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Article

# Despite the Effects of Tension and Intraluminal Pressure, Which Suture Technique Is the Most Appropriate for Prevention of Air Leakage or Anastomotic Dehiscence in Tracheal Anastomoses in the Short Term? An Experimental Research on Ex Vivo Model

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**Purpose:** We performed an experimental study comparing different suture techniques in trachea anastomoses using the ex vivo sheep model, which deals with the parameters that suture tension, air leakage, intraluminal pressure, and tension at which the anastomosis will rupture. We aimed to find an answer to “Which suture technique should be used in tracheal anastomoses?”

**Methods:** In all, 45 sheep tracheas were randomly divided into three groups (each n = 15) differing in suture technique for anastomoses: single stitches, mixed, and continuous suture. The anastomoses were evaluated for air leakage under normal (25 mbar) and high (70 mbar) intraluminal pressures without tension. Then, air leakage was followed under high intraluminal pressure with tensile stress. Tension levels of dehiscence were also recorded. Data were statistically evaluated.

**Results:** No air leakage was observed at 25 mbar intraluminal pressure. At 70 mbar pressure without tension, no statistically significant difference was found among the groups ( $p > 0.05$ ). However, single-stitch technique was the best in terms of air leakage tension and rupture tension levels ( $p < 0.05$ ).

**Conclusion:** The most reliable and advantageous is single-stitch technique for a tracheal anastomosis in short-term results. Further studies are needed to analyze longer ventilation periods in terms of other serious complications as ischemic dehiscence and stenosis.

**Keywords:** trachea, surgical anastomosis, anastomotic leakage, suture techniques, tensile strength

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## Introduction

There are many pathologies requiring surgical approach in trachea. Main headings of these pathologies can be grouped under congenital pathologies, traumas, malignant or benign tumors, tracheoesophageal fistulas and stenotic or inflammatory pathologies. Among the surgical approaches to the trachea, the most common is resection and reconstruction. Reconstruction is often applied by end-to-end anastomosis.<sup>1)</sup>

The most common complications of this type of surgery are formation of granulation tissue or tracheoesophageal fistula on the anastomotic line, tracheal stenosis, dehiscence of anastomosis, and air leakage.<sup>2)</sup>

There are some points that need to be taken into consideration for the healing of anastomoses without complications. These are as follows: the perfusion of both ends should be good, there should be no infection or tumor, and the anastomosis should perform under minimal tension. In addition, some studies have reported that taking measures for air leakage provides improving in the results.<sup>3)</sup>

The tension of the anastomosis and the presence of air leakage are directly related to the suture technique used in anastomosis. There are some suture techniques to perform the end-to-end anastomosis. One of them is single-stitch technique. The other one is continuous suture technique. The mixed suture technique is also present. This technique uses both single and continuous sutures for anastomosis.

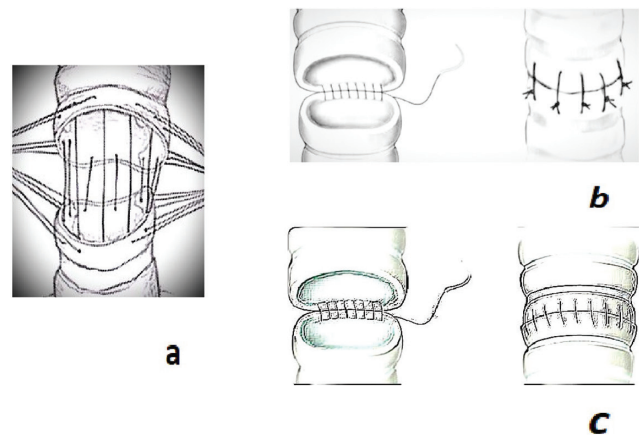
Some studies have been performed to assess the tension in the anastomosis line.<sup>4-9)</sup> However, studies investigating the tension required for anastomosis rupture are very limited. Although it is quite rare (4%–14.2%), over-tension on an anastomosis may cause dehiscence.<sup>5)</sup>

Furthermore, the effect of intraluminal pressure was not adequately investigated in these studies. That is why postoperative coughing should be considered more because it is a condition seen after almost every trachea surgery. Frequent situations after these operations as the neck hyperextension and uncontrolled cough can lead to air leakage in the anastomosis. The intra-tracheal pressure can rise to 70 mbar or higher while these situations.<sup>10,11)</sup>

For these reasons, we performed an experimental study comparing different suture techniques using the ex vivo sheep model, which deals with all of the parameters that suture tension, air leakage, intraluminal pressure, and tension at which the anastomosis will rupture. In this study, we aimed to find an answer to the common question in thoracic surgery practice “which suture technique should be used in tracheal anastomoses?” with these perspectives.

## Materials and Methods

This study was exempt from institutional review board approval as a laboratory-based study with no living subjects. In all, 45 tracheas of healthy sheep were transported to the laboratory within an hour of slaughter. All surgical



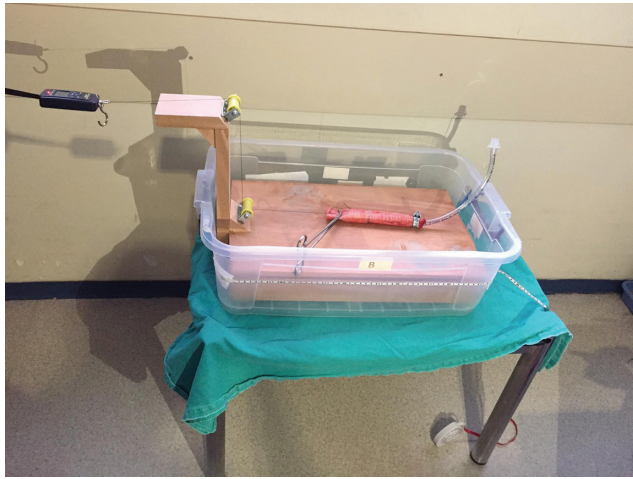
**Fig. 1** Descriptive drawing of suture techniques: (a) single stitches, (b) mixed technique, and (c) continuous suture.

procedures were performed by the same researcher (H.E.) assisted by a medical student.

In all materials, tracheal segments between just below of the larynx and just above of carina were excised. They were isolated from all surrounding tissues with dissection; thus, the experimental materials were prepared. Each material was cut into two with a scalpel.

Then, they were randomly divided into three groups (each  $n = 15$ ) differing in suture technique: single-stitch technique (Group 1), mixed technique (Group 2), and continuous suture technique (Group 3). In Group 1, anastomoses were performed with individual sutures, 5 mm apart (**Fig. 1a**). First, each single stitch was applied without knotting. After all the stitches were finished, each was knotted in order. All nodes were left on the outer surface of the trachea. For the anastomoses with mixed technique (Group 2), continuous suture technique was used on the posterior wall of the trachea, whereas the single-stitch technique was used on the anterior wall. First, single stitches were performed in the corners that connect the front wall with the posterior wall. Then, the posterior wall was sutured with continuous stitching. The ends of the individual stitches remaining at both corners were tied to the end of the thread of the continuous stitch next to it (**Fig. 1b**). Thus, after the posterior wall was completely planted, the single stitches were performed on the front wall with the same technique as Group 1. In the Group 3, anastomoses were performed by a continuous suture only (**Fig. 1c**). USP 4/0 sized polypropylene materials with 16 mm-1/2 round needles (Jinhuan Medical Products LTD, Shanghai, China) were used for all sutures.

After the anastomoses of the materials were completed, the experimental procedure was continued on the



**Fig. 2** Image of the material placed in the experimental setup.

specially prepared apparatus which is similar to the system shown by Kirschbaum et al.<sup>12)</sup> (**Fig. 2**). Thanks to this mechanism, in the meantime, the air (without water) can be sent into the material, air pressure (intraluminal pressure) can be controlled with a mechanical ventilator, the material can be fixed to the floor from proximal end, a tension on the anastomosis which can be adjustable, and measurable can be created from distal end and the material can be kept completely under water for the duration of the process to provide air leakage assessment.

A CH 8.0 tracheal tube was installed through the proximal end and left above the anastomosis line and the cuff was inflated with air until it completely blocked the trachea. Then, the proximal end with tracheal tube fastened to the floor and each other by using a hose clamp. The free end of the tracheal tube was connected to the line of mechanical ventilator (Servo; Drager, Lubeck, Germany). The tracheal lumen of the distal end was closed with a clamp. A more distal from the clamp a suture (silk suture, number 0) was applied and knotted. The other end of this suture was stretched over the two pulleys and above the water level. In order to measure the tension of the anastomosis which we created by hang on to the thread with the grams-force unit, the end of the rope was connected to the portable electronic scale. Since the mechanism was wooden, two sandbags were placed on it to prevent it from swimming in the water. At the end of all these preparations, the container was filled with water.

The tracheas were ventilated at a pressure of 25 mbar, which is considered to be the ideal test pressure to examine the air tightness of an anastomosis. There were no air bubbles indicated anastomotic insufficiency on any material. After this control, the air pressure was increased



**Fig. 3** The image of air leakage on an anastomosis.

to 70 mbar. Air leakage cases were recorded as “70 mbar air leakage.” Until now, only intraluminal pressure was applied to the materials. No tensile force was applied.

Anastomotic tension force was created with increasingly intensity in materials with no air leakage at 70 mbar intraluminal pressure. The intensity of the tension force was increased until air leakage was seen in all anastomoses (**Fig. 3**). The tensile strength at the time of air leakage on the anastomoses was recorded as “air leakage tension level.”

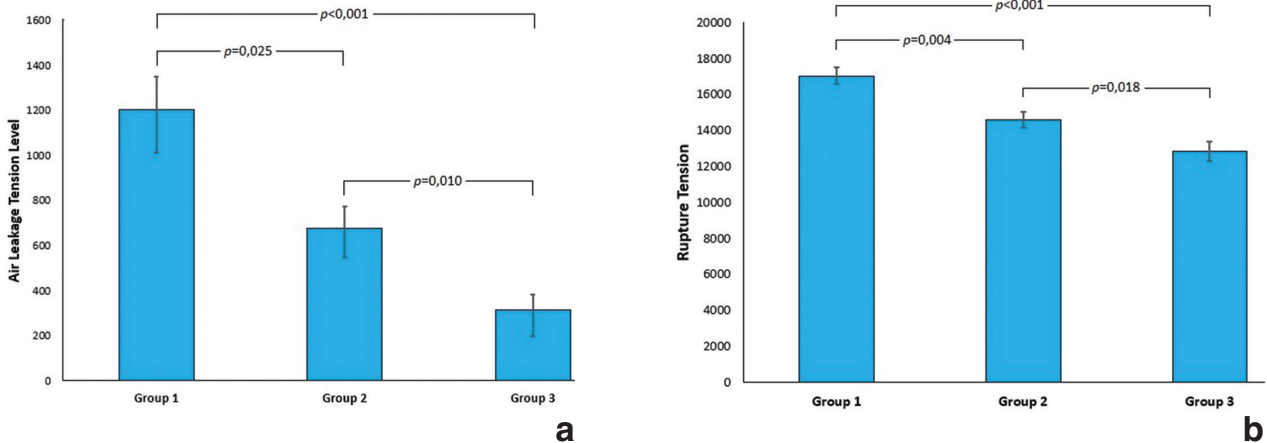
After air leakage was shown in all materials, hanging on to the thread with increasingly intensity was continued. The tension value when the anastomosis suture or sutures broke off was recorded as “rupture tension.”

Data were evaluated in IBM SPSS Statistics 25.0 (IBM, Armonk, NY, USA) statistical package program. As the distribution of the tension levels was very wide, logarithmic transformations of the data of these variables were made and statistical analyses were performed. Descriptive statistics were given as the number of units (n), percent (%), geometric mean (GM), and 95% confidence interval for GM. The normal distribution of the data of tension levels was evaluated by Shapiro–Wilk normality test and Q–Q plots. Comparisons between groups were performed by one-way analysis of variance.

**Table 1** Statistical comparison of the geometric means of the data obtained by logarithmic transformation of the raw data recorded for air leakage tension level and rupture tension among the groups

	Group 1 GM (95% CI for GM)	Group 2 GM (95% CI for GM)	Group 3 GM (95% CI for GM)	p
Air Leakage Tension Level (grams-force)	1203.4 (915.9–1581.1) <sup>a</sup>	676.3 (488.3–936.8) <sup>b</sup>	312.4 (179.9–542.7) <sup>c</sup>	<0.001
Rupture Tension (grams-force)	17032.2 (16120.2–17995.8) <sup>a</sup>	14594.8 (13754.8–15486.1) <sup>b</sup>	12852.1 (11806.5–13990.2) <sup>c</sup>	<0.001

The upper, a, b, c symbols show the differences among the groups. \*Cases with “70 mbar air leakage” (+), were not included in the calculation. CI: confidence interval; GM: geometric mean



**Fig. 4** The graphic that demonstrates the comparison of air leakage tension values (a) and rupture tension levels (b) between the groups separately.

Tukey Honest Significant Difference (HSD) test was used as multiple comparison tests.  $p < 0.05$  was considered statistically significant.

## Results

Considering the results obtained only with intraluminal pressure without any tension, no air leakage was observed at 25 mbar intraluminal pressure.

While “70 mbar air leakage” was not observed in Group 1, it was 20% ( $n = 3$ ) in Group 2 and 46.7% in Group 3 ( $n = 7$ ). No statistically significant difference was found among all of the groups ( $p = 0.08$ ). There was also no significant difference between Groups 1 to 2 ( $p = 0.224$ ), Groups 2 to 3 ( $p = 0.245$ ), or Groups 1 to 3 ( $p = 0.06$ ).

When the tension values were considered, significant differences were observed among the groups in terms of air leakage tension and rupture tension levels ( $p < 0.001$ ) (Table 1).

When the air leakage tension values compared between the groups, respectively, Group 1 was superior to 2 ( $p = 0.025$ ) and 3 ( $p < 0.001$ ). Group 2 was also superior to Group 3 ( $p = 0.01$ ) (Fig. 4a).

The rupture tension levels were also compared between the groups, respectively. Similarly, Group 1 was significantly superior to 2 ( $p = 0.004$ ) and 3 ( $p < 0.001$ ), Group 2 was superior to 3 ( $p = 0.018$ ) (Fig. 4b).

## Discussion

Dehiscence of an anastomosis after tracheal resection and reconstruction is a mortal complication. Although it is quite rare (4%–14.2%), over-tension on an anastomosis may cause dehiscence.<sup>5,11</sup> For this reason, some methods are used. Performing dissections of surrounding tissues to release trachea is one of them. And applying chin suture to provide hyperflexion of the neck is another method.<sup>2,13</sup>

One of the most important factors in this respect is tension on the anastomosis. Despite established mobilization, residual tension on the anastomosis may remain. Another important factor is high intraluminal pressure. In the postoperative period, prolonged ventilator dependence of the patient increases the risk. A pressure challenge during coughing is also a problem. As well as coughing, vomiting, and retching also change the intraluminal pressure.

In our experimental study, we first tested all anastomosis under normal intraluminal pressure (25 mbar) without tension. Air leakage was not observed in any anastomosis test results. It was demonstrated that anastomoses were properly performed. Therefore, in our study, there is no doubt that surgeon-related stitching failure may affect the results.

Then, the effects of high intraluminal pressure (70 mbar) without tension on the anastomoses were evaluated. Although the best results were in single-stitch group (none of the cases had air leakage), the difference was not statistically significant. Moreover, subgroup analysis also did not show any difference between groups. These results showed that the suture technique in anastomoses without tension was not important on the results.

However, in the case of anastomosis tension with high intraluminal pressure, our study revealed that single-stitch technique was significantly superior to the others. Again, superiority of mixed technique to continuous suture technique has been revealed clearly.

End-to-end anastomoses are usually secondary to tracheal resection, so performing under tension surely. For example, 1500 grams-force tensile stress is equal to a tracheal resection with 7 cm length.<sup>14)</sup> Besides the anastomosis tension, because postoperative cough or mechanical ventilator monitoring is frequently associated with tracheal resections, a tracheal surgery without increased intraluminal pressure is unthinkable. Therefore, the high intraluminal pressure and high anastomosis tension we have examined in this study are not rare cases and are the routine problems of daily practice. Therefore, we believe in the importance of using single-stitch technique in all conditions.

In order to confirm this idea, we also considered it appropriate to evaluate the rupture tension values. In one study, the mean tensile strength for rupture of sheep trachea anastomoses was 108 Newtons.<sup>9)</sup> This value range is between 51 and 179.9 Newtons in various human cadaver studies.<sup>4,5,15)</sup> Bicer et al., in sheep, they found the rupture tension as 171.9 Newtons.<sup>16)</sup> In this study, the GM of our

cases was 17032.2 grams-force (167.03 Newtons), 14594.8 grams-force (143.13 Newtons), and 12852.1 grams-force (126.04 Newtons) for Groups 1, 2, and 3, respectively. From this perspective, our study data are consistent with the literature.

Also, when the rupture tension is compared among the groups, single-stitch technique was significantly superior to the others and mixed technique was superior to continuous suture technique. These results are the same as the air leakage tension level results. This parallelism confirms our conclusion from the previous result again. So, it is the safest one to do anastomosis with single-stitch technique in each case.

These results can be explained by a simple rule of physics. When roughly stated, if the force required to combine both tracheal ends is “F,” the force per node is “F/number of knots in anastomosis.” The suture technique, which has the maximum number of knots along the line of anastomosis, is the single-stitch technique and then the mixed technique. There is only one knot in the continuous suture. In other words, the most load per node for combining tracheal ends is in continuous technique while the least load is in single-stitch technique. Therefore, according to the results of our study, while the load we have defined as “F” is zero (while any tension force had not applied yet), no significant difference was found among the suture techniques. However, while there was tension on anastomoses, the single-stitch technique was found to be superior. In contrast to this experimental model, in real life, it is emerging that applying the single-stitch technique is more important, when we consider that it is not possible to complete anastomosis with zero tension.

The same conclusion (suture technique is not important when there is no tension on an anastomosis; however, using the single-stitch technique is significantly superior to the other techniques in case of tensile stress) has also reported by Kirschbaum et al.<sup>12)</sup> However, in their study, constant tension stresses were created with standard weights and air leakage percentages of materials were examined. But in our study unlike that article, the tension was increased until air leakage displayed in all materials and the similar result was achieved by evaluating tensile stress levels at the time of air leakage. In addition, our study has not only examine the anastomoses in terms of air leakage but also has confirmed the result obtained by comparing the rupture tension levels.

When we examine some of the previous animal experiments on the subject in the literature, although there are

some results in contradiction with the results of our study,<sup>17)</sup> most of them have been demonstrating resemble conclusion to this study.<sup>9,18,19)</sup> In the last two studies, although there was no difference between the various suture techniques, the results were consistent with our study because the anastomoses were not performed under tension. Because in our study, it was also concluded that suture technique is not important when there is no tension on an anastomosis. This situation makes clear the importance of working on models which both the intraluminal pressure and tension stress are combined when a study designs on this subject in the future. For these reasons, we investigated the most appropriate suture technique in a tracheal anastomosis with relationship suture tension, air leakage, intraluminal pressure, and rupture tension.

## Conclusion

In conclusion, for a tracheal anastomosis, the most reliable and most advantageous technique is single-stitch technique.

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## Disclosure Statement

Hasan Ersöz has no conflict of interest.

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