midaxillary line, one-two ribs below the level of the nipple 5th–6th intercostal space. Use Ch 28 or larger drain, avoid pure silicone ones, which tend to kinking. Put Heimlich valve at the end of the tube, or fix a multiholed rubber finger/sliced condom at the tip. The aim is decompression of the pleural space, let the lung expand. Never connect the patient to a closed bag—as it is just an extension of the pleural space.

Axillary region of a stretcher case/horisontal patient (polytrauma patients, worked on by different teams) is rarely exposable, as the upper arm is in your way. It is easier to approach the anterior chest wall. The tunneling is harder as the pectoral muscle mass is voluminous and the chest wall is definitely thinner than in the axilla. Prefer the blunt dissection technique. A long Pean/Roberts clamp does the best job. A generous skin incision opens the space to the intercostal bundle. In case of doubt (adhesions?), the last 1–3 mm can be made by using fingertip blind dissection. Once in the pleural space, the finger as a palpating sensor orientates the surgeon. Safe securing the tube to the skin is essential.

Alternatively, especially in extreme environment (roadside, battlefield) as an emergency large bore and long (!) needle decompression is more than nothing, in spite of reportedly high failure rate. Emergency thoracostomy is a relatively newcomer in the field in the pleural decompression of ventilated patients (26).

Thoracotomy

Any DCTS thoracotomy providing good access is appropriate, with the exception of the one which has not been performed. The thoracic cage is forgiving, the bleeding is not. The entrance of the injury dictates approach. Turning a haemodynamically unstable patient to the standard lateral decubitus position is time and theater staff hand consuming (27,28). However, there are injuries, when an access to the back of the victim is needed, also. Isolated one lung intubation—one of the greatest achievements of chest surgery in the past half century—is a luxury in DCTS, few situation allows it (29). Horizontal sternotomy is preferred by many surgeons, as the anterior aspect of all intrathoracic organs is accessible. Left anterior thoracotomy (hemi-clamshell) provides good access to the heart and descending aorta and an extension via a vertical sternotomy enhances field of maneuvers. Where lateral access is considered, the good old posterolateral or anterolateral thoracotomies are recommended. Many of us prefer muscle sparing axillary thoracotomy, but chest trauma is not for limited access experiments. The same consideration excludes any VATS procedure from the DCTS. Never be shy to extend the incision. The emergency thoracotomy is subject to improvisation: even longitudinal sternotomy can

be extended to lateral (step-door thoracotomy) —if access requires. Three tools are invaluable: towels with wide lung retractor, big calibre suckers (not shared with anesthesia) and headlight.

Systemic haemorrhage control

Always consider control of coagulation cascade as an adjunct to surgical arrest of major bleeding. Endemic platelet aggregation inhibition drug taking creates millions of subclinical coagulopathic patients. Communicate with your anesthetist and have tranexamic acid and factor VII in your mind (30). Thrombelastrogram (TEG) and rotational thrombelastometry (ROTEM) are promising methods in detection of trauma induced coagulopathy, dark powers when DCTS is needed at the individual patient (31).

Closure

Closure of emergency thoracotomy must be quick and simple (32). Temporary cover is allowed. Vacuum assisted wound closure system offer an alternative solution in large defects, especially if high degree of contamination is expected.

Injured organs to control in DCTS

Heart and big vessels

The few victims, who arrives alive at the Emergency Department is usually haemodynamically unstable and requires emergency thoracotomy. The objective of the thoracotomy is cardiac tamponade relief and cardiography. Control the site of bleeding with index finger in the hole or slip a Foley catheter in and inflate the cuff. Asking for big needles, making improvised pledgets from the pericardium if teflon pieces are missing improves the chance of success. Avoid coronary artery, but if one cannot do that, remember: an MI might be survivable, while an exsanguination is definitely not. Do not be disappointed if one fails closing completely the heart wound with the first or even by the second stitch. It is sufficient, if the bleeding is reduced at the first attempt, and the second or third attempt will succeed. Purse string stitches around the finger or the Foley catheter are easier to implement. Two long strong needle-holders are better for some than the standard needle-holder in one hand, forceps in another method. U shaped sutures for the ventricular wounds are to stitched using 3/0 or 4/0 non-absorbable monofiles. The bigger the needle, the better. The atrium is more fragile, especially in older patients, but clamps might work, or even staplers applied (33). Knots tend to cut through the myocardium if one is not gentle enough.

Descending aortic crossclamping is performed using Satinsky or Cooley forceps to increase coronary /brain circulation and for temporary centralisation of the blood volume. The first step is an incision of the mediastinal pleura in the esophago-aortic groove, above the diaphragm. Pulmonary artery/veins approached intrapericardially offer central control for pulmonary hilar injuries. More complex injuries need cardiac surgeons, usually cardiopulmonary bypass or at least ECMO, a scenario well beyond the territory of DCTS even if only one patient is in question. However, the positive outcome is rare, and the failure rates remain unreported.

Aortic injury requiring DCTS is a rarity. Partial, incomplete ruptures are benefiting from acute endovascular procedures. Brain circulation protection (local cooling!) and controlled hypotension is the most, what emergency surgery can do for these patients. Intrathoracic vein injuries are more benevolent: their urgent management follows the rules of vascular surgery. Stenting—internal and external—is an option, depending on local resources and time allocation. With the exception of the superior and inferior vena cava and the innominate artery all major vessels are potential subjects of ligation/stapling if no other option was left. Mediastinal and extrapleural haematomas are left *in situ* in an ETDCS scenario.

Lung

Low pressure system in the pulmonary circulation, tissue elasticity and high concentration of thromboplastin makes lung surprisingly trauma resistant. Even deep parenchyma wounds respond beneficially to tenacious compression and approximation by stitches. Success is confirmed, that no further significant bleeding is detected in the endobronchial tube. Multiple superficial tears and wounds need only towels, big swabs soaked with warm salt, and patience also. Tachosyl can spare the 5–10 minutes waiting time, what is usually needed. Through and through lung injuries, creating a tunnel deep down causing profuse bleeding might benefit from tractotomy instead of lung resection. Positioning half of the jaw of a GIA stapler or two long forceps through the tunnel and opening the lung bridge between them allows removing the roof. The bleeding vessels and destroyed

structures in the exposed internal walls become controllable. Obviously devitalised or profusely bleeding parts of the lung might be resected. Non-anatomical (atypical) resections are recommended. Staplers make the procedure quicker—which has an eminent importance in TDCS. Running stitches (3/0, non-absorbable, large needle) below the long forceps, clamps do the same job. Anatomical resections (lobectomy or pneumonectomy) are extremely rarely needed for trauma, and are beyond the territory of TDCS.

Bleeding from hilar structure is a big challenge, a situation where survival is highly uncertain. Manual compression and identification of the bleeding structure/site is the key. Hilar twisting is a wandering motive from one chest trauma article/handbook to the other, but very few saw it ever performing. The author recommends a big size Satinsky or Cooley clamps instead of the complex procedure of freeing the pulmonary ligament and cornering around the hilum before turning the profusely bleeding lung around its roots. Even a generous intrapericardial approach seems to be more promising for central bleeding control. A rubber sling around the PA and the vein complex might work as a tourniquet. Positioning a large TA stapler and close the jaw without firing it, offers another solution. At the end of the day, if no other option is left, an emergency pneumonectomy is still at hand.

Annoying diffuse bleeding without quickly identifiable source may call for packaging. The method, transplanted from liver trauma management is an ultima ratio both for lung and mediastinal/internal chest wall haemorrhage. Recent reports are encouraging and no evidence of circulatory compromises was encountered (34).

Esophagus

Primary suture in two layers and nasogastric tube might be sufficient for limited lesions. For large wounds with uncertain viability at the edges (blast injury, high velocity projectiles) cervical esophagostomy with gastrostomy or jejunostomy is recommended. A T-tube drainage might buy time in case of esophageal injury in the proximal quadrant. While the general condition of the patient improves/upper GI specialist becomes available. A controlled fistula is definitely better than a failed primary suture. Intrathoracic esophageal injury always commands a generous pleural drainage. Paradoxically enough, some hours delay in surgical reconstruction of the injury or exclusion while waiting for general condition improvement does not affect adversely the prognosis.

Trachea at main bronchi

Large tracheal injury is not survivable as suffocation kills the patient on site. Small injuries benefit from temporary bridging tracheal intubation, internal stabilization. Upper third trachea lesion bridged by a Montgomery T-tube means the damage is under control. Major distal third trachea injury needs right sided thoracotomy and cross-field intubation (35). Left sided main bronchus injury is manageable temporarily by a long tracheal tube directed to the right side and unilateral ventilation. Timing of the definite procedure following stabilization needs special consideration. Definitive reconstruction of the central airways and esophagus following a successful TDCS commands as short time window as possible: closer to the 24 than the 48 hours. Again, the biological test offered by the staged DCC approach helps differentiating between devitalised tissue and those healthy enough for a safe anastomosis.

Chest wall

Contrary to the central airways and the esophagus, where the timing dilemma of definite procedure following TDCS is answered by "the sooner the better", the extensive chest wall injury can wait, and the reconstruction is frequently multi staged (19,36). Temporary closure of the chest wall, drainage of the pleural space, and artificial ventilation are the three pillars TDCS of extensive chest wall injury. Voluminosus package of the pleural space is an option as a method of compression (34). The wound needs a close and frequent observation as regaining circulation can result in rebleeding of intercostal/internal mammary arteries. As in the chest generally recommended, bleeding control with stitches is always preferable to ligating or clipping. Artificial ventilation and intensive therapy maintains oxygenisation, while demarcation helps surgical planning. Patience and self-restrain in TDCS for chest wall injury offers a safe and peaceful operational field out the long run for the subsequent reconstruction (19,36). Strict operation time limits in TDCS do not allow osteosynthesis for extensive bony chest injuries other than doing the minimum "on the way out". Chest wall stabilization is for patients with stable circulation acceptable extent of serious lung contusion (LC) (<30%) and well defined hope for survival. Temporary chest closure is a real alternative following abbreviated thoracotomy (32).

Transdiaphragmatic injuries

Nature of injury and direction of the projectil tunnel are

the ringing bells to warn the surgeon. It is always simple to make an exploratory window on the diaphragm to see what is going on in the inferior box (37,38). Thoracophrenotomy is better tolerated than the standard thoracolaparotomy. Injured spleen, kidney can be removed, upper surface of liver repaired.

LC

LC is a handbook-case of multidisciplinary approach. Diagnosis and treatment requires trilateral cooperation between intensive therapeutist, pulmonologist and thoracic surgeon. It occurs in approximately 20% of blunt trauma patients with an injury severity score (ISS) over 15. The mortality ranges from 10 to 25%, and 40–60% of patients will require mechanical ventilation (39). Diffuse parenchyma injury results in cell-death in circumscribed area of the lung, extravasation of blood, alveolar disruption, interstitial oedema and defunct terminal airways, i.e., atelectasis and/or consolidation of lung tissue (40). Same injury/extension of contusion acts differently depending on the subject at the receiving end. COPD, old age, smoking, concomitant disease are influencing dramatically odds ratio for death from LC. Blunt chest trauma is a clinical chameleon (41). As the physiological impact of the contusions tends to develop over 24–48 hours, it is not a per sé TDCS subject, however a respiratory catastrophy can develop very quickly and unexpectedly. Examinations on admission: pulse oxymetry, blood gases, bloods, images: chest X-ray (erect, PA). Ultrasound and CT. will often under-estimate the extent/severity of LC and tends to lag behind the clinical events. Contusions detectable only on a CT scan without impaired gas exchange are clinically irrelevant. Treatment is clinical picture driven and not image directed (42).

The thoracic surgeon in LC has limited role even in DCTS scenario. When LC is combined with extensive lung laceration it might require debridement/resection in the third stage of DCC. Main technical problem is definitely dead tissue identification. Proper timing is crucial. Chest drainage is called to control pleural pressure catastrophies. Caveat: low suction force if not underwater seal alone is recommended to avoid development of bronchopleural fistula. Patients with LC are at risk of developing delirium syndrome which might be induced by other factors than alcohol withdrawal. Always look for central hypoxaemia, plasma chemistry element balance, full blood count abnormality and adverse medication and impending sepsis. Always consider lung embolism.

Conclusions

TDCS became a well-established modality with properly defined terminology and procedures. Some see the beginning of the end of DCC and DCS (43) as the wishful thinking of bleeding control by medication alone produces the periodically returning fake news. In the foreseeable future thoracic surgeons in alliance with traumatologists and emergency doctors will be always needed when profuse bleeding and pleural pressure catastrophies in and around the thorax must be controlled.

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Footnote

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