Journal of Visceral Surgery (2017) 154, S35—S41

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ORIGINAL ARTICLE

Resuscitation thoracotomy

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Available online 21 September 2017

KEYWORDS
Trauma;
Damage control;
Resuscitation thoracotomy

Summary Resuscitation thoracotomy is a rarely performed procedure whose use, in France, remains marginal. It has five specific goals that correspond point-by-point to the causes of traumatic cardiac arrest: decompression of pericardial tamponade, control of cardiac hemorrhage, performance of internal cardiac massage, cross-clamping of the descending thoracic aorta, and control of lung injuries and other intra-thoracic hemorrhage. This approach is part of an overall Damage Control strategy, with a targeted operating time of less than 60 minutes. It is indicated for patients with cardiac arrest after penetrating thoracic trauma if the duration of cardiopulmonary ressuscitation (CPR) is <15 minutes, or <10 minutes in case of closed trauma, and for patients with refractory shock with systolic blood pressure <65 mm Hg. The overall survival rate is 12% with a 12% incidence of neurological sequelae. Survival in case of penetrating trauma is 10%, but as high as 20% in case of stab wounds, and only 6% in case of closed trauma. As long as the above-mentioned indications are observed, resuscitation thoracotomy is fully justified in the event of an afflux of injured victims of terrorist attacks.

Introduction

Resuscitation thoracotomy (RT) is a rarely performed procedure whose use, in France, remains marginal. However, an abundant literature shows that, in the event of cardiac arrest following a penetrating trauma, the survival rate is close to 10% and up to 30% in the case of a cardiac wound [1,2].

Terminology

The literature is sometimes confusing because of the use of multiple terminologies, such as: emergent thoracotomy, urgent thoracotomy, emergency room thoracotomy, emergency department thoracotomy, resuscitation thoracotomy, resuscitative thoracotomy.

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https://doi.org/10.1016/j.jviscsurg.2017.07.003
1878-7886/

To our mind, resuscitative thoracotomy seems to be the most relevant term to describe a thoracotomy performed in a patient in cardiac arrest or in-extremis, unresponsive to reanimation measures, and whose evolution would be a fortiori fatal.

Rationale

If severe head trauma is excluded, the causes of traumatic cardiac arrest are:
- hypoxia, due to airway obstruction or failure of ventilatory mechanics;
- pericardial tamponnade (hemorrhagic or gaseous);
- primary cardiac pump failure associated due to myocardial contusion or air embolism;
- subdiaphragmatic hemorrhage;
- intra-thoracic hemorrhage, due to a wound of the heart, great vessels or pulmonary vessels;

After obtaining airway control and decompressing tension pneumothorax, there are five main objectives of RT that respond point by point to the causes of traumatic cardiac arrest:
- decompression of pericardial tamponnade;
- control of cardiac hemorrhage;
- performance of internal cardiac massage;
- cross-clamping the descending thoracic aorta;
- control of pulmonary injuries and other intra-thoracic hemorrhages.

This approach has to fits into a Damage Control strategy, with a target time of less than 60 minutes.

Technique

Equipment

Classically, the necessary equipment is described as rudimentary. We decline it in ten items:
- scalpel blade;
- heavy-duty scissors also called paramedic shears;
- Finochetto-type self-retaining chest retractor;
- medium length instrument set: Mayo or Metzenbaum scissors, two needle holders and two Debakey forceps, long straight aortic clamp and two large Satinsky-type counter-angled clamps;
- effective suction, ideally connected to a cell-saver® blood recovery device;
- Foley catheter, 18 or 20 French, with saline-filled syringe for balloon inflation;
- Prolene® 2.0 or 3.0 sutures;
- length 90 cm, swaged onto half-curved 36 mm needles — internal defibrillation paddles;
- laparotomy pads or large compresses;
- skin stapler.

Surgical approach

The operator stands to the patient's left, and after a rapid antiseptic skin preparation and draping, incision is made with a cold knife.

The first stage of RT is the incision, a large anterolateral left submammary thoracotomy starting from the sternal margin and extending into the axillary hollow. This approach provides exposure for opening the pericardium, the performance of manual cardiac massage, and for clamping the descending thoracic aorta. It can be extended, without hesitation, into submammary bilateral thoracotomy, a so-called « clamshell-type » incision, offering wider exposure and, if necessary, access to the right chest and mediastinal structures. The horizontal division of the sternum is made with heavy-duty scissors after having displaced the pericardium posteriorly with finger dissection. Internal mammary vascular pedicles are divided, rarely bleeding in these circumstances. The self-retaining chest retractor is positioned at the sternum and widely opened.

Opening of the pericardium

The pericardium is opened anterior to the left phrenic nerve, from the cardiac apex to the aortic root. When the pericardial membrane is under tension and cannot be grasped, the opening is initiated by a scalpel puncture. Then, the left hand passes beneath the heart, allowing its externalization for control of hemorrhage and performance of massage.

Controlling cardiac bleeding

If a cardiac wound is present, initial hemostasis is usually obtained by simple digital pressure. It can also be obtained by insertion of a Foley catheter whose balloon is inflated within the heart and placed on tension to seal the wound. The distal end is then clamped or connected to an infusion device allowing massive intracardiac volume replacement. Atrial wounds are usually controlled by tangential placement of a Satinsky clamp. Cardiomyoraphy is generally performed with interrupted u-shaped sutures, ideally in subcoronary location and possibly reinforced with Teflon or pericardial pledgets, to avoid tearing the myocardium. Finally, when the wound is linear, particularly at the level of the left ventricle, it may be possible to close this with a skin stapler. The use of topical hemostatic agents is of only marginal interest in our view.

Performance of internal cardiac massage

It is urgent to maintain circulating blood volume for cerebral and coronary perfusion. In the case of the exsanguinated patient, we routinely insert a large bore Foley catheter through a right atrial incision secured by a purse-string suture to allow for massive direct intra-cardiac volume replacement. Cardiac massage is done by picking up the heart mass with both hands flat, wrists joined, and making compressions of the palm towards the fingers, in the axis of the left ventricular outflow tract, in a clapping movement. In addition to allowing internal cardiac massage, direct access to the heart also allows performance of internal defibrillation in case of ventricular fibrillation or sustained ventricular tachycardia. Internal defibrillation is performed by applying internal paddles to the front and back of the heart at a setting of 30 Joules in association with adequate systemic anti-arrhythmic medications. Finally, if this does not result in resumption of cardiac activity, direct intra-ventricular injection of drugs, especially adrenaline, is possible.

Clamping of the descending thoracic aorta

Cross-clamping of the descending thoracic aorta achieves two ends: redistribution of the blood volume to the

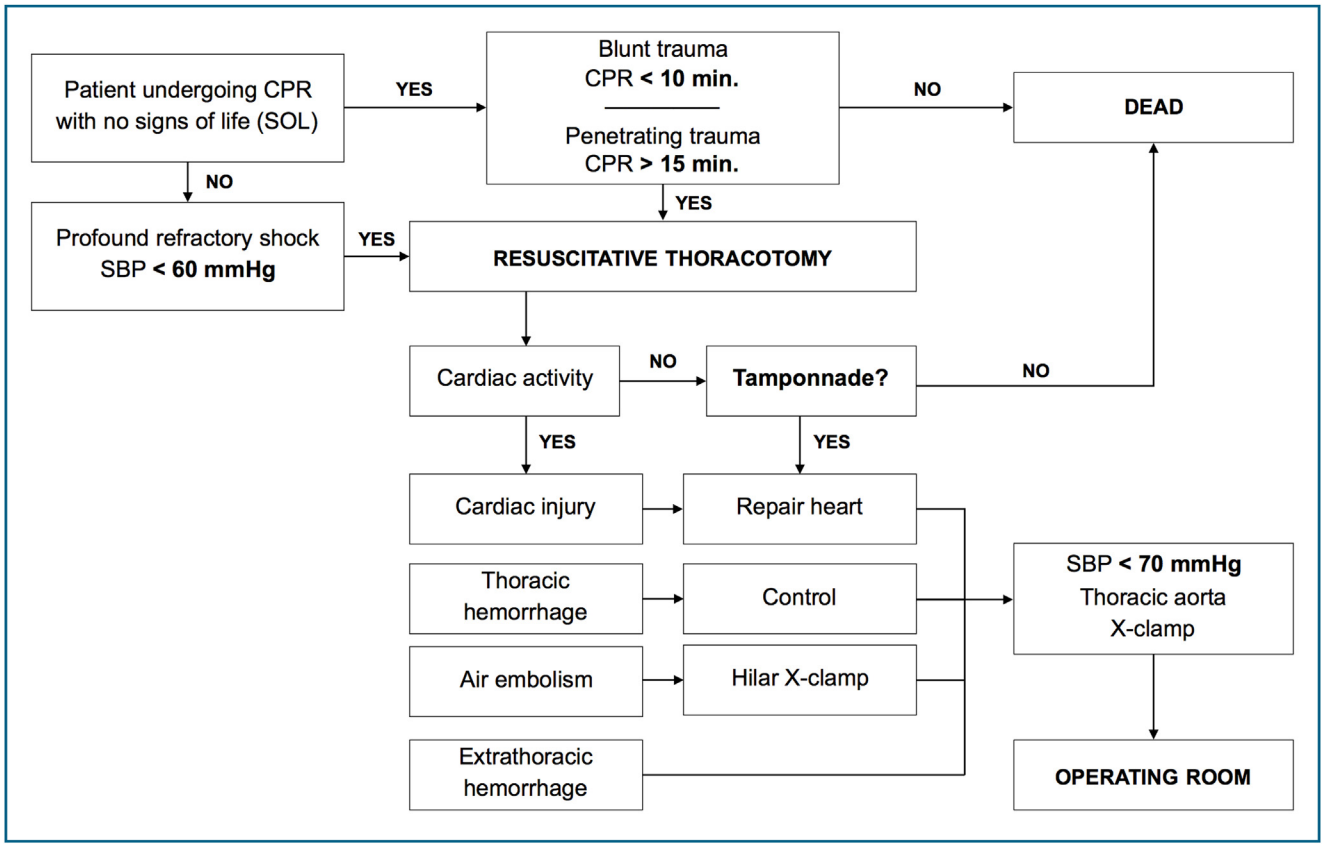

Figure 1. Factors influencing the survival rate of patients requiring resuscitation thoracotomy.

benefit of the coronary and cerebral circulation, and limitation of subdiaphragmatic hemorrhage. Classically, the clamping should not exceed 30 minutes; beyond this limit, there is risk of digestive ischemia and, of course, a risk of spinal cord ischemia with paraplegia. Apart from the indications for any specific lesion, we therefore prefer to clamp the descending thoracic aorta below the left pulmonary hilum. The exposure is done by retracting the left lung forward, exposing the aorta visible alongside the vertebral column. The aorta is initially clamped between two fingers or compressed against the spine. This occlusion is quickly replaced by transverse application of an aortic clamp after having divided the mediastinal pleura with scissors. We advise against trying to dissect around the aorta, which carries the risk of disrupting an intercostal artery. In an exsanguinated patient, the completely flaccid aorta can sometimes be confused with the esophagus. It is worth mentioning the current upsurge in techniques of aortic balloon occlusion also called Resuscitative Emergency Balloon Occlusion of the Aorta (REBOA), whose place remains to be defined but which is likely, in the future, to become an alternative to transthoracic aortic clamping.

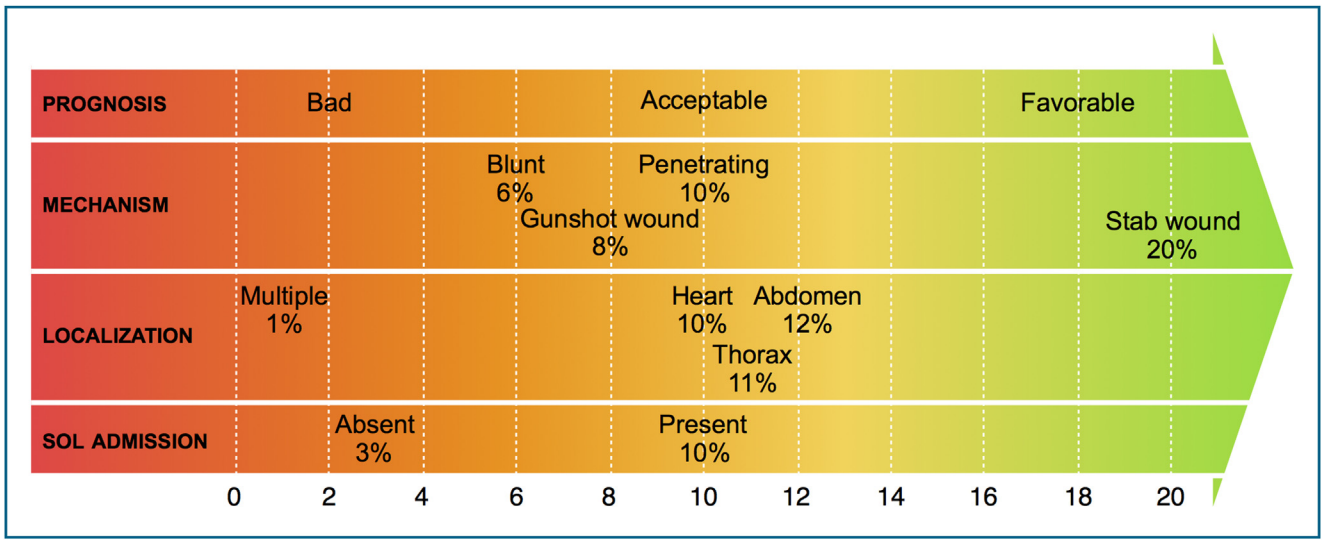

Figure 2. Patient management algorithm for traumatic cardiac arrest (adapted from [5]).

Table 1 Results of the 15 largest series of ressuscitation thoracotomy published in the last ten years[a].

Author, Journal, Year	Survivors	Neuro. sequelae	Blunt	Pentrating	Stab wound	Gunshot Wound	Heart	Thorax	Abdo.	Multiple	SOL admission	No SDV
Keller D et al., Philadelphia, PA, USA, 2013 [7]	37/448 8%	4/16 25%	–	–	–	–	–	–	–	–	–	–
Seamon MJ et al., Philadelphia, PA, USA, 2009 [8]	15/283 5%	2/15 13%	–	15/283 5%	8/33 24%	7/250 3%	–	–	–	2/146 1%	10/176 6%	5/107 5%
Schnuriger B et al., Los Angeles, CA, USA, 2010 [9]	5/263 2%	–	1/76 1%	4/187 2%	–	–	–	–	–	–	–	–
Seamon MJ et al., Philadelphia, PA, USA, 2008 [10]	26/237 10%	0/8	–	8/50 16%	–	–	–	18/177 10%	8/50 16%	–	–	–
Seamon MJ et al., Philadelphia, PA, USA, 2007 [11]	23/180 13%	–	–	23/180 13%	–	–	–	–	–	–	–	–
Passos EM et al., Toronto, Canada, 2012 [12]	3/123 2%	0/3	0/27	3/60 5%	2/27 7%	1/33 3%	–	–	–	–	3/60 5%	0/63
Mollberg NM et al., Chicago, IL, USA, 2011 [13]	7/120 6%	1/7 14%	–	–	–	–	–	–	–	–	–	–
Pahle AS et al., Oslo, Norway, 2010 [14]	20/109 18%	3/20 15%	10/82 12%	10/27 37%	–	–	–	–	–	–	–	–

Table 1 (*Continued*)

Author, Journal, Year	Survivors	Neuro. sequelae	Blunt	Pentrating	Stab wound	Gunshot Wound	Heart	Thorax	Abdo.	Multiple	SOL admission	No SDV
Edens JW et al., Iraq, 2009 [15]	12/101 12%	0/12	0/7	12/94 13%	–	12/94 13%		6/40 15%	2/30 7%	–	–	–
Okoye OT et al. Los Angeles, CA, USA, 2013 [16]	8/97 8%	–	–	8/97 8%	–	8/97 8%	–	8/97 8%	–	–	–	–
Molina, EJ et al., Philadelphia, PA, USA, 2008 [17]	8/94 9%	0/8	–	8/94 9%	4/12 33%	4/82 5%	8/94 9%	–	–	–	5/15 33%	3/79 4%
Capote A et al., Bakersfield, CA, USA, 2013 [18]	13/87 15%	2/13 15%	2/28 7%	11/59 19%	11/59 19%	–	–	–	–	–	–	–
Rabinovici R et al., Boston, MA, USA, 2014 [19]	9/67 13%	2/9 22%	0/17	9/50 18%	8/36 22%	1/14 7%	–	8/50 16%	1/9 11%	–	9/57 16%	0/10
Morrison JJ et al., Afghanistan, 2013 [20]	14/65 22%	–	–	14/65 22%	–	14/65 22%	–	–	–	–	–	–
Lustenberger T et al. Zurich, Switzerland, 2011 [21]	10/49 20%	–	3/39 8%	7/10 70%	3/6 50%	4/4 100%	2/10 20%	–	–	–	9/33 9%	1/16 6
Total[b]	167/1432 12%	12/80 12%	16/276 6%	85/835 10%	32/161 20%	47/557 8%	10/104 10%	40/364 11%	11/89 12%	2/146 1%	31/326 10%	6/196 3%

neuro.: neurological; Abdo.: abdomen; SOL: signs of life.
[a] Data are presented as percentage of survivors/total RT.
[b] The redundancy of series is suppressed in the calculated totals.

Controlling pulmonary injuries and other intra-thoracic hemorrhages

If there is hemorrhagic peripheral lung injury, a simple limited wedge excision with a linear-cutting stapler is possible.

In the case of a deep, non-hilar or transfixing wound of the pulmonary parenchyma the hemorrhagic tract should be laid open by transection of the overlying parenchyma with a linear stapler. One blade of the linear stapler is inserted into the orifice to perform what is called a tractotomy. Control of bleeding and air leak are then completed under direct vision. We advise against the direct closure of a manifestly hemorrhagic parenchymal wound, because of the risk of engendering a parenchyma-destroying hematoma. For difficult-to-control proximal hemorrhagic lesions or for obvious air embolism, mass clamping of the pulmonary hilum is permissible. Vascular control requires the opening of the triangular ligament from the diaphragm to the inferior pulmonary vein. The hilum can then be encircled between the index finger and the thumb and then a large clamp applied. A 180º twist maneuver of the hilum has also been described, whereby torsion allows compression of the vascular axes on the bronchial axis. If all else fails, pneumonectomy is performed by clamp and ligature or by applying a large linear-cutting stapler.

Post-traumatic air embolism is an often unrecognized complication due to a communication between the bronchial tree and the pulmonary venous circulation. The typical picture is that of cardiopulmonary collapse following endotracheal intubation and positive pressure ventilation. The main salvage gesture remains the clamping of the hilum but three classical maneuvers should be known:

- Trendelenburg position allows the air to be trapped at the left ventricular apex where a needle venting can be performed;
- digital clamping of the ascending aorta while air in the aortic root is aspirated;
- and vigorous cardiac massage to promote the dissolution of the coronary air emboli, or, failing that, purging of the emboli.

The management of other intra-thoracic vascular lesions is relatively non-specific. The subclavian artery and the innominate venous trunk can be ligated with impunity. Finally, if there is diffuse parietal bleeding or even diffuse pulmonary parenchymal bleeding, intrathoracic ''packing'' may be performed, taking care however to avoid cardiac and/or ventilatory repercussions.

Closure

Since this gesture is part of a Damage Control procedure, the closure is temporary and should not, in any case, lengthen the operating time. It is usually an exclusively cutaneous closure over tube drainage of the pleura, the pericardium and possibly of the mediastinum. At this moment, thought must be given to ligating the internal mammary pedicles that were divided during the incisional approach. Closure with a negative pressure dressing is possible. Thoracic compartment syndrome is rare and controversial.

Indications

Resuscitation thoracotomy is indicated in patients with cardiac arrest who have a penetrating traumatic injury if the duration of cardiopulmonary resuscitation is <15 minutes, 10 minutes in case of blunt trauma, 5 minutes in the case of neck or extremity trauma, and for patients in refractory shock with a systolic blood pressure <65 mm Hg. If the heart is in asystole when the pericardium is opened with no evidence of tamponnade, the procedure is vain and must be stopped [3—6]. Fig. 1 summarizes the algorithm proposed by the Western Trauma Association in 2012 [5].

Results

Table 1 summarizes the results of the 15 largest series published in the last ten years, totaling 1432 resuscitation thoracotomies [7—21]. The overall survival rate is 12%, with a 12% rate of neurological sequelae. For penetrating trauma, survival is 10% versus 6% for closed trauma. Survival is 20% for knife wounds but only 8% for gunshot wounds. Depending on wound localization, the survival rate is 10% for cardiac trauma, 11% for thoracic trauma, 12% for abdominal trauma, but only 1% for multiple localizations. If signs of life (SOL) are present at admission, survival is 10% compared to 3% in their absence. Fig. 2 illustrates this stratification. It appears that the most favorable prognosis corresponds to a stab wound in a patient who still has signs of life at admission. Conversely, the worst prognosis corresponds to a patient with closed polytrauma without signs of life at admission.

Conclusion

In conclusion, the performance of RT is based on a clear rational approach. The overall survival rate is 12% and may be up to 20% in the case of a stab wound. It is conceivable only for patients suffering from severe trauma or in-extremis cardiac arrest in the context of a Damage Control procedure. In this context, it is fully justified in the event of a multiple casualty incident due to a terrorist attacks, as long as its indications are strictly observed.

Key points

The five objectives of resuscitation thoracotomy are:

- decompression of a pericardial tamponnade;
- control of a cardiac hemorrhage;
- performance of internal cardiac massage;
- cross-clamping of the descending thoracic aorta;
- control of pulmonary lesions and other intra-thoracic hemorrhages;
- resuscitation thoracotomy is indicated for:
  - patients with penetrating trauma and cardiac arrest if the duration of cardiopulmonary resuscitation is <15 minutes,
  - patients with closed trauma and cardiac arrest if the duration of cardiopulmonary resuscitation is <10 minutes,
  - trauma patients with refractory shock and systolic blood pressure <65 mm Hg.

Disclosure of interest

The authors declare that they have no competing interest.

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