Experimental study of the effects of different stapling devices in healing of the mechanically sutured bronchial stump

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Abstract

Objective: The invention of the mechanical suture of the bronchial stump resulted in the significant decrease of the incidence of bronchial fistulas. Bronchial fistula constitutes the most dangerous complication of the pulmonary resection. In connection with some negative opinions in world literature regarding the safety of applying some types of mechanical suture, the multi-factor analysis of efficacy of bronchial stump closure following the total pneumonectomy by two different types of stapling devices was performed. Methods: The experimental study was performed on 22 sheep. Each sheep underwent left pneumonectomy. In group I the bronchus was closed by the hinged-jaw stapling device (TA-Premium, Auto-Suture®). In group II the bronchus was closed by the stapling device of parallel pattern (RLV 30 Ethicon®). The macroscopic parameters (i.e. linear structure of staples, degree of staples closure, the symmetry of staples closure in the medial and lateral part of bronchial stump) as well as microscopic parameters (i.e. degree of inflammatory reaction, degree disorder in collagen fibbers system, degree of disorders in cartilaginous system, degree of vascular proliferation and nervous regeneration) were evaluated. Results: In three cases of group I the serious abnormalities in staples closure in the medial part of the bronchial stump were revealed. Abnormalities were found also in microscopic evaluation of the specimens. In the whole group the inflammatory reaction predominated in the medial part of bronchial stump near the hinge of the cartridge (P value <0.05). The disorder in the collagen fibbers system as well as in the stratified structure of muscular fibbers and cartilaginous system was proved. On the other hand, in group II all staples were properly closed in adequate linear structure, without any symmetry in both medial and lateral end of the bronchial stump. The microscopic findings were only the subtle inflammatory process and a slight disarrangement in muscular, collagen and cartilaginous systems. Conclusion: The listed abnormalities of mechanical, hinged-jaw suture of bronchial stump seem to be due to the inaccurate placement of staples, their incomplete closure, and excessive damage to the sutured tissues. We conclude that the application of the hinged-jaw mechanical suture of the bronchial stump might result in higher incidence of bronchial fistula after pneumonectomy. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Bronchial fistula; Bronchial closure; Mechanical suture

1. Introduction

Suturing the human body’s various anatomical structures has posed a problem since the surgery’s beginning. Throughout time, progress has been made toward resolving this dilemma. In the 19th century healing processes became better understood [1–5]. In 1908, Hunter Hult presented a suturing method using a new mechanical device based on two rows of V-shaped metal staples which were uniformly completely closed achieving a final B-shape [6]. As developed by Hult, the general rules of practice for mechanical stapling devices are still in use today. In 1958, M.M. Ravitch introduced stapling devices into thoracic surgery for bronchial stump closure [6]. As initially reported by Ravitch, closure by stapling devices reduced the rate bronchial fistulae to 4.2% as compared to 30% for conventional suturing techniques [7].

Numerous studies have validated the role of mechanical stapling devices in reducing serious complication after pulmonary resection. Bronchopleural fistula is one complication which results in high mortality rates (60% and higher) [8]. Postpneumonectomy fistulae are rapidly fatal, and are an especially difficult and distressing complication of pulmonary resection [9].

The factors leading to this complication are mostly well-known. Extensive resection in the lung cancer patient after chemoradiotherapy increased the risk of postoperative complication and forces surgeons to seek new method for avoiding them. The search for safer bronchial stump closure...
method has led to the development of mechanical stapling devices (in thoracic surgery) [10,11].

There are two types of mechanical devices used to close a bronchial stump: parallel and hinged-jaw stapling devices. Despite extensive clinical use and the definition of specific indications for the two mechanical sutures, they have not been formally compared in the context of an experimental study.

Moreover there are several papers reporting higher risk of bronchial fistula associated with the usage one of the types of stapling devices. Smiell et al. [12] suggested that bronchial fistula was more likely to result in cases where the bronchial stump was closed with hinged-jaw type of stapling device. Similar results were obtained by Hakim and Milstein [13]. They reported the rate of bronchial fistula as high as 15.2% in a group of patients where hinged-jaw equipment was used as compared with 4.2% in a parallel stapling devices group. These data suggest a need for an objective study to compare both types of stapling devices. We conducted this study to evaluate the healing of the bronchial stump after using parallel and hinged-jaw staplers.

2. Material and methods

Our study was carried out in a group of 22 sheep (14 female, eight male) with a mean age of 4 years (range, 3–5 years) and a mean weight of 55 kg (range, 50–60 kg). The animals were divided into two equal groups of 11 sheep each. In animal group I (numbered from 1 to 11) the bronchial stump was closed using hinged-jaw stapling devices (TA-Premium, Auto Suture®). In group II, (numbered from 12 to 22) using parallel staplers (RLV 30 Ethicon®) 22 left pneumonectomies were completed. The choice of side resulted from the anatomy of the animal where the greater part of the stomach is placed on the left side of abdomen. During the process of digestion a large volume of fermented gases is freed which can press through the diaphragm on the left lung causing respiratory complications. Animals stopped being fed 24 h before the operation, but were given water. The operation was carried out under general anesthesia. The introduction of anesthesia was started through the intramuscular administration of propionylproclain (Combelan at a dose of 10 mg/kg). The sheep was placed in the right lateral position. An intravenous infusion of atropin (0.01 mg/kg) and thiopental (8–10 mg/kg) was administered. The sheep was intubated. The anesthesia was continued using a mixture of halotan (4vol.%) and oxygen in concentration of 1.5–2 vol.%. The feeding tube inserted to empties of stomach. Muscle relaxation was obtained using chlorosuccinilin (0.005 mg/kg). During the operation all of parameters were observed using echocardiography and pulsoxymetry. All animals received penicillin intramuscularly on the day of surgery and once daily for the following 7 days.

The thoracic cage was opened through fifth intercostal space with antero-lateral approach. The pulmonary ligament was released and vessels sutured and cut. The main left bronchus was divided from surrounding tissues up to the carina level. The bronchial stump was closed with one of the two mechanical stapling devices depending on the group. In group I hinged-jaw staplers were used. The stapler was applied near the carina from the medial toward the lateral portion of bronchus in such a way that hinge of cartridge near the medial wall of bronchus was placed. In the first stage of closure cartridge on the opposite to the hinge end is closed. At this point, the lateral portion of the bronchial stump is compressed. In the second stage the clamps of the cartridge close near the hinge and the medial portion of bronchus is compressed. In group II the bronchial stump was closed with parallel stapling devices.

The animals were extubated primarily or within a few hours after the operation. All animals were maintained under the care of a veterinarian in accordance with the National Society of Medical Research Principles of Laboratory Animal Care.

On the 7th postoperative day the animals were sacrificed by lethal intravenous injection of pentobarbital. The thoracic cage was opened and distal trachea with bronchial stump was removed. All postmortem specimens were examined and radiologically photographed. All specimens were fixed in 10% formaldehyde and stained (hematoxylin, and eosin, elastin van Gieson). The slides were examined by a pathologist blinded to the group from which the specimen was obtained. The parameters are divide into two groups. The first group of parameters (including the macroscopic parameters, i.e. linear structure of staples, degree of staples closure, the symmetry of staples closure in the medial and lateral part of bronchial stump as well as microscopic parameters, i.e. degree of inflammatory reaction, degree disorder in collagen fibres system, degree of disorders in cartilage system) presented the degree of disturbances in closure of staples and histological abnormalities as consequence of incomplete closure of staples. In this group, 3 was a predictor of poor healing. The second group of parameters (degree of vascular proliferation and nervous regeneration) were used to estimate the degree of proper healing processes of bronchial stump. In this group the great degree of vascular proliferation and nervous regeneration means proper healing of bronchial stump.

The radiological findings were evaluated with a scoring system as follows:

- I. Degree of complete stapler closure:
  1. complete closure of staples;
  2. incomplete closure of one staple;
  3. incomplete closure of more than one staple.

- II. Degree of closure line disturbances (According to proposed scale 1 means alignment of staples versus 3 – non-alignment):
1. regular closure line;
2. moderate degree of disturbance;
3. severe degree of disturbance.

- III. Degree of closure symmetry between both ends of bronchial stump:
  1. staples closed uniformly;
  2. moderate degree of asymmetry;
  3. severe degree of asymmetry.

The light microscopic findings were evaluated with a scoring system as follows:

- I. Degree of inflammation reaction. Degree of inflammation was assessed by pathologist microscopically using general rules of definition of inflammatory reaction (concentration of lymphocytes, macrophages and histiocytes):
  1. mild inflammation;
  2. moderate inflammation;
  3. severe inflammation.

- II. Degree of collagen fiber disturbance:
  1. regular collagen fibers;
  2. moderate degree of collagen fiber disturbance;
  3. severe degree of collagen fiber disturbance.

- III. Degree of muscle fiber disturbance:
  1. mild;
  2. moderate;
  3. severe.

- IV. Degree of cartilaginous system disturbance:
  1. mild;
  2. moderate;
  3. severe.

- V. Degree of blood vessel proliferation:
  1. low;
  2. middle;
  3. great.

- VI. Degree of nerve fiber regeneration:
  1. low;
  2. middle;
  3. great.

2.1. Statistics

Differences in microscopical and radiological data between lateral and medial portion of bronchial stumps in group I and II were compared by using rank test for paired data. A P-value of less than 0.05 was considered to be significant. The Fisher exact test was used to assess statistical differences between the groups. A differences of $P < 0.05$ were significant.

3. Results

The animals tolerated the thoracotomy well. All of the sheep survived the operation and all of their wounds healed well. No signs of skin infection or respiratory insufficiency were observed. No stump leakage occurred in any sheep. In both groups the sheep remained alive for the duration of the experiment and were subsequently killed for the histological examinations.

The bronchial lumen ranged from 1.2 to 1.9 cm (mean, 1.55 cm) and no calcifications or thickening of bronchial walls were observed.

In group I radiological findings ranged from 3 to 1. There were distinct differences in staple closure depending on the end of the bronchus observed. Especially, in three animals (Nos. 1, 3 and 10) incomplete closure of one or more staples was found near the hinge of the cartridge Figs. 1 and 2. In contrast staples achieved final B-shape in the middle and opposite end of bronchial closure line. Also, light microscopic examination showed asymmetry between both ends of the bronchus. The microscopic findings ranged in this group from 3 to 1. Near the hinge, moderate and severe degrees of inflammation, and disturbances of muscle and collagen fibers were observed. On the other hand healing process measured by degree of regeneration of nerves fibers and proliferation of blood vessels in this group of animals were weakened. Moreover, in cases where incomplete closure of staples was found microscopic examination showed the presence of pseudomicroabsceses, degeneration and necrosis of mucosa near the hinge of the cartridge. The lining mucous membrane was colonized by organisms and partially disrupted. Incomplete closure staples were surrounded by infiltrations of lymphocytes. This showed a poorly structured collagen network. The degree of microscopic inflammation was much greater than in places where there were complete staple closure. The comparison between lateral and medial portion of bronchial stumps in group I showed significant asymmetry in degree of staples closure, degree of disorder in collagen’s fibres system, as well as in the stratified structure of muscular fibres and cartilaginous system ($P < 0.05$). A negative correlation was evident between the inaccurate placement of staples near the hinge of the cartridge and the healing of bronchial stump.

In group II there was no incidence of incomplete closure of staples. All staples were closed uniformly Fig. 3. Only mild disturbances in the structure of the closure line were observed. There was no difference between the ends of the bronchus and asymmetry was not detected. Microscopic
findings showed moderate degrees of disturbance in structures of collagen and muscle fibers. However, a high level of blood vessel proliferation and regeneration of nerve fibers proved an aid to the healing process in this group of animals. There were no significant differences between lateral and medial portion of bronchial stumps in group II. The comparison between groups proved to be significant only on medial portion of bronchial stump \((P < 0.05)\). All results are summarized in Tables 1 and 2.

4. Discussion

Although a number of clinical studies of the feasibility of bronchial stump closure with mechanical suture devices have been undertaken, the evidence that this technique may be associated with an increase in the incidence of bronchial fistula has not been found \([14–17]\). It has been reported that stapling is superior to hand suturing in preventing bronchial fistula after major pulmonary resections. Antypas et al.
[18] reported a significant shortening of operation length (about 50%) and a decrease in blood lost in patient whose bronchial stump is closed with staplers. Moreover major complications including bronchial fistula (3.2%) and pulmonary embolism (1.2%) were found only in patients who underwent resection with conventional bronchial closure technique. On the other hand, several reports have presented negative opinions concerning mechanical suturing.

In studies presented by Weissberg and Kaufman [19] no difference in risk of complication between parallel and hinged-jaw staplers was found. These results contrast with those reported by Hakim and Milstein [13]. They observed a significantly higher rate of bronchial fistula (15.2%) associated with the use of hinged-jaw stapling devices. The same investigation on cadaveric bronchus showed incomplete closure of staples near the hinge end of the closure line was the cause of the fistulas. It has been postulated that hinged-jaw type of staplers should be modified. Smiell et al. [12] inspired by previous studies, carried out a clinical investigation to estimate the safety of hinged-jaw stapling devices. They used completely disposable equipment. Radiological films showed malformation of staples near the hinge in a patient who developed a fistula after pneumonec-tomies. These findings confirm that only parallel stapling devices offer an acceptable level of safety in pulmonary resections. In contrast other authors have obtained satisfactory results using both types of staplers.

In our study, although the fistula did not occur, there were several differences in radiological and microscopic findings between the two groups of animals. Only in group I was incomplete closure of one or more staples near the hinge of the cartridge found. Histologically, pseudomicroabscesses, degeneration, and necrosis of mucosa were observed. Also the colonization and disruption of mucosa visible in group I lets us suggest that healing of the bronchial stump may be

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<th>Severe</th>
<th>Moderate</th>
<th>Mild</th>
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<tr>
<td></td>
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<td>Group II</td>
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<tr>
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<tr>
<td>Cartilagenous disorder</td>
<td>6</td>
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Fig. 3. Radiograph of bronchus stapled with the parallel stapler. All staples are properly closed in adequate linear structure, without any symmetry in both medial and lateral end of the bronchial stump.

Table 1
Number of animals in both groups in which the severe, moderate and mild degree of disturbances were found.
decreased. This was proved microscopically by a low degree of blood vessel proliferation and regeneration of nerve fibers.

The mechanisms responsible for disturbance of staple closure are incompletely understood. Injury to the bronchial stump is likely initial event causing fistula production. During the initial stage of hinged-jaw stapler closure, the exertion of force needed to close sutures creates a pressure which can crush the bronchial wall near the hinge. While the bronchial stump is not a homogenous structure and consist of different elastic elements, the pressure caused by force exerted during closure of the hinge bear the bronchus influences the movement of each structure inside the bronchial wall. A thickening of the bronchial stump near the cartridge’s hinge may result and consequently produce a malformation of staples at this site. This is especially important in the case of pneumonectomy where the lumen of bronchial stump is bigger.

In the present study we have demonstrated the possibility of an increased risk of bronchial fistula when hinged-jaw stapling devices are used for bronchial stump closure. These suggest that hinged-jaw mechanical staplers are suitable for vessel and lobar bronchi closure, but should not be used for main bronchus closure after pneumonectomy.

References


Table 2

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<th>Category</th>
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<td>m.s.</td>
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<td>m.s.</td>
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<td>m.s.</td>
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* NS, not significant; L.s., lateral side; m.s., medial side.