Lung-Sparing Surgery After Penetrating Trauma Using Tractotomy, Partial Lobectomy, and Pneumonorrhaphy

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Objective: To evaluate the role of lung-sparing surgical techniques in the surgical management of penetrating pulmonary injuries.

Design: Retrospective case series.

Setting: Academic level I trauma center.

Patients and Methods: Forty patients underwent thoracic surgery for penetrating lung injuries during a 63-month period from January 1993 to March 1997. Five (12.5%) underwent anatomical lobectomy, 3 (7.5%) pneumonorrhaphy, 9 (22.5%) stapled wedge resection, and 23 (57.5%) stapled tractotomy. In total, 34 patients (85%) were treated with stapling techniques (1 anatomical lobectomy, 1 pneumonorrhaphy, 9 stapled wedge resections, and 23 stapled tractotomies) and 35 (87.5%) underwent had lung-sparing surgery for trauma.

Results: Morbidity and mortality rates were 40% and 5%, respectively. Patients who underwent anatomical lobectomy required longer mechanical ventilatory support, intensive care unit stay, and hospital stay and had a higher morbidity rate compared with patients who underwent lung-sparing surgery for trauma but had central and extensive pulmonary injuries. Stapled tractotomy was efficient in controlling bleeding and bronchial leaks, but, in 3 patients, parts of the divided lung parenchyma were devascularized and had to be resected.

Conclusions: Lung-sparing surgery for trauma with the use of staplers can be used in the majority of patients with penetrating pulmonary injuries requiring operation. Stapled tractotomy is a rapid and effective method for controlling hemorrhage and air leaks.

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The majority of injuries to the lung are managed by tubal thoracostomy.1 The combination of lung expansion, low intravascular pressures, and high concentration of tissue thromboplastin provides adequate hemostasis in most instances.2 Thoracotomy to control bleeding is reserved for approximately 10% to 15% of penetrating thoracic injuries.1,2 In contrast with the abdominal cavity, where surgical exploration is frequently mandated by abdominal tenderness even in the presence of hemodynamic stability, operations in the chest are almost exclusively done for severe intrathoracic blood loss affecting the vital signs. Therefore, rapid bleeding control with the least possible physiologic insult is highly desirable.

Anatomical or nonanatomical lung resections and suturing superficial lacerations are the main techniques used to achieve hemostasis.3-7 An alternative method has been suggested to achieve the same goals without destroying lung parenchyma. Wall et al8 described tractotomy, the opening of the pulmonary injury tract over vascular clamps and the selective ligation of bleeding vessels, as a safe and straightforward procedure. Our group has practiced this technique by using linear staplers instead of vascular clamps to expedite and simplify the procedure.9 Lung-sparing surgery can be performed by using techniques such as tractotomy, wedge resection, and pneumonorrhaphy as alternatives to anatomical resection. The purposes of this study were to analyze our experience with pulmonary tractotomy and evaluate the role of lung-sparing techniques in pulmonary surgery for trauma.

RESULTS

Of 40 patients, 5 (12.5%) underwent AL (1 underwent a pneumonectomy) and 35 underwent lung-sparing surgery: PR in 3 (7.5%), SWR in 9 (22.5%), and ST in 23 (57.5%). Linear stapling devices were used in 1 AL, 1 PR, and all SWRs and STs. The mean age and score on the Injury Severity Scale for the group was 27 years and 17, respectively. Additional injuries to the chest included lacerations to the heart (4 patients) and subclavian artery (1 patient). Twenty-two patients (55%) un-
PATIENTS AND METHODS

Forty patients (38 male and 2 female) who underwent surgery between January 1993 to March 1997 for a penetrating injury to the lung (32 gunshot wounds and 8 stab wounds) were included in this study. Patients who underwent thoracic procedures for isolated vascular or cardiac injuries and those who underwent thoracotomies in the emergency department but did not survive the procedure were excluded.

All patients admitted to the Los Angeles County and University of Southern California Medical Center, Los Angeles, are treated by a dedicated trauma team. Attending physicians provide in-house, around-the-clock coverage and participate in all resuscitations and surgical interventions. Patients with hemodynamic instability due to blood loss were taken immediately to the operating room. An immediate chest tube output of more than 1000 to 1500 mL was an additional indication for surgical exploration. However, rigid adherence to numbers was avoided; the decision for operative or expectant management was usually made by combining information on the hemodynamic status of the patient, thoracotomy tube outputs, and clinical and radiographic findings.

Emergent surgical access to the injured lung was usually achieved by anterolateral thoracotomy (27 patients), unless suspected heart injury prompted a median sternotomy (3 patients). One of these 3 patients received both incisions, since manipulation of the lung through the sternotomy, which is done for an associated cardiac injury, was followed by desaturation and hemodynamic instability. Two patients underwent an additional laparotomy for abdominal tenderness, bleeding, or inability to evaluate the abdomen. In 16 of these patients, injuries to intra-abdominal structures such as the liver (3), spleen (3), stomach (3), small bowel (2), colon (2), pancreas (1), or retrohepatic inferior vena cava (1) were identified and repaired. All but one patient required admission to the intensive care unit (ICU), with an average ICU length of stay of 7 days. Complications developed in 16 patients (40%) and were related to the lung surgery in 11 (27.5%).

Two patients (5%) died. One of these patients underwent a thoracotomy in the emergency department, where a gunshot wound through the hilar region with profuse bleeding was discovered. After achieving temporary control of the bleeding, he was taken to the operating room, where a pneumonectomy was performed with a stapler (TA90, US Surgical Corporation). During the operation he experienced cardiac arrest twice and was resuscitated. The bleeding was controlled, but he experienced cardiogenic shock in the ICU later that day. The other patient had multiple truncal and extremity gunshot wounds. A laparotomy revealed injuries to the liver and retrohepatic inferior vena cava that were controlled by total liver isolation, primary vascular repair, and packing. Bilobular lacerations to the right lung were managed by SWR. The patient died in the ICU on the third postoperative day owing to fulminant multiple organ failure. The mean hospital stay among survivors was 15 days.

Table 1 shows injury characteristics and physiologic parameters in patients who underwent ST, SWR, PR, or AL. Although statistical comparisons are limited by the low number of patients in the various groups, it appears that these parameters were not different. All injuries that required lobectomy were close to the pulmonary hilum. Of the 35 patients who underwent lung-sparing surgery, 14 (39%) had extrathoracic injuries requiring exploration compared with 2 (40%) of 5 patients who underwent lobectomies. The latter group required a higher median volume of intraoperative fluid (8600 vs 5000 mL) and blood resuscitation (7 vs 12 U) compared with the former group. The number of days on which mechanical ventilation was used, the duration of tubal thoracostomy, the number of days spent in the ICU and hospital, and the morbidity rates were different between the 2 groups (Table 2).

There were 10 complications that were directly related to the type of lung surgery (Table 3). Seven (20%) occurred in the lung-sparing group and 3 (67%) in the lobectomy group. Two patients developed empyema, which was drained percutaneously using computed tomographic guidance in both cases. All 4 persistent air leaks were sealed using expectant management within 11 to 15 days. Three patients required reoperation. Two of these patients underwent ST as the primary procedure. One patient underwent reoperation the same day for recurrent bleeding. No bleeding source was identified, and he subsequently recovered. The second patient underwent reoperation for sepsis on the 13th day after a middle- and upper-lobe ST of the right side. A large segment of the divided upper lobe was necrotic and, for this reason, was resected by linear staplers. The patient was discharged from the hospital after 50 days. The third patient underwent bilateral anterolateral thoracotomies. Posterior thoracotomy was reserved for 11 patients who were hemodynamically stable and had bullet or knife trajectories that clearly excluded the probability of associated injuries in other body cavities. Single-lumen endotracheal intubation was used in most patients (37) due to the need for rapid airway access. Once the thoracic cavity was entered, the injury to the lung was evaluated. In the presence of profuse bleeding or significant air leakage from central cavities, the corresponding hilar pedicle was cross-clamped (9 patients). Stapled tractotomy (ST) was the preferred method of operative management by a technique previously described (Figure 1 and Figure 2). In short, a staple (GIA [gastrointestinal anastomosis] stapler 55 or 75, US Surgical Corp, Norwalk, Conn) was used to open the tract, and individual ligation of exposed vessels and bronchi was used to control bleeding or air leaks. Peripheral injuries were frequently controlled by stapled wedge resections (SWRs). Central injuries were managed by anatomical lobectomy (AL) only if they were extensive and therefore not amenable to tractotomy or if they involved hilar vessels. Oversewing (pneumorrhaphy [PR]) was reserved only for superficial lacerations. The entry and exit sites of a trajectory were never oversewn, since oversewing leaves the central cavity as a source of uncontrolled bleeding or air embolism.

Data on injury characteristics, management, and outcome were collected from the patients’ medical records and the trauma registry. Statistical analysis was performed using the Student t test, Fisher exact test, and analysis of variance. P values of less than .05 were considered significant.
initially underwent a middle lobectomy of the right side but
developed sepsis on the basis of unexplained occlusion of
the right upper bronchus with interruption of blood flow
to the corresponding lobe. Reexploration on the third post-
operative day revealed an upper lobe torsion in the right side.
The lobe was resected, but the patient had a difficult post-
operative course complicated by pneumonia and respiratory
failure. He was eventually discharged from the hospital 52
days after admission. In 2 more patients (not included in the
postoperative morbidity list), portions of devascularized lung
after ST were resected at the primary operation.

There has been a remarkable change in the types of opera-
tions for lung trauma in the last decade.10-14 Although older
reports10,11 recommend lobectomy as the typical operative
management of pulmonary injuries, more recent experi-
ence13,14 suggests that the use of lung-sparing techniques
is equally effective. Stapling devices play a central role in
such management as they facilitate and expedite the execution
of these techniques.12,13 In our series, 34 (85%) of 40
patients were treated using staplers: tructotomy in 23, partial
resection in 9, PR in 1, and pneumonectomy in 1.

Tractotomy has been identified as an easy and rapid
method of controlling bleeding without subjecting the pa-
tient to unnecessary lung resection.8,9 The technique was
first described by Wall et al,8 who reported excellent results
in 16 patients with penetrating lung injuries. Our modifi-
cation includes the application of a stapler (GIA) through
the injurious weapon’s trajectory to visualize the bleeding
areas and allow direct ligation.9 The use of staplers makes
the procedure easier and faster. Oversewing the staple line
is not necessary unless it is thought that the tissue incor-
porated in the staples is too thick, which may occur with
central trajectories. During tractotomy, a portion of the di-
vided tissue may become ischemic due to interruption of
its vascular supply. Careful inspection at the end of the pro-
cedure to detect and resect such areas is essential. In our
series, 1 patient required reoperation for removal of a ne-
crotic part of the tractotomized upper lobe. For the same
reason, 2 more patients underwent small wedge resections
during the initial operation following tractotomy.

Although with increasing experience the appropriate
procedure is selected as soon as the site and severity of in-
jury is recognized, bleeding control by expeditious stapled
tractotomy can be attempted initially for most injuries. How-
ever, in cases where bleeding cannot be satisfactorily con-
trolled by this technique—usually due to a central location
of the injury with larger vessels or bronchi involved—
conversion to some form of resection should be done early.
Partial lobectomies are easily done with the use of staplers.
We used a linear stapling device in all 9 patients in our study
who required a partial lobectomy. Even ALs or pneumo-
nectomies have been described with the use of staplers.15,16
The rapidity in completion of the procedure is the main ad-
vantage for patients who are bleeding severely. However,
there are concerns on the appropriateness of en masse sta-

![Figure 1. Placement of stapler through bullet trajectory.](image1)

![Figure 2. Opening the tract, individually ligating vessels, and, if necessary, oversewing the staple line.](image2)

**Table 1. Injury Characteristics and Physiologic Data in Patients Who Underwent Different Types of Lung Surgery for Penetrating Pulmonary Injuries**

<table>
<thead>
<tr>
<th></th>
<th>Stapled Tractotomy (n = 23)</th>
<th>Stapled Wedge Resection (n = 3)</th>
<th>Pneumonorrhaphy (n = 5)</th>
<th>Anatomical Lobectomy (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Severity Score</td>
<td>16 ± 8</td>
<td>19 ± 7.5</td>
<td>10 ± 0.5</td>
<td>20 ± 12</td>
</tr>
<tr>
<td>Abbreviated Injury Score (chest)</td>
<td>3.4 ± 0.7</td>
<td>3.3 ± 0.7</td>
<td>3.0 ± 0.0</td>
<td>3.8 ± 0.8</td>
</tr>
<tr>
<td>Gunshot wound, %</td>
<td>78</td>
<td>90</td>
<td>66</td>
<td>80</td>
</tr>
<tr>
<td>Systolic blood pressure on admission, mm Hg</td>
<td>104 ± 33</td>
<td>115 ± 30</td>
<td>116 ± 16</td>
<td>98 ± 60</td>
</tr>
<tr>
<td>Hematocrit level on admission</td>
<td>0.34 ± 0.05</td>
<td>0.34 ± 0.07</td>
<td>0.31 ± 0.07</td>
<td>0.35 ± 0.04</td>
</tr>
<tr>
<td>Lowest pH level</td>
<td>7.2 ± 0.1</td>
<td>7.2 ± 0.1</td>
<td>7.2 ± 0.1</td>
<td>7.0 ± 0.1</td>
</tr>
<tr>
<td>Lowest mean arterial oxygen saturation, %</td>
<td>96</td>
<td>98</td>
<td>97</td>
<td>97</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD unless indicated otherwise. The P values were not significant; P values less than .05 were considered significant.*

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pling together of the pulmonary hilum, including vessels and bronchi. Our experience is limited. We performed a stapled pneumonectomy on an exsanguinating patient who had a gunshot wound in the right side of the chest and had a cardiac arrest after arriving at the hospital. Although the bleeding was controlled, the combined cardiorespiratory burden of the injury and the traumatic pneumonectomy did not allow him to survive beyond 24 hours. After the end of the study, we performed 1 more stapled pneumonectomy. In this anecdotal case, the stapler was fired close to the mediastinum, the stapled stump was retracted backward, and the patient began to bleed uncontrollably. If a stapling device is used for traumatic lobectomy or pneumonectomy, we recommend firing the stapler twice before transecting the lung and leaving a long stump.

Only 3 patients in our study underwent PR. One of these injuries was controlled by stapling. We believe that this technique has a role only in superficial lacerations that can be sutured or stapled closed without leaving a cavity behind. As such wounds are unlikely to require surgical management, PR is not commonly used. Leaving a cavity predisposes the patient to recurrent bleeding and, more importantly, to air embolism, a potentially lethal complication.17,18 For this reason, transmural wounds should never be managed by oversewing the entry and exit sites without controlling bleeding and air leaks from the tract. Finally, hemostasis should not be the sole end point in pulmonary surgery for trauma. Identification and repair of significant bronchial leaks is important to avoid persistent postoperative bronchopleural fistulae. At the end of the procedure, the lung should be fully inflated by manual ventilation and thoroughly inspected for the presence of recurrent bleeding, residual air leaks, or failures of staple lines. Careful repositioning in the thoracic cavity without twisting the hilar region is essential to avoid pulmonary torsion.19 Anchoring the remaining lobes together or against the interior thoracic wall by a suture is advisable for the same purpose.19

Although the majority of lung injuries can be managed nonoperatively, severe bleeding may still require exsanguinating thoracic surgery. Lung-sparing surgery can be frequently done by using stapling devices with good results. In particular, stapled pulmonary tractotomy is becoming the preferred technique for the management of a notable number of penetrating lung injuries.

Table 2. Comparison of Outcome Parameters Between the Patients Who Underwent Either Lung-Sparing Surgery or Anatomical Lobectomy*

<table>
<thead>
<tr>
<th></th>
<th>Lung-Sparing Group</th>
<th>Lobectomy Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 35)</td>
<td>(n = 5)</td>
</tr>
<tr>
<td>Duration of mechanical ventilation, d</td>
<td>4 ± 6</td>
<td>19.5 ± 17</td>
</tr>
<tr>
<td>Intensive care unit stay, d</td>
<td>5 ± 7</td>
<td>21.5 ± 20</td>
</tr>
<tr>
<td>Hospital stay, d</td>
<td>14 ± 13</td>
<td>36 ± 24</td>
</tr>
<tr>
<td>Duration of tubal thoracotomy, d</td>
<td>9 ± 9</td>
<td>24 ± 13</td>
</tr>
<tr>
<td>Mortality, No. (%)</td>
<td>1 (3)</td>
<td>1 (20)</td>
</tr>
<tr>
<td>Total morbidity, No. (%)§</td>
<td>12 (35)‡</td>
<td>4 (100)‡</td>
</tr>
<tr>
<td>Lung-related morbidity, No. (%)§</td>
<td>7 (21)</td>
<td>3 (75)</td>
</tr>
</tbody>
</table>

* Ellipses indicate not applicable.
† One operation for right upper lung torsion.
‡ Persistent lower lobe collapse that required reimplantation and prolonged positive pressure ventilation.

Table 3. Complications Related to Lung Surgery*

<table>
<thead>
<tr>
<th></th>
<th>Staped Tractotomy (n = 23)</th>
<th>Staped Wedge Resection (n = 9)</th>
<th>Anatomical Lobectomy (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empyema</td>
<td>1 (4)</td>
<td>1 (11)</td>
<td>...</td>
</tr>
<tr>
<td>Air leak ≥10 d after surgery</td>
<td>2 (9)</td>
<td>1 (11)</td>
<td>1 (20)‡</td>
</tr>
<tr>
<td>Reoperation</td>
<td>2 (9)‡</td>
<td>...</td>
<td>1 (20)‡</td>
</tr>
<tr>
<td>Other</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Total</td>
<td>5 (22)</td>
<td>2 (22)</td>
<td>3 (67)</td>
</tr>
</tbody>
</table>

* Ellipses indicate not applicable.
† One operation for bleeding and 1 for partial lobar necrosis.
‡ One operation for right upper lung torsion.
§ Excluding pneumonia.

REFERENCES