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Effect of age on resistance to distraction after tracheal anastomoses with two suture patterns in cats

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Abstract

Objectives The aim of the study was to assess the effect of age on the ability of tracheal anastomoses in 24 feline cadaveric tracheae that were performed with two suture patterns to sustain distraction.

Methods Tracheae were obtained from 16 immature and eight adult cats and were divided into three groups. Each trachea underwent end-to-end annular ligament anastomosis using a simple continuous pattern with a 4/0 polypropylene suture on a round-body needle. In one immature group, three additional simple interrupted tension-relieving sutures were placed. The samples were tested with a tensiometer set at a drop head speed of 50 mm/min, and failure during distraction was defined by tissue pull-through or suture material failure. The force and elongation at failure were compared among groups.

Results Tracheal anastomoses in immature cats failed at lower mean forces (11.49 ± 1.30 N) compared with those with tension-relieving sutures and with adult cats (19.74 ± 4.55 N and 18.02 ± 1.28 N, respectively) ($P<0.001$). Tracheae from both immature groups sustained greater mean elongation (46.60 ± 0.06% and 46.53 ± 0.06%) compared with those from the adult group (33.85 ± 0.11%) ($P=0.017$ and 0.09, respectively).

Conclusions and relevance Tracheal anastomoses with tension-relieving sutures in immature cats and anastomoses in adult cats showed greater resistance compared with immature cats without tension-relieving sutures. Tracheae from immature cats showed greater elasticity compared with adult cats. Immature cats may resist longer tracheal resection than adult cats, but reinforcement techniques are necessary to improve resistance to tension.

Keywords: Trachea; anastomosis; distraction to failure; elongation

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Introduction

Tracheal resection and anastomosis (TRA) are seldom performed in cats.[1–3] In cats, indications for TRA include removing tracheal masses, repairing tracheal ruptures or avulsions, and correcting tracheal stenoses.[2–4] Tracheal resections and anastomoses have been documented in both immature and adult cats.[3,5–8] The surgical goal is to achieve a precise apposition of the tracheal ends with minimal tension at the anastomosis site, thereby promoting rapid healing and a low complication rate.[4,9] The extent of tracheal resection depends on the lesion's location and the animal's age.[9] Extensive resections may

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increase the risk of anastomotic failure and stenosis.[10] The safe amount of trachea to resect in cats is not well established. Resections of up to 30% are recommended, allowing removal of five to ten rings. [1–3,11–13] In a recent ex vivo study, the impact of age on the ability of tracheal anastomoses to withstand distraction was examined; in immature dogs, the anastomoses failed at lower forces but exhibited greater elongation than in adult dogs.[14] Reinforcement techniques, such as horizontal mattress sutures placed away from the anastomosis, are necessary to enhance resistance to tension.[15,16]

The objective of the present study was to investigate the effect of age on resistance to distraction after tracheal anastomoses with two suture patterns in cats. We hypothesised that tracheal anastomosis in immature cats might require less distraction force and longer elongation to create failure compared with adult cats, and that tracheal anastomosis reinforced with tension sutures in immature cats might require similar distraction force to create failure compared with adult cats.

Materials and methods

The graduate programme coordinating committee of the School of Veterinary Medicine approved the study and supervised its implementation on client-owned cats, ensuring that informed consent was obtained from their owners. Breeds of cats prone to brachycephalic obstructive airway syndrome, such as Persian, Himalayan, Exotic Shorthair, Scottish Fold and Burmese cats, were excluded from the study.[17,18] Study groups were formed based on the cats' age as recorded in medical records. Respiratory status was considered normal based on history, clinical examination and thoracic imaging.

Whole tracheae were collected after humane euthanasia for reasons unrelated to respiratory disease. All soft tissue attachments to the tracheae were excised, and samples were frozen at –20°C for 30 days. They were defrosted by submerging them in 0.9% sodium chloride at 7 °C for 20 mins. The length of the specimens obtained from the immature cats was 10 cm, while for the adults it was 12 cm. The study consisted of three groups, each consisting of eight specimens: the adult cat tracheae group (AT), the immature cat tracheae group (IT) and the immature cat tension tracheae group (ITT). Each one of the specimens was divided in the middle by incising the annular ligament, and an end-to-end anastomosis was performed, using a 4/0 polypropylene suture armed with a round body needle in a simple continuous pattern. The annular ligament-cartilage technique was applied by including the tracheal rings adjacent to the incision.[19] Each suture bite was placed 3 mm apart, and both starting and ending knots were extraluminal and comprised six square throws. For the ITT group, three tension-relieving mattress sutures spaced equally apart were additionally placed under tension by encircling the cartilage of the tracheal ring, two rings away, both proximally and distally to the anastomosis. Their knots were tied outside the tracheal lumen using the same type and size of suture material composed of five square throws. All anastomoses were conducted by the same clinician (LGP).

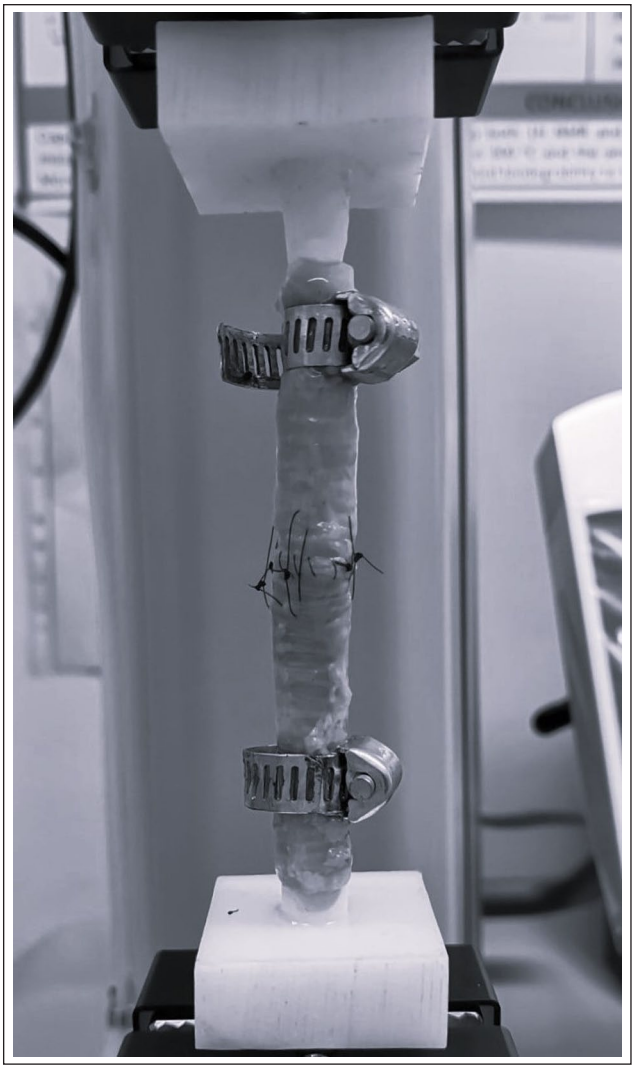


Figure 1 Construct of an immature cat with end-to-end anastomosis accompanied by tension-relieving sutures prepared for biomechanical testing: the specimen is affixed to the tensiometer with properly sized plastic rods and secured at both ends using hose clamps

Tracheal specimens were attached to an EZ-LX Test Tensiometer (Shimadzu). They were mounted by inserting plastic rods of similar size, which were fastened at each end with hose clamps. The specimens were then stretched at a drop head speed of 50 mm/min until failure (Figure 1).[14] Failure was defined as total anastomosis disruption caused by suture material failure or tissue pull-through. If the constructs exhibited both types of failure, the primary failure mode was recorded as the failure mode. The maximum force to failure, measured in Newtons (N), and the elongation to failure, expressed as the percentage of permanent change in tracheal length

(initial length divided by length at failure multiplied by 100), were recorded. The segment's elongation to failure was timed from when force was applied until the segment failed.

Statistical analysis

A commercial program (SPSS Statistics 22 software; IBM) was used for the statistical and power analyses. Data normality was evaluated using hypothesis tests and the Shapiro–Wilk test. For the force to failure, data are presented as mean ± SD. One-way ANOVA was performed to compare the differences among groups, followed by Fisher's least significant difference post-hoc test. For the elongation to failure, data are expressed as mean ± SD. Statistical comparisons were conducted using the Kruskal–Wallis test, followed by Dunn's post-hoc test with Bonferroni correction. A P value of <0.05 was considered statistically significant. Power analysis indicated that a group size of eight individuals per group was a sufficient number to provide 90% power to detect differences at $P<0.05$.

Results

The sample size of the current study included 24 cadaveric tracheae: eight were harvested from adult cats aged 2–16 years, and 16 tracheae were harvested from immature cats aged 4–8 months. Regarding the breed of the cats, 22 were domestic shorthairs, while the remaining two were both adult domestic longhairs.

All end-to-end tracheal anastomoses were conducted employing a simple continuous suture pattern with the annular ligament-cartilage technique, while in the eight samples of the ITT group, three simple interrupted tension-relieving sutures were also placed. Overlapping or misalignment of tracheal segments was observed in one construct per group. Tracheal diameters were in the range of 0.4–0.6 cm in immature cats and 0.7–1 cm in adults. The tracheal constructs were mounted to the tensiometer by inserting plastic rods of 0.5 cm in diameter. Constructs from immature cats failed under lower mean distraction forces (11.49 ± 1.30 N) compared with those from adult cats and immature cats with the extra tension-relieving sutures (18.02 ± 1.28 N, 19.74 ± 4.55 N; $P<0.001$, respectively) (Table 1). The load-displacement curve of tracheal anastomoses in adult cats displayed a phase of increasing distraction force, followed by a decline and a plateau. The curve in immature cats with tension-relieving sutures (group ITT) showed one phase of linear increasing load, followed by a slight drop, a further increase, a drop in the distraction force phase and a third increase followed by a decline. The curve of immature cats (group IT) showed a linear increase followed by a drop, a slight increase followed by another drop and a third increase followed by a plateau in the distraction force phases. In all tests, the initial spike was recorded as the failure point (Figure 2). Tracheal anastomoses underwent

Table 1 Distraction force and elongation to failure of feline tracheal anastomoses

Group	Distraction force (N)	*P* value	Elongation (%)	*P* value
IT	11.49 ± 1.30	<0.001	46.60 (a)	0.017
ITT	19.74 ± 4.55		46.53 (b)	0.009
AT	18.02 ± 1.28		33.85 (c)	

Values are mean ± SD unless otherwise indicated. a = significantly different from c; b = significantly different from c
AT = adult tracheae; IT = immature tracheae; ITT = immature tracheae with tension-relieving sutures; N = Newtons

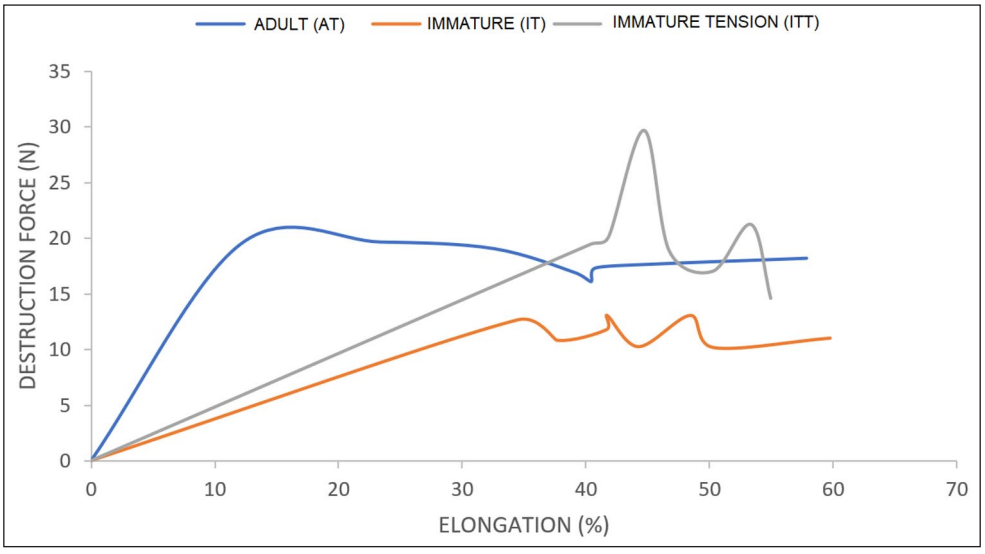


Figure 2 Representative load-displacement curves of tracheal anastomoses subjected to elongation testing. The initial spike was considered the failure mode. N = Newtons



Figure 3 Failure by rupture of the annular ligament in a tracheal anastomosis performed on an adult cat

longer elongation in both immature cat groups (IT 46.60% and ITT 46.53%) than in adult cats (AT 33.85%; $P=0.017$ and $P=0.009$, respectively) (Table 1). All constructs ultimately failed due to suture tearing through the annular ligament near the dorsal tracheal anastomosis ring and, before breaking, the annular ligament experienced initial stretching (Figure 3).

Discussion

In the present study, we found that tracheal anastomoses in immature cats failed under less distraction than those in adult cats and immature cats with added tension-relieving sutures. Tracheal anastomoses experienced greater elongation in both immature cat groups compared with adult cats.

Two primary techniques for end-to-end tracheal anastomosis are most frequently reported in the veterinary literature: the split cartilage technique and the annular ligament-cartilage technique.[19] The split cartilage technique provides more accurate anastomotic alignment and results in less dorsoventral stenosis compared with the annular ligament-cartilage technique.[19] In addition, due to the disparity in tracheal diameter after resection, this technique is generally preferred, as the annular ligament technique often causes segmental overlap.[14,16,19] However, these differences appear to have limited clinical relevance, as both techniques effectively restore tracheal function and any resulting stenosis rarely causes clinical signs.[15,19,20] In a recent clinical study involving eight dogs and 12 cats that underwent TRA using the annular ligament-cartilage technique, stenosis was observed in only two cats.[3] In the present study, we opted to perform the annular ligament-cartilage technique for the end-to-end tracheal anastomosis in cats because it was easier to perform and resulted in less segmental overlap and misalignment than the split cartilage technique, which can be much more technically demanding. Tracheal ring needle penetration during the split cartilage technique may also cause fracture or tear in older or immature cats, respectively.[3]

The choice of suture material is not viewed as a key factor in tracheal anastomotic outcomes or the development of stenosis, and selection depends on the surgeon's preference.[16,20] However, barbed sutures are generally not recommended for these procedures, and braided sutures should be avoided because they increase the risk of granuloma formation.[2,21] Conversely, monofilament non-absorbable sutures are frequently used in clinical and cadaveric canine studies.[14,16,22] In a recent study, absorbable or non-absorbable monofilament sutures were employed to perform end-to-end annular ligament-cartilage tracheal anastomosis in cats.[3] In addition, it is advisable for both the body and tip of the needle to be as minimally invasive and atraumatic as possible.[14] In our study, we used round needles to perform tracheal anastomosis in cats. The risk of fracture or tearing of the cartilages can be reduced with round needles if the split cartilage technique is applied in both older and younger patients.[14]

In theory, the continuous pattern may create a better distribution of suture tension across the anastomosis, reducing the likelihood of focal ischemia and producing a more effective air and watertight seal.[15,16,23] The simple continuous pattern has been used to close end-to-end anastomoses in clinical dogs, resulting in less precise tissue apposition and shorter operating time, along with statistically but not clinically significant stenosis compared with the simple interrupted pattern.[15] In a recent clinical study, a simple interrupted pattern was performed in 12 cats to complete tracheal anastomoses using an annular ligament-cartilage technique; only two cats showed stenosis.[3] Accurate tissue apposition was more difficult to

produce with the simple continuous pattern, and overriding, misalignment of tracheal segments was reported in two cadaveric studies in dogs.[14,16] In contrast, in our investigation, overlapping or misalignment of tracheal segments occurred less frequently than in the studies above.

Tension at the anastomotic site is a key factor limiting the success of tracheal anastomosis.[15] Extensive tracheal resections can lead to anastomotic distraction, healing through granulation tissue formation and luminal stenosis.[10] The tension at the anastomotic site varies depending on the number of tracheal rings removed and the percentage of tracheal elasticity.[10,24] The maximum limits for canine and feline tracheal resections have not been established.[3] Studies in dogs and humans suggest that no more than 50% of the tracheal length should be resected to prevent tension at the anastomotic site and abnormal healing.[25,26] In cats, tracheal resections of up to 30% are recommended.[1] Reports of extensive tracheal resections, with a range of three to ten rings, have been documented in cats.[2,12] In the largest retrospective study involving 12 cats, a median of three tracheal rings were resected, with only 17% developing stenosis.[3] Tension-relieving sutures in the trachea have been described, consisting of three simple interrupted sutures placed one or two tracheal rings away from the anastomosis, positioned ventrally and laterally at equal intervals.[15] These sutures are placed around or through the tracheal rings, sometimes in combination with small pledgets, or without them.[9] In cats, the preferred approach is to use tension-relieving sutures around the tracheal rings without pledgets.[9,27] In small animal surgery, the primary purpose of these sutures is to prevent anastomotic dehiscence, thereby reducing the risk of severe postoperative complications that could increase morbidity and mortality.[14–16] Basdani et al[22] used tension-relieving sutures to reinforce the anastomotic site in five dogs, from which only three to five tracheal rings had been removed. There is evidence to suggest that tension-relieving sutures are necessary for younger patients, such as puppies;[14,28] however, there is no supporting evidence for the same indications in immature cats. A recent ex vivo canine study showed that tracheal anastomoses failed at lower forces in immature dogs (44.91 ± 59.03 N) compared with adult dogs (149.31 ± 45.36 N).[14] In our study, we found that tracheal anastomoses in immature cats failed at lower forces than those in adult and immature cats with tension-relieving sutures. Our values in adult cats (18.02 ± 1.28 N), immature cats (11.49 ± 1.30 N) and immature cats with tension-relieving sutures (19.74 ± 4.55 N) were significantly lower than in dogs. It seems that the differences among species may account for this discrepancy between our tension measurement results and those observed in dogs.

Variations in tracheal preparation or storage may influence measurements, as many of these studies used live dogs, fresh cadaveric specimens or live tracheal tissue from sheep for tensiometry assessments.[20,23,28] However, fresh and frozen tracheal constructs showed no significant difference in maximum distraction force to failure.[14,16] In the present study, due to the extended time required for cadaveric trachea collection, we followed the same protocol and opted to freeze the tracheal specimens, conducting the testing after thawing at a later time.

The water content of immature canine tracheal anastomoses appears higher, and collagen content appears lower, than in adults, indicating greater fragility in tracheal anastomoses of immature dogs compared with adults.[10] Our findings suggest that immature cats may have more 'elastic' tracheae, allowing for greater elongation to accommodate longer tracheal resections than in adult cats. However, since the tracheae of immature cats also withstood lower distraction forces, anastomotic reinforcement is recommended. These results align with those of Brisimi et al,[14] in which immature and adult dogs showed responses similar to those of immature and adult cats in our study, respectively. The failure of our constructs through rupture of the annular ligament agrees with the findings of Demetriou et al[16] and may be due to the inherently lower tensile strength of ligamentous tissue compared with cartilage.

In the study presented here, the inherent variability of all tracheal anastomoses led to distraction force failures occurring at different sites within the tracheal tissue. In adult cats, the distraction force to failure occurred after the spike appeared, followed by a plateau. In immature cats, a plateau was observed after the third spike. No plateau was seen in immature cats with tension-relieving sutures after the second spike. Conversely, in the experimental study by Brisimi et al,[14] both adult and immature dogs exhibited a plateau and two spikes in distraction force. The presence of multiple spikes in the force-elongation curves reflects the different structural properties of the constructs.

Several limitations exist in this study. Many were attributed to its experimental nature, as it was conducted ex vivo under laboratory conditions. Therefore, the results should be interpreted cautiously and are not directly applicable to biological processes in live cats. In addition, only normal tracheal samples were used; assessing tensile strength in diseased tracheae might have yielded different results. Freezing feline tracheal samples could impact the study results, highlighting the need to repeat this study with fresh tissues to confirm the findings. The traction force was applied with a specialised tensiometer, maintaining a constant velocity and a parallel axis to the tissue. However, in vivo traction forces and angles can vary greatly, making it challenging

to accurately simulate these conditions. Measuring the dry weight of specimens after testing could have provided an estimate of water content, giving a biomechanical explanation for the observed differences. Finally, the degree of luminal stenosis before tensile testing, after anastomosis, was not evaluated.

Conclusions

Healthy cadaveric tracheal anastomoses from immature cats required less distraction force to create failure compared with those from adult cats and immature cats with extra tension-relieving sutures. Tracheal anastomoses in immature cats and tension-relieved immature cats showed longer elongation than in adult cats.

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical approval The work described in this manuscript involved the use of non-experimental (owned or unowned) animals. Established internationally recognised high standards ('best practice') of veterinary clinical care for the individual patient were always followed and/or this work involved the use of cadavers. Ethical approval from a committee was therefore not specifically required for publication in *JFMS*. Although not required, where ethical approval was still obtained, it is stated in the manuscript.

Informed consent Informed consent (verbal or written) was obtained from the owner of all animal(s) described in this work (experimental or non-experimental animals, including cadavers, tissues and samples) for all procedure(s) undertaken (prospective or retrospective studies). No animals or people are identifiable within this publication, and therefore additional informed consent for publication was not required.

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