

## Pitfalls in penetrating thoracic trauma (lessons we learned the hard way...)

Penetran toraks travmalarındaki tehlikeler (zor yoldan öğrendiğimiz dersler...)

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The majority of patients with penetrating thoracic trauma are managed non-operatively. Those requiring surgery usually go to theater with physiological instability. The critical condition of these patients coupled with the rarity of penetrating thoracic trauma in most European countries makes their surgical management challenging for the occasional trauma surgeon, who is usually trained as a general surgeon. Most general surgeons have a general knowledge of basic cardiothoracic operative surgery, knowledge originating from their training years and possibly enhanced by reading operative surgery textbooks. Unfortunately, the details included in most of these books are not extensive enough to provide him with enough armamentaria to tackle the difficult case. In this anatomical region, their operative dexterity and knowledge cannot be compared to that of their cardiothoracic colleagues, something that is taken for granted in their cardiothoracic trauma textbooks. Techniques that are considered basic and easy by the cardiothoracic surgeons can be unfamiliar and difficult to general surgeons. Knowing the danger points and the pitfalls that will be encountered in cardiothoracic trauma surgery will help them to avoid intraoperative errors and improve patient outcome. The purpose of this manuscript is to highlight the commonly encountered pitfalls by trauma surgeons operating on penetrating trauma to the chest.

**Key Words:** Penetrating; pitfall; thoracic; trauma.

Penetran toraks travmalı hastaların çoğunluğu ameliyatsız tedavi edilmektedir. Cerrahi gerektiren hastaların klinik tablosu, genellikle fizyolojik instabiliteyle birlikte seyretmektedir. Bu hastaların durumunun kritik oluşu ve birçok Avrupa ülkesinde toraks travmasının seyrek görülmesi, uzmanlık eğitimlerini genellikle genel cerrahi alanında almış travma cerrahlarına güçlü çıkarmaktadır. Çoğu genel cerrah, temel kardiyotorasik operatif cerrahi konusunda genel bir bilgi ve kendi eğitim yıllarından kaynaklanan ve muhtemelen cerrahi kitaplarını okumak suretiyle artan bir bilgiye sahiptir. Bu kitapların çoğuna dahil edilen ayrıntılar, maalesef bu güç olgunun üstesinden gelmek üzere genel cerraha yeterli donatım sağlamaya yetecek kadar kapsamlı değildir. Bu uzmanların bu anatomik bölgede, kardiyotorasik travma kitaplarından edinilmiş beceri ve bilgileri kardiyotorasik cerrah arkadaşlarının operatif becerisi ve bilgisi ile karşılaştırılmaz. Kardiyotorasik cerrahlar tarafından temel ve kolay olarak kabul edilen teknikler, genel cerrahlar için yabancı ve zor olabilir. Kardiyotorasik travma cerrahisinde karşılaşılabilecek tehlikeli noktaları ve güçlükleri biliyor olmak, bu uzmanların operasyon sırasındaki hatalardan sakınmalarına ve kendi hasta sonuçlarını geliştirmelerine olanak sağlayacaktır. Bu yazıda, göğüs bölgesine nazif penetran travmaları ameliyat eden cerrahların yaygın şekilde karşılaştıkları tehlikeler vurgulandı.

**Anahtar Sözcükler:** Penetran; tehlike; torasik; travma.

Historically, penetrating trauma was uncommon in most parts of the world. The experience reported has mainly originated from the United States and South Africa. Recently, there has been an increase

in penetrating trauma in parts of the world previously considered 'immune' to this scourge. Europe serves as an example, with its increased illegal immigration characterized by poverty and com-

pounded by organized crime, the redefining of national borders causing local conflicts, and the participation of the European military in United Nations missions to war-torn regions outside of Europe. This results in the presentation of significant numbers of patients with penetrating trauma who have to be managed by doctors whose experience with such patterns of injury is inadequate. There are several excellent books dealing with operative techniques in penetrating trauma that can be used by the 'uninitiated' to prepare oneself, and that can even be kept available in theater for easy reference. However, intra-operative pitfalls are not covered in detail in such books, and it is these pitfalls that can make the difference between a successful and unsuccessful operation. It is the aim of the present manuscript to discuss these intra-operative pitfalls in managing penetrating trauma, in an attempt to assist the occasional thoracic trauma surgeon in avoiding substandard operative outcome.

Judgement of when to perform a thoracotomy or sternotomy comes with experience and knowledge of the indications for the procedure, as well as accurately assessing the clinical scenario with which you are faced. Following intercostal drain insertion, a chest X-ray is a mandatory step in correctly evaluating your patient and it cannot be neglected. It may well alert you to the presence of a retained hemothorax, a clinical scenario likely to result in a false sense of security when less than 1500 ml has drained from the chest (1500 ml being the cut-off at which a thoracotomy should be performed). Veiling of the corresponding lung field should alert us to this possibility and you should then have a low threshold for an emergency thoracotomy.

There are several incisions that can be applied in patients with penetrating thoracic trauma, depending on the urgency of intra-thoracic access and the site of the injury. Median sternotomy is the ideal incision for repair of injury to the heart and arch of the aorta and proximal branches, and must be performed properly so that complications are avoided. Perhaps the most common pitfall of this incision is to miss the midline on splitting the sternum. It is important, when the skin incision is first made, to use the diathermy and extend the incision deep to the anterior aspect of the sternum, from sternal notch to xiphoid, marking the midline of the sternum with the diathermy. The necessary division of

the intra-clavicular ligament in creating the retrosternal space at the sternal notch, whether made with a diathermy or with a right-angled Lahey, sometimes leads to alarming bleeding from the area that is difficult to control due to its limited access. In this case, if rapid opening of the sternum is not of paramount importance, insertion of a swab, application of pressure and waiting will stop the bleeding. Remember that you are too superficial to have injured a large vessel, with the innominate vein being too deep to be injured with this maneuver! If you cannot waste time for the bleeding to stop, plug the region and complete the medial sternotomy by starting from the xiphisternum, upwards. If this option is chosen, be extremely careful, as the caudal part of the sternum is thinner, and hence allows you to easily miss the midline and enter the intercostal cartilages. Irrespective of which direction the sternum is opened, missing the midline should always be avoided. The sternum is opened along the diathermy line using a pneumatic saw or Lebsche knife and hammer, always following the diathermy line religiously, making sure that you apply only the necessary force to split the sternum. Applying more force than necessary may result in sudden giving way of the resistance of the sternum, resulting in loss of the midline plane and incision through the intercostal cartilages. If a Lebsche knife and hammer are to be used (on opening the sternum from manubrium to xiphoid direction - the recommended route), a sand-bag must be placed between the shoulder blades of the patient and the neck extended. The hammer should hit the Lebsche knife at an angle of 30° with the horizontal plane so as to avoid hitting the patient's jaw (we have seen it happen)! After splitting of the manubrium, there is enough distance from the jaw so that the sternum is split by hitting the hammer on the knife horizontally. Of course, this problem does not arise if the pneumatic saw is used, but it is always advisable to have a Lebsche knife available as it is quite common to be let down by a pneumatic saw when you need urgent access to the mediastinum. The sternal retractor should be placed into the sternotomy as close to the manubrium as possible, minimizing the risk of fracturing the sternum on rapidly opening the retractor. As with opening a median sternotomy, there are many pitfalls in closing the median sternotomy. Getting the needle and wire through the sternum may be easy for the cardiotho-

racic surgeons, but may be quite taxing for the occasional thoracic trauma surgeon. Insertion of the needle is facilitated by applying the needle holder, not in the recommended junction of the middle and distal third of the needle, but rather at the junction of the proximal and middle third of the needle, and advancing in a vertical direction rather than in the usual rotational movement. As pressure is applied with the needle on the sternum, it is not uncommon for the sternum to give way and the needle to penetrate suddenly, damaging underlying structures. The use of a spoon with the concavity facing upwards, applied under the sternum at the point of penetration, will safeguard against inadvertent injury of mediastinal structures. Bleeding from the edges of the divided sternum is controlled with the application of bone wax or electrocautery. Ensure to apply only enough wax as is necessary, as excess application carries an increased risk of an infection to the sternum. Good approximation of the edges of the divided sternum is also of paramount importance to avoid sternal infection. This is sometimes difficult to achieve, particularly when inserting the wires through areas of the sternum that are technically difficult or when the two halves of the sternum do not approximate easily on tying the wires. If this is the case, after an initial wire has been placed through the manubrium, wires to the body can be applied, not through the sternum but around it. If difficulty is still encountered in approximating the two halves of the sternum, an assistant, probably the anesthetist (if you have good relations with him!), places both hands on the scapula facing upwards. By flexing his fingers, the scapula is lifted forward, transmitting force upwards and medially, approximating the two sternal edges and giving you the opportunity to twist the wires under less tension. Remember to make sure that you have not damaged the internal mammary arteries as the needle goes around the body of the sternum.<sup>[1]</sup>

Although the indications for an emergency department (ED) thoracotomy are related to a patient in extremis, and there may be significant urgency as well as stress weighing on the staff of the ED, it is of paramount importance to ensure adequate precautions are taken by all to minimize the ever present risk of transmission of blood-borne infections and injuries from sharp objects. Neglecting the use of protective gear, particularly of the eyes, when the patient has 'bled out' and 'has

no blood pressure' is foolish! It is common on opening the chest for rapid decompression to be sprayed with blood from traumatized lung tissue (due to the insult itself or iatrogenic in origin), particularly if the patient is ventilated. In performing the thoracotomy incision that is antero-lateral and at the level of the 5th intercostal space, one should bear the female anatomy in mind. An incision through breast tissue is not only aesthetically unacceptable, but also makes access to the pleural cavity more cumbersome. Ask your assistant to pull the breast upwards to ensure your incision is sub-mammary.

Insertion of the rib retractor should not limit your access through your incision. The joint of the retractor should be on the sternal side of the incision, parallel to the sternum and away from the region you are trying to expose, not limiting your ability to extend the incision laterally if you decide to do so. Abrupt opening of the retractor, as is always the case in an ED thoracotomy, will always cause rib fractures, therefore, this cannot be considered a pitfall. Instead, the pitfall lies in not covering the edge of your incision with large abdominal swabs and not warning your assistant of the possible existence of rib spikes. The ED thoracotomy incision is usually on the left but can also be initiated on the right if it is obvious that this is the side from which the exsanguinating hemorrhage is arising. In any case, this can be extended to either side by dividing the sternum transversely, the so-called clam-shell incision. Although transverse division of the sternum is recommended with the use of Gigly-saw or bone-cutter, we find it easier with the use of a pneumatic saw, or in its absence, a Lebsche knife and hammer. There are two pitfalls with this method of dividing the sternum: firstly, accidental injury to the heart as the intact pericardium holds its contents in close proximity with the posterior aspect of the sternum. Injury to the heart can be easily avoided by applying upward traction of the pneumatic saw or Lebsche knife, coupled with a forward and upward rotation of the distal saw/blade tip. The second pitfall is to forget that with this incision, the internal mammary arteries will always be severed. In the patient in extremis, it is common for them not to bleed. Bleeding, however, may commence once the patient has been well resuscitated, and in an unfortunate scenario, when the patient has left the operating theater. It is important to find and

ligate the four edges of the severed internal mammary arteries in the loose tissue lateral to the sternum, even if they appear not to be actively bleeding.

On opening the thoracic cavity, the pericardium should be inspected to exclude tamponade, unless there is an obvious source of active bleeding, in which case direct pressure or a Satinsky clamp should be applied onto the bleeding site. Hemopericardium may be recognized by the presence of a bulging tense pericardium, or sometimes only by the white-bluish color from the underlying clot. A classic pitfall lies in leaving the pericardium unopened due to its normal appearance from the outside. The pericardium, in the absence of other sources of bleeding, should be opened even if it looks normal. It is surprising how often there is a significant amount of blood inside the pericardial sac, from injury to the heart or intrapericardial mediastinal vessel, which is not visible through the intact pericardium. The pericardium should be fully opened in a vertical direction, avoiding injury of the phrenic nerve, which should run parallel and to the left of your pericardial incision. If further access is required, a transverse pericardial incision should be added at the caudal end of the vertical incision (an inverted T). If the heart is found to be in asystole or ventricular fibrillation, internal cardiac massage must be commenced. The incision should be extensive enough for you to be able to insert not one, but both your hands. A common error of intrapericardial massage is to use the palm of one hand to compress the heart against the spine and ribs. This traumatizes the heart and will be apparent from the extensive bruising on the heart seen thereafter. The correct technique is to put one palm posterior to the heart, palm facing upwards, fingertips toward the base of the heart, and the other hand, palm facing downwards, on the anterior aspect of the heart. The heart can then be compressed between the two palms by maintaining good, firm contact between the heart and palms at all times, which minimizes the chance of potential injury from the application of cardiac massage. For a non-perfusing ventricular arrhythmia, start with a shock of 20 joules with one internal paddle behind the heart and the other in front. Defibrillation should be repeated if required but a maximum of 40 joules should be used. Defibrillation of complete cardiac standstill is an error and will further damage the myocardium.

When a penetrating injury to the anterior aspect of the heart is met on opening the pericardium, repair is not complete without checking for a posterior wall injury. The patient may leave the theater only to reaccumulate a new hemopericardium. Alert the anesthetist of your intention to lift the heart out of the pericardial sac in order to inspect the posterior wall, and then do this by putting the tips of your fingers at the base of the heart, as superiorly as possible, so that the heart does not 'kink' as it is lifted. The heart tolerates this maneuver poorly and you should repair quickly as bradycardia develops rapidly with transition to asystole. As soon as the bradycardia develops, drop the heart back into the pericardial sac, even if the bleeding has not been controlled. Continue repair of the defect only when the rhythm returns to normal. During this piece-meal repair of the posterior wound, the heart is very irritable and may develop a non-responsive bradycardia even though it has been replaced to its bed. A trick of the trade in this situation is to pour hot saline onto the heart, which results in the heart starting to gallop again, 'like a horse'. Keep in mind that the auricle and atria have a more delicate wall than the ventricles. Control the defect with a Satinsky clamp; here a steady assistant is of great value. Traction must be avoided as it may avulse a piece of the wall, making the defect even larger. Equally, allowing the Satinsky to fall uncontrolled may have a similar consequence. On closing the pericardium, remember to leave open the distal 2 cm. Hopefully, if there is secondary bleeding, this gap will prevent the formation of hemopericardium and consequent cardiac tamponade. Increased drainage of blood from the drain (placed in front of the pericardial gap) will also alert you to ongoing bleeding.<sup>[1-5]</sup>

Controlling bleeding from the anterior aspect of the ascending aorta is achieved by digital pressure or side-biting clamp. This can be facilitated by intermittent aortic occlusion (partial or complete) and concomitant caval occlusion. These maneuvers are useful both during exposure and subsequent suturing (by reducing blood pressure). In desperate situations, complete aortic occlusion can be practiced, but we should remember that it results in a profound increase in afterload and peripheral resistance. Never forget to discuss your move with the anesthetist prior to the maneuver as he is the one who will manage the hemodynamic changes.

Remember that even if the patient is rendered 'stable' by the anesthetic team, aortic cross-clamp time should be kept to a minimum, not more than 20-30 minutes. The repair of the aorta by whatever method is necessary (continuous horizontal mattress and over and over suture or synthetic patch) is technically easier if the intraluminal pressure is kept low while the sutures are tied. Do not hesitate to ask the anesthetist (even if he is not your friend!) to reduce the systemic pressure, and if he is unable to do so, you may apply a side clamp around the involved aorta. Again, a pitfall encountered is to miss the corresponding posterior wall injury. Do not dissect bluntly to expose the posterior aspect of the ascending aorta. This will lead only to frustration, and damage of the posterior aortic wall. Dissection in this area should be done only sharply. Although primary repair of anterior lacerations is usually accomplished without adjuncts, cardiopulmonary bypass may be needed in posterior wall injuries. Always consider the possibility of peripheral bullet embolus in all patients with gunshot wounds to the aorta and major veins, irrespective of the anatomical site!

The door to access the aortic arch is the thymus and left innominate vein. This vein should be divided and transfixed without second thought, as its presence is not missed and its division makes the operative dissection of the aortic arch easier. Simply tying this vessel is a mistake, you should suture ligate it. Aortic injuries sometimes present with a hematoma of the anterior mediastinum. In this instance, 'only fools rush in!' Remember that anterior mediastinal hematomas never extend into the pericardial sac. The pericardium is adherent to large vessels, originating from the heart, as they exit the pericardial sac, acting as an anatomical barrier. Therefore, it is safer to start the dissection of the anterior aspect of the aorta from its intrapericardial portion, proceeding distally. The pericardium is opened and umbilical tapes applied to both the ascending aorta and cava in preparation of possible temporary partial occlusion of the aorta or cardiac inflow, respectively. Also, always establish distal control of the branches of the arch; this may require extension of the median sternotomy to the neck, in order to expose the carotid sheath. Only now should dissection proceed from the intrapericardial anterior aspect of the ascending aorta, and the hematoma is entered at its base, following the anterior surface

of the aortic arch. Digital compression, rather than blind application of clamps, should control the bleeding until the injury has been dissected and a vascular clamp can be applied. Dissection of the posterior and concave surface of the arch should also start from the pericardium, as the fibrous layer of the pericardium becomes one with the aortic wall and becomes part of the adventitia. Dissection starting outside the pericardium can lead to an apparent plain of cleavage, which may actually be within the aortic wall. This, as you can imagine, may have disastrous consequences.

The surgeon who is treating injuries to branches of the aortic arch must be aware of the vascular anomalies of the region. Their presence may complicate diagnosis, control and repair. In 5% of the Caucasian population and up to 30% of the African-American population, the innominate and left carotid arteries have a common origin from the aortic arch. Intraoperatively, the surgeon must not assume that the next vessel proximal to the origin of the left subclavian artery is the left common carotid artery. If it is the innominate artery, and the common origin of these two vessels is clamped, the entire cerebral circulation will be compromised.<sup>[6,7]</sup>

Avoid operating on the subclavian artery if you can manage the injury by endovascular stenting. This should be only practiced in a physiologically stable patient. In the unstable patient, a sternotomy and supraclavicular incision should be done, as this is the best incision for proximal and distal control of the injury site. It has been suggested that for proximal control of injuries of the left subclavian artery, the third intercostal space thoracotomy will provide the opportunity to control the bleeding until access to the area has been attained through a different incision. Although theoretically possible, practically, it never works. The space between the ribs at this level is too narrow and expansion is very difficult, visibility is poor and there is great difficulty in performing the appropriate maneuvers to apply a vascular clamp to the site of injury. Never use a trap door incision for the subclavian artery; it too does not offer sufficient exposure. Working through this access is strenuous and postoperative recovery is prolonged. In desperate situations, remember that it is better to ligate the subclavian artery as a damage control option than to struggle, wasting valuable time with an end to end graft or

complex anastomosis at another site of the aortic arch.<sup>[8,9]</sup>

It is amazing how many doctors we have seen, who possess good knowledge of the anatomy, who, in the heat of the moment of an ED thoracotomy, forget that the descending aorta is posterior to the lung, and spend valuable time looking for it anterior to the left lung! Lift the left lung outside the pleural cavity, and directly visualize the great vessel. A pitfall here is to attempt to clamp the aorta without dividing the pleura. For this maneuver to be successful, both sides of the aorta must be cleared from the pleura at the position where you intend to place the clamp. If this is not done, the clamp is bound to slip. Full mobilization of the lung is often required during a thoracotomy and for this the inferior pulmonary ligament has to be divided. The books suggest sharp dissection with scissors, but this is difficult in the emergency procedure; we suggest bluntly ripping off the ligament from the diaphragm with the palm of the hand. Remember that the pulmonary vein is attached medially to the inferior pulmonary ligament and can be easily damaged at this stage of the procedure, resulting in unnecessary, torrential bleeding. The inflated lung can also be easily damaged during surgical maneuvers by forceful handling. For example, rotating the lung as is suggested for torrential bleeding (including bleeding from the hilum) may result in several fingers penetrating the lung parenchyma. We avoid this by handling the lung using abdominal swabs between the palm and lung. In order to keep the lung rotated, it may be necessary to pack 2 or 3 dry swabs into the apex of the pleural cavity so as to stop the lung from popping back into the thoracic cavity. Rotating the lung for control of bleeding is an impressive maneuver that may be utilized in desperate situations. The preferred maneuver is clamping of the hilum with a large Satinsky clamp.

The tendency of the inexperienced trauma surgeon is to stitch holes of the lung that are significantly bleeding, in the hope that this will stop by tamponade. There is a good chance that the bleeding will not stop, an intraparenchymal hematoma will form, and the sutures will probably give way due to the increased pressure, all this leading to exsanguination of the patient. Tractotomy and suture ligation of the bleeding source is the correct practice. It is suggested in books that this be done

with staplers. Avoid the use of staplers with a fully inflated lung. Ask the anesthetist to stop ventilating, apply pressure to partially deflate the lung, and then staple. Beware that when the lung re-inflates, the staplers may give way and there will be bleeding or air leak. Have a monofilament suture available to overrun the bleeder with continuous locking suture. If no staplers are available, use soft bowel clamps and a continuous locking stitch.<sup>[10]</sup>

In penetrating injuries to the esophagus, time is of utmost importance. If suspected, gain access through a right posterolateral thoracotomy, irrespective of the level of the injury. The method of suture-repair is not of importance (we do it in one layer). The most important aspect is to include 4 mm of mucosa of the esophagus (the layer that looks white). Keep in mind that the connective tissue of the wall of the esophagus is in the mucosa, which renders it the strongest of the layers. Inverting the esophageal wall during the repair makes little difference as long as the edges used are healthy. All stapled anastomoses/repairs of the gastrointestinal tract have everting edges, and do not have higher complication rate than with standard suture anastomosis. If doing a second layer, remember that the muscle fibers of the esophagus tear easily and avoid this if you find it adds tension to the repair. Mediastinitis is the most feared complication of this injury. If it is suspected, open the pleura over the length of the esophagus via a right thoracotomy. A thick yellow exudate infiltrating the loose tissues around the esophagus is usually a sign of a collection at the posterior aspect of the esophagus. Mobilize the esophagus circumferentially at that point to find the injury and drain the collection. Good drainage of the area with large intercostal drains should be applied as this may save the day.<sup>[11]</sup>

When there is trauma to the intrathoracic trachea and bronchi, diagnosed preoperatively, remember that the intrathoracic trachea travels slightly to the right of the midline. As a result, access to the right bronchus, carina and proximal 2 cm of the left bronchus should be achieved using a right posterolateral thoracotomy, while access to the left bronchus necessitates a left posterolateral thoracotomy. Repair the injuries of the airway using absorbable sutures; otherwise the patient may develop a stitch granuloma within the airway, resulting in poor pulmonary drainage as the expected complication.

The present manuscript on pitfalls of penetrating trauma to the chest by no means covers the full extent of the subject. There is no doubt that other surgical colleagues could add other pitfalls and means of avoiding them. Hopefully, this will be the catalyst for a stimulating discussion and further manuscripts regarding pitfalls in all types of trauma. This will help the less experienced of us in trauma to improve our surgical technique, resulting in better patient outcome.

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