Initial Load Stability of Different Trachea Suture Techniques: Tests on an Ex Vivo Model

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Abstract

Objective. Tracheal anastomosis can be performed with different suture techniques. In this experimental work, the resilience of anastomotic techniques to pressure and tensile stress was studied.

Study Design. Ex vivo pig model.

Setting. Experimental.

Subjects and Methods. The trachea with the 2 main bronchi in freshly slaughtered pigs was isolated and intubated (CH 8.0). Both main bronchi were closed distally by a stapler. After resection of the trachea, an anastomosis (n = 15 per group) was created: group 1, single interrupted sutures; group 2, continuous running suture; group 3, mixed technique. A continuous tensile stress of 0, 500, 1000, or 1500 g was applied to the preparations. Mechanical ventilation with a maximum pressure of 70 mbar was initiated. The airtightness of the anastomosis was verified by submerging the entire preparation under water.

Results. At tensile loads of 0.5 and 1.0 kg, all anastomoses created in the single-stitch technique were airtight; at 1.5 kg, 93.3% were without leaks. In the continuous suture technique, the airtightness of anastomoses decreased with increasing tensile load: from 93.3% at 500 g to 73.3% at 1 kg and 66.6% at 1.5 kg (P = .02 at 1.5 kg). Anastomoses in the mixed technique were airtight in 80% at 500 g, 66.6% at 1 kg, and 46.6% at 1.5 kg (P = .01 in comparison with single stitches).

Conclusion. Anastomoses created with single interrupted sutures showed the highest resilience against combined pressure and tensile stress.

Keywords
tracheal anastomosis, tracheal resection, anastomotic suture technique, anastomotic tension, intratracheal pressure

Surgical removal of part of the trachea due to stenosis or tumors has been successfully carried out for decades.¹ After excision of the diseased portion of the trachea, an end-to-end anastomosis is performed.²,³ This can be achieved with various suture techniques. Sutures can be either single stitches or continuous. However, mixed techniques can also be employed, which consist of a continuous suture for the posterior wall and single stitches for the anterior parts of the reconstruction. If the anastomosis is to heal without complications, certain prerequisites should be met: sufficient blood supply to the corresponding tracheal ends, minimal tension on the anastomosis, and absence of infection.

The amount of tension exerted on an anastomosis is dependent on the extent of resection.⁴ To reduce this tension, various mobilization techniques are applied.⁴ Often, the front of the trachea is dissected with only the fingers and no surgical instruments. Alternatively, a video mediastinoscope can help when dissecting longer distances distally.⁵,⁶ In addition, a suprahyoid release can be performed (ie, a downward mobilization of the larynx).⁷,⁸ In particular, if resection length exceeds 7 cm, then tension on the anastomosis cannot always be avoided, despite utilization of various techniques.

Excessively high tension on the anastomosis can lead to sudden complete rupture with highly deleterious consequences for the patient.⁹ According to the literature, the rates of this range from 4% to 14.2% of cases.⁹ Hyperextension of the neck or uncontrolled coughing are among the causes. Coughing can hardly be suppressed, and intratracheal pressure may rise to ≥70 mbar.¹⁰,¹¹ Nevertheless, in clinical practice, patients are extubated early to avoid vocal cord swelling or an excess production of secretions.¹²

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Since coughing after the procedure cannot be reliably controlled or suppressed, with respect to potential anastomotic dehiscence surgical technique, the mechanical strength of a given surgical suture may be particularly important.

To test for mechanical strength of different surgical sutures, the sort of which are frequently used by surgeons, we designed an experimental model. This allows variations of a combination of anastomotic tension and intratracheal pressure to anastomoses in a controlled and reproducible manner. In addition, a defined maximum intratracheal pressure can be applied to the specimen.

**Material and Methods**

Immediately after harvest, complete heart-lung blocks were prepared in 45 freshly slaughtered pigs (weight, EU standard: 90 kg). All procedures were performed on commercially slaughtered animals (nutritional purposes); therefore, ethical approval was not needed.

Each trachea was cut below the end of the larynx. Diaphragm, pericardium, and heart were removed. Starting from the proximal trachea, the remaining trachea was exposed up to the 2 main bronchi. At the distal end, both main bronchi were closed by a stapler (Endo GIA 60 mm Tri-Staple; Covidien GmbH, Neustadt, Germany) and divided. All products thus obtained were wrapped in dressings and immediately transported to our laboratory, where a resection of the trachea was performed at the level of the right-sided accessory bronchus.

Three groups were defined, and anastomoses (suture material, PDS; yarn thickness, USB 4-0; Ethicon, Norderstedt, Germany) were performed according to group assignment. In group 1 (n = 15), all anastomoses were created by single stitches. On the posterior wall, stitches were placed in a series and tied only after they had all been properly placed and checked for correct positioning. The distance between individual stitches was set at 0.5 cm. The same procedure was applied to the front wall. In group 2 (n = 15), 2 needles were used to create an anastomosis in a continuous suture technique. Suturing was commenced at the proximal end of the trachea at 3 o’clock in a lithotomy position. First, the rear wall was reconstructed. At all times, the sutures were kept under constant tension by a surgical assistant. Spacing of the stitches was again at a distance of 0.5 cm. The anastomoses in group 3 (n = 15) were created in a mixed technique. The rear wall of the anastomosis was reconstructed by a continuous suture and the front wall by single stitches, both as described before (see Figure 1). All anastomoses were created by an experienced surgeon with the help of a medical student.

Assignment to the groups was by randomization. The trachea were intubated and blocked by a tube (CH 8.0). The tube tip was placed above the anastomosis. The tube was fixed onto a specially designed board and connected to the hose of a ventilator (Servo; Dräger, Lübeck, Germany). The entire board was placed into a trough. The trough was filled with water and the tracheal preparation completely submerged. The preparation was then ventilated with a pressure of 25 mbar. This corresponds to the pressure at which at our hospital airtightness of anastomoses is checked during operations. Any air bubbles in the area of the anastomosis indicated anastomotic insufficiency. In the experiment, 2 preparations showing initial air leaks at this pressure were carefully checked for technical suturing irregularities. In both cases, incorrect sutures were found, and the entire preparations were excluded from the experiment.

Filaments were fixed at both stapled ends and then connected to specific weights via pulleys (to ensure an even application of tension). Four types of weights were used: 0, 500, 1000, and 1500 g. A weight of 1500 g pulling on the trachea corresponds to the tension on a tracheal anastomosis after resection of 7 cm.13 Several human studies demonstrated that during coughing intratracheal pressure rises to ≥60 mbar. There was no gradual increase in tensile load on the same preparation. For each newly applied weight, a new anastomosis was constructed. To simulate the influence of coughing in our experimental setting, we evaluated the airtightness of our anastomoses at pressures of 70 mbar (the maximum pressure of the ventilator) during 5 ventilations (see Figure 2). Groups were compared by Fisher’s χ² test, and significance was set at P = .05. GraphPad Prism 7.0 software (La Jolla, California) was used for statistical analysis.

**Results**

One hundred percent of the single interrupted stitches in group 1 and continuous sutures in group 2 were airtight if no weight was added. With this setup in the mixed technique (group 3), airtightness was achieved in 93.3% (n = 14 of 15). Differences among groups were not significant without tensile stress applied (P = .11).

At 500-g tensile stress, 100% of specimens in group 1, 93.3% in group 2, and 80% in group 3 were airtight (P = .98). At an additional weight of 1 kg, 100% of single stitches remained without leakage. Running sutures were airtight in 73.3%, as opposed to 66.6% in the mixed

![Figure 1](Image 305x587 to 545x719)

**Figure 1.** (A) System of anastomosis by single interrupted stitches. (B) Continuous suture. (C) Mixed technique: continuous suture on back wall, with front wall reconstructed by single interrupted sutures.
technique. Only differences between groups 1 and 3 were significant ($P = .01$).

If 1.5 kg was applied, 93.3% in group 1, 66.6% of group 2, and only 46.6% in group 3 were airtight. Groups 1 and 2 ($P = .02$) and groups 1 and 3 ($P = .01$) differed significantly. Differences between groups 2 and 3 were not significant ($P = .39$). Table 1 and Figure 3 give an overview of the results obtained.

**Discussion**

Complete dehiscence of an anastomosis after tracheal resection is a feared postoperative complication. The result is usually asphyxia and death. Fortunately, this complication is not common; however, individual cases have been reported.\(^{10}\)

The cause of this complication is usually excessive tension on the anastomosis, combined with a pressure challenge during coughing. Despite established mobilization, residual tension on the anastomosis may remain, especially if long tracheal segments are excised.

In our experimental study, anastomoses created with single interrupted stitches performed best at high-tension and high-pressure loads. The majority of these anastomoses (93.3%) were airtight at a maximum tensile stress of 1.5 kg. This result was significantly different from the other 2 groups. At lower tensile stress, 100% of the anastomoses of this group were airtight. In our view, single interrupted stitches seem to provide optimum adaptation of the 2 corresponding tracheal ends. This suture technique works best in

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**Figure 2.** Experimental setting.

**Table 1.** Tracheal Resections.\(^a\)

<table>
<thead>
<tr>
<th>Weight, g</th>
<th>Single Stitches (n = 15)</th>
<th>Continuous Suture (n = 15)</th>
<th>Mixed Technique (n = 15)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
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<td>93.3</td>
<td>.11</td>
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<td>.01(^b)</td>
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<tr>
<td></td>
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<td>66.6</td>
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</tbody>
</table>

\(^a\)Percentage of airtight anastomoses at a maximum intratracheal pressure of 70 mbar and different weights pulling on the specimen (0, 0.5, 1, 1.5 kg).

\(^b\) $P < .05$. 
the compensation of morphologic tissue mismatches. In the group of continuous sutures, airtight anastomoses decreased to 66.6% at 1.5 kg. This suture technique appears to lack sufficient strength with larger tensile stress. Presently, it is not clear whether technical details, such as spacing of the individual stitches, are the cause of reduced resilience. Mismatches in tissue thickness and shape cannot be easily compensated by varying distances between the individual stitches without creating irregularities.

Our ex vivo model was designed to investigate the initial resilience of tracheal anastomosis by employing tensile stress and simultaneous pressure in a reproducible and controlled way. Although a braided resorbable thread (Vicryl; Ethicon) is more commonly used in clinical practice, we deliberately used a monofilic resorbable thread (PDS; Ethicon) in our experiments. In the surgical community, especially for continuous suturing techniques on the trachea, it is regularly used due to its excellent tissue tolerance. PDS is the standard material for clinical tracheal anastomosis at our institution. Under the conditions described, differences in surgical techniques were clearly significant, and the results may be relevant to daily clinical practice. Comparable studies in the literature are not available.

There are several limitations to the study. The ex vivo model can simulate clinical conditions to only a small extent. Clinically relevant complications could not be analyzed, such as delayed formation of anastomotic leaks, delayed tracheal stenoses, and wound healing. However, there are some advantages of the model. Uncontrollable influences of a complex living organism were excluded from the observation. Thus, the model allowed for a clear statement concerning the initial stability of different suturing techniques in a controlled manner, thereby allowing a focus on mechanical properties.

Our results emphasize the importance of pressure and tension as factors in the analysis of anastomotic techniques.

**Conclusion**

In case of persistent tracheal tension after resection, the technical type of anastomosis may influence leakage. In an ex vivo model, single interrupted stitches appear to be superior to other methods.

**Ethical Approval**

All procedures were performed on animals commercially slaughtered for nutritional purposes. Ethical approval was not needed.

**Author Contributions**

Andreas Kirschbaum, substantial contribution to the conception of the work, drafting, final approval, agreement to be accountable for all aspects of the work; Helen Abing, substantial contribution to the conception of the work, agreement to be accountable for all aspects of the work, revising it critically for important intellectual content; Nikolas Mirow, substantial contribution to the conception of the work, drafting, final approval, agreement to be accountable for all aspects of the work.

**Disclosures**

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**References**


