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DAMAGE CONTROL TECHNIQUES IN THE MANAGEMENT OF SEVERE LUNG TRAUMA

Alberto Garcia, MD, **Juan Martinez, MD**, **Julio Rodriguez, MD**, **Mauricio Millan, MD**, **Gustavo Valderrama, MD**, **Carlos Ordoñez, MD**, and **Juan Carlos Puyana, MD**

Abstract

Background—Damage Control (DC) has improved survival from severe abdominal and extremities injuries. The data on the surgical strategies and outcomes in patients managed with DC for severe thoracic injuries is scarce.

Methods—Retrospective review of the patients treated with DC for thoracic/pulmonary complex trauma at two level I trauma centers from 2006 to 2010. Subjects 14 and older, were included. Demographics, trauma characteristics, surgical techniques, and resuscitation strategies were reviewed.

Results—A total of 840 trauma thoracotomies were performed. Damage control thoracotomy (DCT) was done in 31 (3.7%). Pulmonary trauma was found in 25 of them. The median age was 28 (IQR 20–34) years, Revised Trauma Score was 7.11, (IQR 5.44–7.55), and Injury Severity Score was 26 (IQR 25–41). Nineteen patients had gunshot-wounds, four stab-wounds and two blunt trauma.

Pulmonary trauma was managed by pneumorrhaphy in three cases, tractotomy in 12, wedge resection in one and packing as primary treatment in 8. Clamping of the pulmonary hilum was used as a last resource in 7 cases. Five patients returned to the ICU with the pulmonary hilum occluded by a vascular clamp or an *en masse* ligature. These patients underwent a deferred resection within 16 to 90 hours after the initial DCT. Four of them survived.

Bleeding from other intra-thoracic sources was found in 20 cases: major vessels in nine, heart in three, and thoracic wall in nine.

DCT mortality in pulmonary trauma was 6/25, (24%) due to coagulopathy or persistent bleeding in five cases and to multiorgan failure in one.

Corresponding author information: Alberto Garcia, M.D. (c)MSc in Epidemiology. Department of Surgery and CISALVA Institute, Universidad del Valle, Cali, Colombia Departments of Surgery and Intensive Care Unit, Fundación Valle del Lili, Cali, Colombia Calle 6 Oeste # 10 – 85. Torre 7, Apartamento 202 Cali, Colombia agfm2011@gmail.com; alberto.garcia@correounivalle.edu.co Phone: 57 315 4676870 Fax: 57 2 331 7499.

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AUTHOR CONTRIBUTIONS

Alberto Garcia, Gustavo Valderrama, Carlos Ordonez, and Juan C. Puyana contributed to the study concept and design. Alberto Garcia, Juan Martinez, and Mauricio Millan conducted the literature search. Juan Martinez, Mauricio Millan, and Julio Rodriguez acquired the data. Alberto Garcia contributed to data analysis, which all authors interpreted. Alberto Garcia and Juan C. Puyana drafted the manuscript, which all authors reviewed and approved.

Conclusion—This series describes our experience with DCT in severe lung trauma. We describe pulmonary hilum clamping and deferred lung resection as a viable surgical alternative for major pulmonary injuries, and the use of packing as a definitive method for hemorrhage control.

INTRODUCTION

Damage Control (DC) strategies have gained wide acceptance in the management of abdominal trauma patients physiologically exhausted by coagulopathy, hypothermia, and acidosis. Patients managed with DC strategies show higher than expected survival rates (1-7).

Specific DC maneuvers have been created to speed up critical thoracic trauma surgery. These strategies include pulmonary tractotomy (8-10), stapling of cardiac wounds (11-14), and ligating or temporarily bypassing a main vessel (1, 2, 5-7, 15). Twisting the hilum to control bleeding from central pulmonary lesions has been proposed to gain temporary hemorrhage control and to postpone pneumonectomy (16, 17). Other authors have expedited the procedure by stapling the hilar structures *en masse* (18). Packing has been advocated, but its use to control bleeding in the thoracic cavity is controversial (19-21). The temporary closing of the thorax is achieved by using a number of methods, including towel clip closure, skin only closure with or without packing the chest wall, and temporary dressings such as the Bogota bag (22-24).

We describe a series of patients with lung trauma and other intrathoracic complex injuries that required DC procedures that were managed over a five-year period at two major level I trauma centers in Cali, Colombia.

MATERIALS AND METHODS

In this observational study, we retrospectively reviewed the clinical records of patients with lung trauma who underwent damage control thoracotomy (DCT) from 2006 – 2010 at the Hospital Universitario del Valle and Fundación Valle del Lili Hospital, two level I trauma centers in Cali, Colombia, a city with a population of 2,119,908 in 2005 and characterized by a high incidence of deaths from interpersonal violence, as well as an increasing incidence of pedestrians and motorcyclists injured in traffic events.

PATIENT SELECTION

We included patients 14 years of age and older that were managed with DCT at two participant level I trauma centers.

One hundred and seven patients who were treated with pulmonary tractotomy without any other DC procedure were not included, as this technique has become standard for most through-and-through bleeding lung lesions in our hospitals. Patients admitted to the emergency department with torso injuries were initially assessed using Advanced Trauma Life Support (ATLS) protocols.

Emergent thoracotomy was performed in all patients with any of the following clinical presentations: agonal (25); hypotensive, non-responding; hypotensive, transiently responding; and initially managed with a chest tube that drained more than 1500cc upon insertion or more than 200cc blood/hour for more than three hours.

SURGICAL TECHNIQUES

Agonal patients underwent a fifth intercostal space left antero-lateral thoracotomy. The rest of the patients received antero-lateral incisions on the same side of the lesion.

The decision to perform DCT was based on early evidence of physiological exhaustion or the presence of multiple bleeding sources, often outside the thorax.

Injuries to the pulmonary hilum or multiple bleeding lung wounds were transiently managed by clamping the pulmonary hilum. Lobar lesions were managed by local compression.

The definitive treatment method was chosen according to the anatomy of the wound and the physiologic condition of the patient. Isolated lobar injuries were managed with pulmonary tractotomy (9, 10), pneumorrhaphy, wedge resection, and packing of the pulmonary wound as primary methods of treatment in selected cases.

In central lesions where major resections were considered, a vascular clamp or an *en masse* ligature was left in place, **as selective as possible**, to permit the resuscitation of the patient in order to perform a deferred resection (lobectomy or pneumonectomy) at a later time.

Packing with laparotomy pads was used on bleeding lung surfaces after tractotomy within the traumatic wound and in the surgical incision. In some cases the packing was the only method used to control bleeding.

Chest tubes were left in the posterior recesses. Packing the muscular layers and suturing the skin with a running monofilament suture was used for temporary closure of the initial thoracotomies.

Patients were taken to the operating room again to unpack the thorax and to repair the injuries managed with temporizing measures once hypothermia, acidosis, and coagulopathy were corrected.

STATISTICAL ANALYSES

Demographics, trauma characteristics, surgical techniques, and resuscitation strategies were reviewed. Complications attributable to trauma were recorded: organ dysfunction as defined by Vincent *et al.* (SOFA score) (26), infectious complications as defined by the CDC Healthcare Infection Control Practices Advisory Committee (27), reoperation for bleeding, and death, cause of death, and time elapsed from the trauma to death.

Descriptions of all patients were performed using relative and absolute frequencies for qualitative variables. Continuous variables were summarized by reporting medians and inter-quartile ranges.

This was a retrospective chart review and therefore was considered a low-risk study according to the rules for research in health in Colombia (Res. No. 8430/1993 of Colombia's Health Department). Personal identification variables from subjects in the study were removed to preserve patient confidentiality. The Fundacion Valle del Lili Hospital and Universidad del Valle ethics committees approved this study.

RESULTS

During the five years observed, 840 trauma thoracotomies were performed in patients older than 14 years of age in the participant hospitals. Damage control thoracotomy was performed in 31 cases (3.7%). In 25 of them, pulmonary lesions were treated.

Most of the subjects were male and three quarters were less than 35 years old.

Only two patients had blunt mechanism of trauma and the majority were victims of firearms.

Trauma severity was reflected only partially by trauma indexes. Revised Trauma Scores ranged from 1.16 to 7.84 with one quarter less than 5.4.

Injury Severity Scores ranged from 10 to 54, with half of the patients scoring more than 26. The calculated survival probability fluctuated between 0.03 and 0.99, with less than 0.63 in 25% of the cases (Table 1).

The number of compromised thoracic structures averaged 2.28 per patient. The average number of bleeding sources from inside the thorax was 1.72 (Table 2). The most common source of bleeding was the lungs, followed by the thoracic wall in 17 cases (68.0%), and major vascular structures in nine (36.0%).

The abdomen was the most prevalent location associated with concomitant injuries in 13 patients (52%), followed by the head and neck and the extremities in seven cases each (28%). These lesions were additional sources of bleeding in most of the cases. Traumatic lesions were located exclusively in the thorax in three patients (Table 2).

Anterolateral thoracotomies were performed in 24 cases. Left thoracotomy was performed in seven (28.0%), right in 13 (52.0%), and bilateral in four (16.0%). Transverse sternotomies (clam shell) were performed on two of these patients (Table 3). Resuscitative thoracotomies were carried out in eight cases, and a median sternotomy in one patient with clinical suspicion of subclavian artery trauma.

Hemorrhage control was achieved with local compression in 17 cases and with clamping of the pulmonary hilum in seven. In five of these patients, a central or hilar lesion was identified, and the decision to defer resection was made. The vascular clamp was left in place on two occasions and the hilar occlusion was placed in a more selective position according to the damaged structures in three occasions. Other methods used to treat lung trauma were tractotomy in 12 cases, (48.0%), pneumorrhaphy in three (12.0%), and packing as the primary method in eight (24.0%).

DEFERRED MAJOR PULMONARY RESECTIONS (Table 4)

Five patients underwent deferred major pulmonary resections. (Table 4) Central lesions were found in all of them and the decision to postpone the resection was based on whether the condition was too unstable for the patient to tolerate the procedure during the initial intervention.

A pneumonectomy was performed in three patients, in two (cases 10a and 13a) after prolonged occlusion of the pulmonary hilum with a vascular clamp and in one after the ligation of the main right bronchus (case 12a).

Two patients underwent deferred lobar resections. In both cases, the lobar vessels were occluded by ligation with umbilical tape.

While four of these patients survived after complications and reoperations, one died (case 12a). He was a blunt trauma patient with transection of the right main bronchus and a laceration, which extended to the distal trachea. He was managed with suturing of the distal trachea and closing of the right bronchial stump. The patient developed progressive hypoxemia and hypercarbia, which were very difficult to manage, as well as hemodynamic instability, requiring fluids, vasopressors, and progressive oliguria. A right pneumonectomy was performed 50 hours after the first procedure. The patient's condition continued to deteriorate until his death three days later.

PACKING OF PULMONARY LESIONS

Packing was used as a complementary treatment in nine coagulopathic patients. It was used after tractotomy in five cases, as a complement to the occlusion of the pulmonary hilum in three, and after multiple methods in one.

The pulmonary lesion was managed primarily with packing in eight cases (Table 5). In most of them, the lesion was deemed not complicated enough to justify a different method in patients with multiple sources of bleeding, six of them outside of the thorax. In two patients, the lesions were located in the thorax. In one of them, (case 30b), a through-and-through central wound of the right inferior lobe was managed successfully by packing.

REOPERATIONS, COMPLICATIONS, AND MORTALITY

Reoperations were performed on 24 patients. Persistent bleeding occurred in six cases that required re-exploration. Four of them died.

Five of the patients who died were reoperated on only one time. The other patient died in refractory shock without a reoperation.

In the group of survivors, reconstruction and definitive management was undertaken in one or two surgeries in 16 cases.

Organic dysfunction occurred in 22 patients (88.0%). The median Sequential Organ Failure Assessment score was 7; 75% of the patients scored 5 or more. The respiratory and

cardiovascular systems were the most frequently failing systems. Thirteen patients developed persistent coagulopathy. Only one of the five patients who presented alteration of renal function required hemodialysis (Table 6).

Infectious complications occurred in 11 patients (44.0%) with pneumonia and empyema as the most frequent complications. Three of the six infections of the pleural space arose among the patients with major pulmonary resection (Table 6).

Six patients (24%) died. Mortality occurred on the first day in five cases due to refractory shock. Two had persistent bleeding in spite of reoperation and apparent control of the mechanical sources of hemorrhage. In one case, wounds of the superior vena cava, right atrium, left inferior lobe, and liver were found. They were managed with resuscitation thoracotomy, descending aorta cross clamping, suture of the vascular and cardiac lesions, pneumorrhaphy, and perihepatic packing. The patient's condition improved temporarily while a chest tube was inserted. The thoracic incision was temporary closed as described and the abdomen with a vacuum pack system. Due to blood bank shortages, only two units of packed red blood cells were transfused. The patient deteriorated in spite of apparent hemorrhage control and died few hours later.

One patient, (case 12A), who was managed with a deferred pneumonectomy after ligation of the main right bronchus, died five days after the trauma due to multi-organ failure.

DISCUSSION

The current series represents a highly selected set of patients with lung trauma treated with DCT, indicated by the severity of the anatomic lesion, complexity of the associated trauma, and severity of the physiologic deterioration. Only 31 (4%) of the 804 patients treated with trauma thoracotomy in the participating hospitals required DCT.

The decision to perform DC was made as early as possible and was based on a combination of evidence of physiological exhaustion, magnitude of lesions, number of bleeding sources, and local resources available for treatment. About two thirds of the patients had more than one bleeding source in the thorax, and a similar proportion had extrathoracic hemorrhages.

Of the DC procedures used for the management of pulmonary lesions, tractotomy complemented with placing packs over the repair were effective in controlling non-mechanical bleeding in the coagulopathic patients. This was the most frequently employed method of hemorrhage control. Tractotomy was successful in most of the cases, as has been reported by other authors (8-10, 16, 28-31).

Packing was used liberally in this series as a complement to hemostatic efforts in hemorrhage from the thoracic wall, from the lung, and after the repair of vascular structures. Contrary to the opinion of some authors (20, 21, 23), we have found that it is indeed possible to arrest low pressure bleeding coming from repairs in coagulopathic subjects with two or three abdominal pads placed over the oozing surfaces and held gently by hand. Packing was particularly useful in patients bleeding from multiple sources with destructive thoracic wounds. It was initially attempted as a temporary measure, but was later left in

place as a definitive treatment due to its effectiveness and unstable conditions in eight cases with severe pulmonary parenchymal injuries and in six cases of thoracic wall lesions.

The use of packing as a primary form of treatment in some cases of pulmonary trauma deserves special mention. This group of patients differed from the rest, as their main lesions were located in places other than the lung, and for most of them, other than the thorax. In every case, the surgeon used a limited number of pads to stop the bleeding and confirmed the effectiveness of the method. One patient with wounds to the right ventricle and the three lobes of the right lung was managed with tractotomy of the superior lobe, occlusion for deferred resection of the middle lobe, and packing of a central through-and-through wound of the inferior lobe. To our knowledge, these are the first reported cases of lung trauma treated with packing as a primary method.

The chosen method for the thoracic closure was a temporary skin running suture with packing of the incision with three to four abdominal pads in order to expedite the procedure and control the bleeding associated with coagulopathy. Recently, a nonrandomized comparison of methods was published, showing better airway pressures in the group managed with temporary closures compared with those definitively closed. Mortality and infectious complications did not differ (24).

A fifth of the reported patients were managed with deferred pulmonary major resections. Several studies have reported improved survival following pulmonary resection, which has been attributed to the introduction of the stapled pneumonectomy and better intensive care unit/ventilator support (16, 18, 30-32). However, we preferred to avoid these major surgical procedures in these critically wounded patients by temporizing the resection by clamping the hilum in two cases and ligating the traumatized structures in three. This allows for reanimation and reoperation when the patient's condition improves (17, 33). While the vascular occlusion was well tolerated, the bronchial ligation was not.

The present study has several limitations, including the small number of cases, its retrospective nature, and the unique conditions of trauma care in our city: a high level of interpersonal violence, young patient age, and pre-hospital and hospital care limitations. Despite the aforementioned conditions, our data supports the use of packing as a complement to other DC measures in the treatment of complex thoracic trauma as a primary treatment in selected situations, and the postponement of a major pulmonary resection by occluding the pulmonary hilum or the bleeding vessels with a vascular clamp or by other means. These observations should be confirmed prospectively in future multicentric studies.

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TABLE 1

Characteristics of Patients with Lung Trauma and DCT*

	Total of Patients (N = 25)	
Demographics		
Age in years (n, %)		
Median [IQR]	28 [20-34]	
<30	15	(60.0%)
>30	10	(40.0%)
Gender (n, %)		
Male	21	(84.0%)
Female	4	(16.0%)
Trauma Mechanism		
Fire arms	19	(76.0%)
Stab wound	4	(16.0%)
Blunt	2	(8.0%)
Trauma Severity		
RTS		
Median [IQR]	7.1 [5.4 – 7.55]	
ISS		
Median [IQR]	26 [25 – 41]	
PS**		
Median [IQR]	0.84 [0.63 – 0.98]	
Mortality (N,%)	6	(24.0%)

* Damage Control thoracotomy

** Probability of survival

TABLE 2

Characteristics of the Trauma in Patients with Lung Trauma and DCT*

	Total of Patients (N = 25)	
Thoracic trauma		
Lung AIS Mean [SD]	2.7 [+/− 1.13]	
Heart, (N, %)	3	(12.0%)
Vascular, (N, %)	9	(36.0%)
Thoracic wall, (N, %)	17	(68.0%)
Esophagus, (N, %)	1	(4.0%)
Trachea/bronchus, (N, %)	1	(4.0%)
Main Thoracic Lesion		
Lung, (N, %)	15	(60.0%)
Major Vascular, (N, %)	4	(16.0%)
Heart, (N, %)	2	(8.0%)
Combined, (N, %)	4	(16.0%)
Number of Thoracic Bleeders		
One, (N, %)	10	(40.0%)
Two, (N, %)	12	(48.0%)
Three or Four, (N, %)	3	(12.0%)
Extrathoracic Trauma		
Head/Neck, (N, %)	7	(28.0%)
Face, (N, %)	1	(4.0%)
Abdomen, (N, %)	13	(52%)
Extremities, (N, %)	7	(28.0%)
External, (N, %)	9	(36.0%)
Extrathoracic Sources of Bleeding		
Neck, (N, %)	5	(20.0%)
Abdomen, (N, %)	12	(48.0%)
Extremities, (N, %)	5	(20.0%)
Physiological Impact		
Worst Base Deficit in the First Day, Median [IQR]	10.0 [8.9 – 19.0]	
Worst Temperature in the First Day, Median [IQR]	34.9 [34.2 – 35.0]	

TABLE 3

Treatment of Patients with Lung Trauma and DCT*

	Total of Patients (N = 25)	
Thoracic Incision		
Left Anterolateral, (N, %)	7	(28.0%)
Right Anterolateral, (N, %)	13	(52.0%)
Bilateral Anterolateral , (N, %)	4	(16.0%)
Sternotomy, (N, %)	1	(4.0%)
Lung Management		
Tractotomy, (N, %)	12	(48.0%)
Wedge Resection, (N, %)	1	(4.0%)
Major Resection, (N, %)	5	(20.0%)
Deferred Lobectomy/Bilobectomy, (N)	2	
Deferred Pneumonectomy, (N)	3	
Pneumorrhaphy	3	(12.0%)
Packing as Primary treatment	8	(32.0%)
Packing as a Complement	9	(36.0%)
Other Thoracic Procedures		
Cardiorrhaphy	3	
Subclavian Artery Suture or Grafting	4	
Subclavian Vein Ligation	1	
Superior Vena Cava Suture	1	
Pulmonary Artery Suture	1	
Pulmonary Vessels Prolonged Occlusion	2	
Packing of the Traumatic Wound	6	
Tracheal Suture	2	
Esophageal Suture	1	
Transfusions and Fluids in the First Day, Median, [IQR]		
Crystalloids, (c.c.)	10.000	[8.000- 13.000]
Packed Red Blood Cells (u)	6	[4 – 9]
Fresh Frozen Plasma (u)	6	[3 – 8]
Platelets (u, equivalent)	0	[0 – 10]

TABLE 4

Characteristics of the Patients Managed with Deferred Pulmonary Resection

Case	Age	Sex	Mec	ISS	Lesions	Occlusion Method	Hours Occlusion	Resection	Outcome
10a	37	M	GSW	54	Central LL, Iliac Vein, Spleen.	Vascular Clamp	16 - 48	Left Pneumonectomy	Live
12a	28	M	Ped	33	MRB, DT, laceration. Face, Humerus Fractures	Bronchial Ligation	50	Right Pneumonectomy	Death
12b	20	M	GSW	26	Laceration of the RSL, Bronchus and Vein of the ML	En Mass Bronchial and Venous Ligation of the MRL	90	Middle and Inferior Right Lobectomy	Live
13a	22	M	GSW	25	Central RL	Vascular Clamp	54	Right Pneumonectomy	Live
30b	52	M	GSW	26	Laceration of the RSL, the Vein of the ML, and RIL. RV	Vein Ligation with Umbilical Tape	38	Right Middle Lobectomy	Live

Mec, Trauma mechanism. M, male. GSW, gunshot wound. Ped, pedestrian. LL, Left lung. MRB, main right bronchus. DT, distal trachea. RSL, Right superior lobe. ML, middle lobe. RL, right lung. RIL, right inferior lung. RV, Right ventricle

TABLE 5

Characteristics of the Patients Managed with Primary Packing of the Lung

Case	Age	Sex	Mec	ISS	Lung AIS	Thoracic Lesions	Extra Thoracic Lesions	Reop	Outcome
3a	34	M	SW	50	2	RV, ILL, BTW	Neck Soft Tissues Liver, Colon	1	Death
5a	48	F	GSW	41	2	LIL, BTW	Liver, Iliac Vein, Colon	1	Death
7a	20	M	GSW	25	2	RIL, BTW	--	1	Live
8a	29	M	GSW	45	2	RIL	Liver, IVC, SB	2	Live
9a	33	F	Blunt	29	3	LSL, LIL, TW	Liver, Femur Fracture	3	Live
15a	28	M	GSW	34	3	RML, RIL, BTW	RML, RIL, BTW	1	Live
19b	17	M	GSW	14	2	RIL, BTW	Diaphragm, Right Liver Lobe	2	Live
30b	25	M	GSW	26	4	Laceration of the RSL, the Vein of the ML and RIL. RV	Soft Tissues Right Arm	1	Live

Mec, Trauma mechanism. AIS, abbreviated Injury score. M, male. F, female. SW, stab wound. GSW, gunshot wound. Blunt, blunt trauma. RV, right ventricle. ILL, inferior left lobe. BTW bleeding thoracic wall. RIL, right inferior lobe. IVC, inferior vena cava, SB, small bowel. RSL, Right superior lobe. ML, middle lobe.

TABLE 6

Complications in Patients with Lung Trauma and DCT*

	Total of Patients (N = 25)	
Infections		
Pneumonia, (N, %)	5	(20.0%)
Empyema, (N, %)	4	(16.0%)
Infection of the Traumatic Wound, (N, %)	1	(4.0%)
Extrathoracic infections, (N, %)	5	(20.0%)
Organ Dysfunction		
Respiratory dysfunction, (N, %)	21	(84.0%)
Cardiovascular dysfunction, (N, %)	19	(76.0%)
Coagulopathy, (N, %)	13	(52.0%)
Renal dysfunction or insufficiency, (N, %)	5	(20.0%)
SOFA, Median [IQR]	7	[5 – 8]
Thoracic Hypertension	1	(4.0%)
Reoperation due to bleeding	6	(24.0%)