

Mechanical properties of various suture materials and placement patterns tested with surrogate in vitro model constructs simulating laryngeal advancement tie-forward procedures in horses

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Objective—To compare the mechanical properties of laryngeal tie-forward (LTF) surrogate constructs prepared with steel fixtures and No. 5 braided polyester or braided polyethylene by use of a standard or a modified suture placement technique.

Sample—32 LTF surrogate constructs.

Procedures—Surrogate constructs were prepared with steel fixtures and sutures (polyester or polyethylene) by use of a standard or modified suture placement technique. Constructs underwent single-load-to-failure testing. Maximal load at failure, elongation at failure, stiffness, and suture breakage sites were compared among constructs prepared with polyester sutures by means of the standard (n = 10) or modified (10) technique and those prepared with polyethylene sutures with the standard (6) or modified (6) technique.

Results—Polyethylene suture constructs had higher stiffness, higher load at failure, and lower elongation at failure than did polyester suture constructs. Constructs prepared with the modified technique had higher load at failure than did those prepared with the standard technique for both suture materials. All sutures broke at the knot in constructs prepared with the standard technique. Sutures broke at a location away from the knot in 13 of 16 constructs prepared with the modified technique (3 such constructs with polyethylene sutures broke at the knot).

Conclusions and Clinical Relevance—Results suggested LTF surrogate constructs prepared with polyethylene sutures or the modified technique were stronger than those prepared with polyester sutures or the standard technique. (*Am J Vet Res* 2014;75:500–506)

Intermittent DDSP is the most common cause of upper respiratory tract obstruction in racehorses, affecting 10% to 20% of Thoroughbreds and Standardbreds.^{1,2} The etiopathogenesis of DDSP is not fully understood; therefore, there are numerous treatments used for the management of this condition.³ Conservative treatments include rest, systemic and local administration of anti-inflammatory medications, changes in tack, and the use of a tongue-tie.^{3,4} These nonsurgical treatment options have success rates of 53% to 61%.⁴ A throat-support device has been developed to mimic the effect of an LTF procedure (ie, surgical advancement of the

ABBREVIATIONS	
DDSP	Dorsal displacement of the soft palate
LTF	Laryngeal tie-forward

larynx in a cranial direction)⁵; however, no reports have been published regarding the success of that device for restoration of racing performance in horses with DDSP, to the authors' knowledge. The surgical procedures advocated for prevention or treatment of DDSP include staphylectomy, sternothyrohyoideus myectomy, sternothyroideus tenotomy, ventriculectomy, tension palatoplasty, epiglottal augmentation, and thermocautery of the soft palate.^{3,4} These surgical procedures have reported success rates of 35% to 70% for improvement or restoration of racing performance or capacity.⁶

Dysfunction of the thyrohyoideus muscles during exercise has been implicated in the pathophysiology of DDSP in horses.⁷ Experimental bilateral resection of the thyrohyoideus muscles in healthy horses induces intermittent DDSP during exercise.⁷ Replacement of the action of the thyrohyoideus muscles with prosthetic sutures by means of an LTF procedure restores naso-

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pharyngeal stability in such horses during exercise.⁷ During that surgical procedure, the larynx is anchored in a more rostral and dorsal position to the basihyoid bone relative to its original position; paired sutures are placed between the thyroid cartilage of the larynx and the basihyoid bone along the orientation of the thyrohyoideus muscles.^{7,8} The specific mechanism by which the thyrohyoideus muscles prevent intermittent DDSP has not been determined, to the authors' knowledge. The LTF procedure may mimic the action of the thyrohyoideus muscles and prevent ventral and caudal movement of the larynx and DDSP.⁸ The LTF procedure has a success rate of approximately 80% for restoration of airway function and nasopharyngeal stability in horses with intermittent DDSP.^{8,9}

Despite widespread clinical use of the LTF procedure, no studies have been performed regarding the mechanical strength of LTF constructs. Given that the implanted sutures must withstand high mechanical forces, the LTF procedure is typically performed with No. 5 braided polyethylene sutures coated with polyester⁸ or No. 5 braided polyester sutures coated with polybutylate.⁷ Evaluation of mechanical characteristics of LTF constructs with various suture materials may help improve the procedure and assist surgeons in the selection of biomechanically suitable suture material.

Although suture failure after LTF procedures is rare,^{8,9} it is our experience that braided polyester sutures coated with polybutylate can break during the immediate postoperative period as a result of suddenly applied high loads during recovery from anesthesia, leading to LTF failure and the need for revision surgery. However, suture material may not be the weakest material in LTF constructs; failure can occur as a result of suture pullout from the thyroid cartilage.¹⁰⁻¹² Consequently, the LTF surgical technique has been modified to increase the strength of the surgical constructs and decrease surgical failure.⁵ Moreover, another modification of the LTF surgical technique has been described¹⁰ in which metallic implants are used to increase resistance to pullout of suture from the thyroid cartilage.

An objective of the study reported here was to determine the mechanical properties and breakage sites of 2 types of sutures (No. 5 braided polyethylene sutures coated with polyester and No. 5 braided polyester sutures coated with polybutylate) in LTF surrogate constructs tested in single loading to failure *in vitro*; this was intended to simulate dynamic loading during anesthetic recovery in horses that have undergone LTF procedures. Another objective was to determine whether a modification of the standard LTF surgical technique would increase the tensile strength and change the breakage site of the LTF constructs for both suture materials evaluated. Non-biological LTF surrogates were used in the study to eliminate the effects of variability

in tissue characteristics and viscoelastic deformation of cartilage at suture anchoring sites. We hypothesized that no differences would be detected in the strength, elongation, stiffness, or suture breakage site between LTF constructs performed with the 2 types of sutures or between constructs prepared by use of the standard and modified techniques.

Materials and Methods

Samples—Measurements for the design of LTF surrogate constructs were determined during performance of LTF procedures in cadavers of 5 Standardbred racehorses (age range, 3 to 7 years) that were euthanized for reasons unrelated to upper respiratory tract problems. Cadavers were placed in dorsal recumbency immediately after euthanasia, and standard technique LTF procedures were performed by use of a technique described by Ducharme.⁴ Briefly, a No. 5 braided polyester suture coated with polybutylate was passed twice through the right lamina of the thyroid cartilage ventral to the insertion of the sternothyroideus muscle, and another suture was passed twice through the left lamina of the thyroid cartilage in a similar manner. Both free ends of the left and right sutures were passed in a cranial direction over the dorsal surface of the basihyoid bone by use of a wire passer. Then, the sutures were tied over the ventral aspect of the lingual process (Figure 1), ensuring that the rostral aspect of the thyroid cartilage was approximately 10 to 15 mm rostral to the caudal

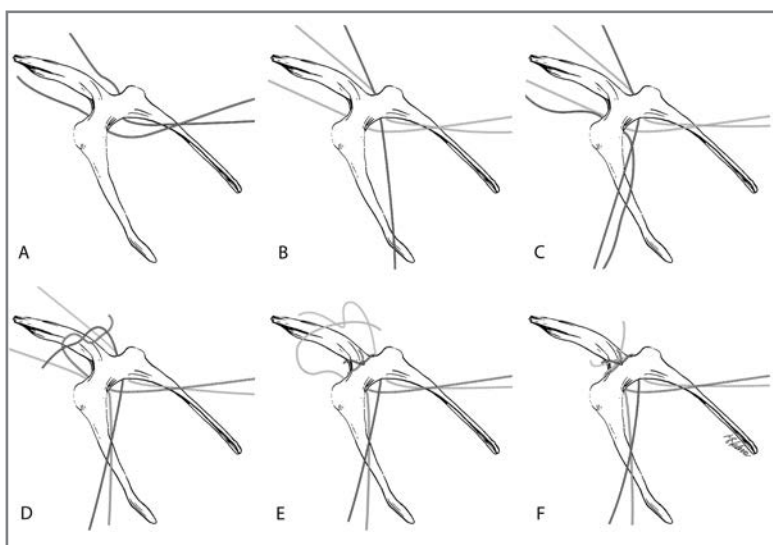


Figure 1—Illustrations depicting the suture configuration around the basihyoid bone used for performance of standard LTF procedures in cadavers of horses. After suture placement in the left and right aspects of the thyroid cartilage, the ends of the right suture (ie, the suture secured in the right aspect of the thyroid cartilage) were passed over the dorsal aspect of the basihyoid bone with the dorsal end (ie, the end secured in the dorsal aspect of the thyroid cartilage) of the suture exiting on the right side of the lingual process and the ventral end (ie, the end secured in the ventral aspect of the thyroid cartilage) of the suture exiting on the left side of the lingual process (A). Then, the ends of the left suture (ie, the suture secured in the left aspect of the thyroid cartilage) were passed over the dorsal aspect of the basihyoid bone with the dorsal end of the suture exiting on the left side of the lingual process and the ventral end of the suture exiting on the right side of the lingual process (B and C). The right ventral end of the suture was tied to the left ventral end of the suture over the ventral aspect of the lingual process (D), and the right dorsal end of the suture was tied to the left dorsal end of the suture over the ventral aspect of the lingual process (E). After the sutures were tied, both knots were positioned at the junction of the lingual process and the basihyoid bone (F).

border of the basihyoid bone.⁴ This distance has been recommended to move the larynx approximately 35 to 40 mm rostrally and 20 mm dorsally, which increases the probability of racing for horses after surgery.¹³

Modified technique LTF procedures were also performed in cadavers. During this technique, No. 5 braided polyester sutures coated with polybutylate were passed through the thyroid cartilage in the same manner as for the standard technique. Then, the dorsal end of the right suture and the ventral end of the left suture were passed in a cranial direction with a wire passer, ensuring that both sutures were placed over the dorsal surface of the basihyoid bone. The wire passer was replaced under the hyoid bone, and the sutures were inserted into the wire passer and retrieved cranially, forming a loop around the basihyoid bone. This procedure was repeated on the contralateral side. Then, the ventral end of the right suture was tied to the ventral end of the left suture, and the dorsal end of the right suture was tied to the dorsal end of the left suture over the ventral aspect of the junction of the basihyoid bone and lingual process (Figure 2).

Four measurements were obtained for each cadaver after performance of standard and modified LTF procedures. These measurements included the following: the distance between the caudal border of the basihyoid bone and the suture penetration site in the caudoventral portions of the right and left aspects of the thyroid cartilage, the distance between the suture penetration sites in the caudoventral aspects of the thyroid cartilage (length between the exit point of the dorsal ends of the sutures through the right and left aspects of the thyroid cartilage [approx 15 mm rostral to the caudal border of the cartilage]), the angle of the sutures relative to the long axis of the lingual process (measured at the inter-

section of a line parallel to the lingual process and another line parallel to the plane of the dorsal and ventral ends of the sutures at the level of the caudal border of the basihyoid bone), and the length of the suture loop (total length of the suture material used to create each LTF surrogate construct).

After completion of measurements, the hyoid apparatus of each horse was removed and the shape and circumference of the basihyoid bone and the base of the lingual process were determined (Figure 3). The mean circumferences of the basihyoid bone and base of the lingual process were 40 and 30 mm, respectively. These measurements were used to fabricate a custom steel fixture with dimensions that matched these measurements. This steel model basihyoid bone fixture was constructed by welding 2 pieces of mild (ie, low-carbon) steel together. The horizontal piece was 26 mm long and had a 6.3-mm horizontal measurement and a 12-mm vertical measurement. This piece was machined from a 26-mm-thick plate by means of electron discharge machining and then manually polished by hand. The vertical piece was built from a 7/16-inch, 20 threads/inch threaded rod (for connection to the load frame) that was machined with a lathe to a 9.5-mm diameter. Before testing, sharp edges and welding slag on the steel model basihyoid bone fixture were removed by grinding and sanding by hand (Figure 4).

Sample sizes were calculated for test groups. Sample sizes for each tested group of constructs were determined on the basis of assumptions of $\alpha = 0.05$, power = 90%, an expected difference in load at failure of 100 N between constructs prepared with polyethylene sutures and those prepared with polyester sutures, a load at failure SD of 60 N for constructs prepared with polyethylene sutures, and a load at failure SD of 30 N for constructs prepared with polyester sutures.

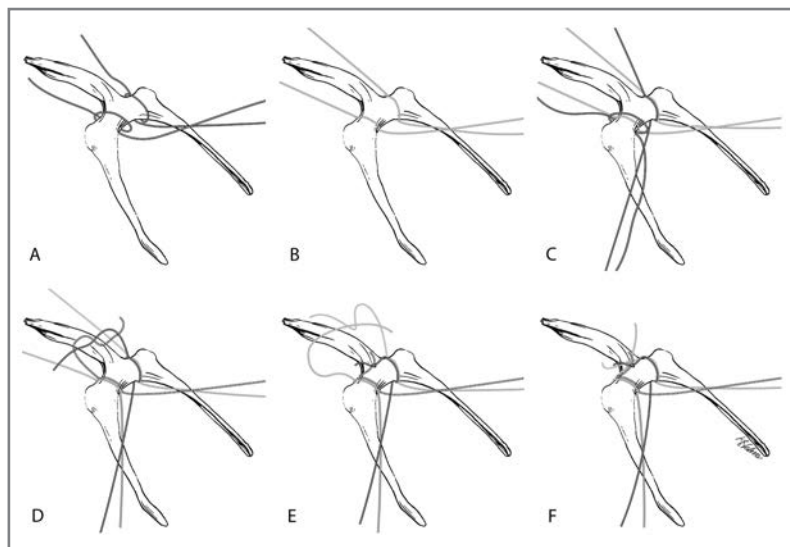


Figure 2—Illustrations depicting the suture configuration around the basihyoid bone used for performance of modified LTF procedures in cadavers of horses. The ends of the right suture were passed over the dorsal aspect of the basihyoid bone, the dorsal end was wrapped once around the basihyoid bone on the right side of the lingual process, and the ventral end was wrapped once around the basihyoid bone on the left side of the lingual process (A and B). That same procedure was performed with the left suture (C). The ventral end of the right suture was tied to the ventral end of the left suture over the ventral aspect of the lingual process (D), and the dorsal end of the right suture was tied to the dorsal end of the left suture over the ventral aspect of the lingual process (E). After the sutures were tied, both knots were positioned at the junction of the lingual process and the basihyoid bone (F).

LTF surrogate constructs—Thirty-two LTF surrogate constructs were prepared with No. 5 braided polyethylene covered with polyester (polyethylene suture)^a or No. 5 braided polyester coated with polybutylate (polyester suture)^b; all constructs were prepared by the same investigator (MPS). The sutures were looped between a 0.25-inch Steinmann pin and the custom steel model basihyoid bone fixture mounted in a servohydraulic material testing machine with a 4.5-kN load cell attached to the crosshead.^c A 0.25-inch Steinmann pin was used to secure suture loops because a pin of that diameter fit into the distractive portion of the material testing machine and it was unlikely to break during testing. The sutures were oriented to simulate the orientations of prostheses placed in horses during LTF procedures. Sutures were tied with a square knot followed by 4 single throws. The mean angle (40°) at which the sutures were oriented relative to the long axis of the steel fixture was similar to that determined during performance of LTF procedures in cadavers of horses.

Each construct was assigned by use of a randomization procedure to a surgical technique and suture material. For constructs prepared by use of the standard LTF technique with polyester sutures ($n = 10$), 2 No. 5 polyester sutures were wrapped clockwise twice around the Steinmann pin (1 on each side of the pin), the free ends of the left and right sutures were passed under the transverse portion of the steel model basihyoid bone fixture to exit on the contralateral side of the vertical portion of the fixture, and the ends were tied together over the junction of the vertical and horizontal portions of the fixture. The ends of the right and left sutures attached to the needles were passed under the transverse portion of the fixture to exit on the same side of the vertical portion of the fixture and were tied together over the junction of the vertical and horizontal portions of the fixture (Figure 5).

For constructs performed by use of the standard LTF technique with polyethylene sutures ($n = 6$), 2 No. 5 polyethylene sutures were wrapped clockwise twice around the Steinmann pin (1 on each side of the pin), the free ends of the left and right sutures were passed under the transverse portion of the steel model basihyoid bone fixture to exit on the contralateral side of the vertical portion of the fixture, and the ends were tied together over the junction of the vertical and horizontal portions of the fixture. The ends of the left and right sutures attached to the needles were passed under the transverse portion of the fixture to exit on the same side of the vertical portion of the fixture and then tied together over the junction of the vertical and horizontal portions of the fixture.

For constructs prepared by use of the modified LTF technique with polyester sutures ($n = 10$), 2 No. 5 polyester sutures were wrapped clockwise twice around the Steinmann pin (1 on each side of the pin), the free ends of the left and right sutures were passed under the transverse portion of the steel model basihyoid bone

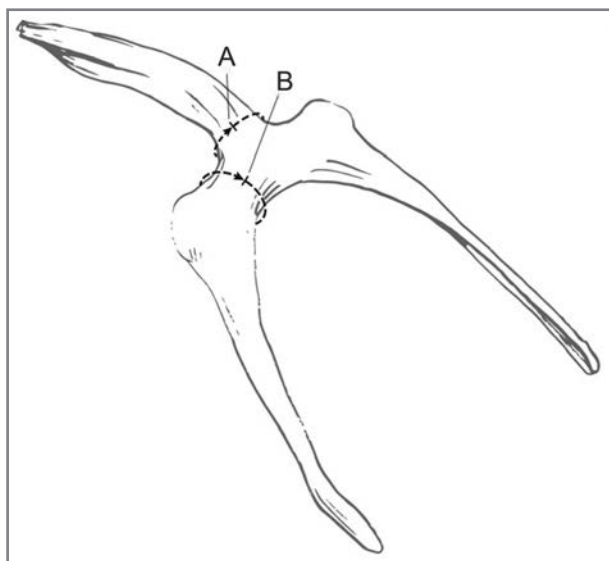


Figure 3—Illustration depicting the basihyoid bone of a horse indicating the locations of measurements of the shape and circumference of the lingual process (A) and the portion of the bone immediately adjacent to the lingual process (B) determined for preparation of a steel model fixture for *in vitro* simulation and mechanical testing of LTF surrogate constructs.

fixture on the opposite side, and those sutures were wrapped counterclockwise once around the transverse portion of the fixture and then tied together over the junction of the vertical and horizontal portions of the fixture. The ends of the right and left sutures attached to the needles were passed under the transverse portion of the fixture on the same side, wrapped counterclockwise once around the transverse portion of the fixture, and tied together over the junction of the vertical and horizontal portions of the fixture (Figure 4).

For constructs prepared by use of the modified LTF technique with polyethylene sutures ($n = 6$), 2 No. 5 polyethylene sutures were wrapped clockwise twice around the Steinmann pin (1 on each side of the pin), the free ends of the left and right sutures were passed under the transverse portion of the steel model basihyoid bone fixture on the opposite side, and those sutures were wrapped counterclockwise once around the transverse portion of the fixture and then tied together over the junction of the vertical and horizontal portions of the fixture. The ends of the left and right sutures attached to the needles were passed under the transverse portion of the fixture on the same side, wrapped counterclockwise once around the transverse portion of the fixture, and tied together over the junction of the vertical and horizontal portions of the fixture.

For all constructs, the distance between the Steinmann pin and the steel fixture was 70 mm, which was similar to the measured distance between the basihyoid bone and the anchoring point of the sutures in the thyroid cartilage in cadavers. This distance resulted in a closed suture loop that had an approximate circumference of 460 to 470 mm for the standard surgical technique and 600 mm for the modified surgical technique with 2 equidistant square knots. The 460-mm-circumference loop was



Figure 4—Photograph of an equine basihyoid bone and a custom-made steel model basihyoid bone fixture. Notice that the short transverse bar of the model fixture is oval, whereas the base of the lingual process in the basihyoid bone is round. The horizontal portion of the fixture had a 26-mm-long oval cross-section and was 6.3 mm in diameter horizontally and 12 mm in diameter vertically. The width of the horizontal portion of the steel model basihyoid bone fixture was identical to the distance between right and left basihyoid-ceratothyoid bone articulations in an equine cadaver examined during design of the fixture.

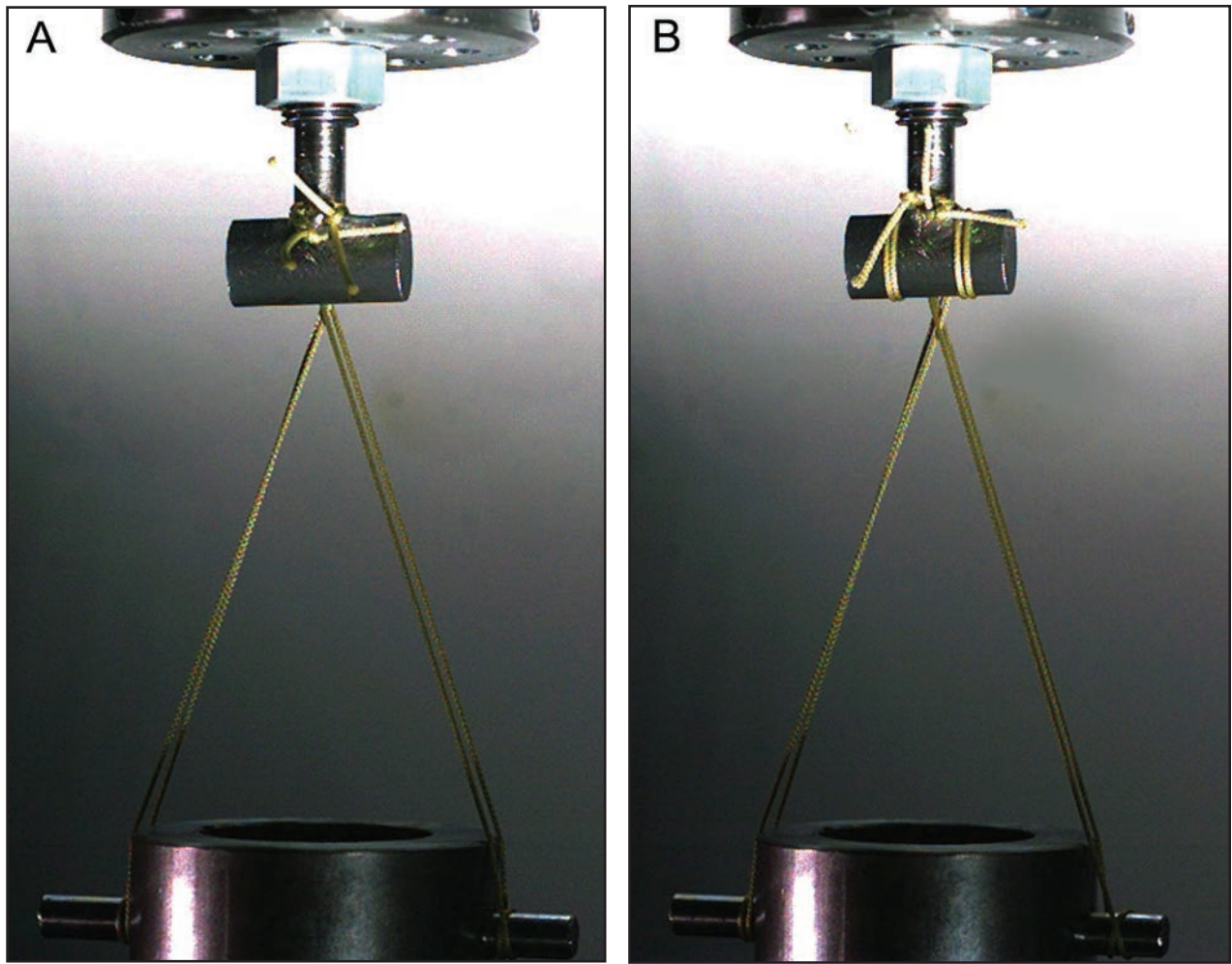


Figure 5—Photograph of representative LTF surrogate constructs prepared by use of a standard (A) or modified (B) technique. For constructs prepared by use of the standard procedure (A), sutures were wrapped around the Steinmann pin of the testing apparatus, the free ends of the sutures were passed to the contralateral sides of the vertical portion of the steel model basihyoid bone fixture, and the ends were tied; the suture ends attached to the needles of the sutures were passed under the ipsilateral sides of the vertical portion of the fixture and tied. For constructs prepared by use of a modified technique (B), sutures were wrapped around the Steinmann pin, the free ends of the sutures were wrapped around the contralateral sides of the horizontal portion of the steel model basihyoid bone fixture, and the ends were tied; the suture ends attached to the needles were wrapped around the ipsilateral sides of the horizontal portion of the fixture and tied.

similar to the circumference of the suture loop created during LTF procedures performed in cadaver horses. The distance between the sutures where they were wrapped around the Steinmann pin was 51 mm, which was similar to the distance between the anchoring suture sites of sutures in the thyroid cartilage in cadavers.

Mechanical testing—Sutures were pretensioned to 10 N and then subjected to a single cycle load to failure, with the load frame operating in the position control setting at a rate of 5 mm/s. Constructs were recorded with a high-speed digital video camera^d during testing to identify the suture breakage sites. For each trial, the maximal load (in Newtons) and elongation (in millimeters) at failure were recorded and used for determination of mechanical properties. Stiffness (in N/mm) was calculated as the slope of the line of best fit through the linear (ie, elastic) portion of the force-versus-elongation curve. The suture breakage site was defined as occurring at the knot or away from the knot. Suture

breakage sites were determined by inspection of sutures and evaluation of video recordings after each trial.

Statistical analysis—The Shapiro-Wilk test was used to verify that load, elongation, and stiffness had normal distributions. To identify significant differences between suture types and surgical techniques, ANOVA was performed by use of a variance components mixed-model analysis. For each variable, the Tukey honestly significant difference test for pairwise comparisons was performed following ANOVA. Pearson correlation coefficients (r) were also calculated to assess the relationship between load and elongation at failure for both suture materials tested. Continuous data are reported as mean \pm SD. Commercially available statistical software^e was used for data analyses. Values of $P < 0.05$ were considered significant.

Results

The maximal load at failure was significantly higher for LTF surrogate constructs prepared with polyeth-

ylene sutures than it was for such constructs prepared with polyester sutures for both standard ($P < 0.001$) and modified ($P < 0.001$) techniques (Table 1). Stiffness was significantly higher for constructs prepared with polyethylene sutures than it was for constructs prepared with polyester sutures for both standard ($P < 0.001$) and modified ($P < 0.001$) techniques. The maximal elongation at failure was significantly lower for constructs prepared with polyethylene sutures than it was for constructs prepared with polyester sutures for the standard ($P < 0.001$) technique. Constructs prepared with polyester sutures by use of the modified technique had significantly higher maximal load ($P = 0.035$) and elongation ($P < 0.001$) at failure than constructs prepared with polyester sutures by use of the standard technique. Constructs prepared with polyethylene sutures by use of the modified technique had significantly higher stiffness ($P < 0.001$) and maximal load ($P < 0.001$) and elongation ($P < 0.001$) at failure versus constructs prepared with polyethylene sutures by use of the standard technique. Load and elongation at failure had a significant ($P < 0.001$) positive correlation ($r = 0.842$) for constructs prepared with polyester sutures. Load and elongation at failure had a significant ($P = 0.040$) negative correlation ($r = -0.599$) for constructs prepared with polyethylene sutures.

All 10 constructs prepared with polyester sutures by use of the standard technique failed at one of the knots, whereas all 10 constructs prepared with such sutures by use of the modified technique failed at locations away from the knot. All 6 constructs prepared with polyethylene sutures by use of the standard technique broke at the knot, whereas 3 of 6 constructs prepared with polyethylene sutures by use of the modified technique broke at a location away from the knot and 3 of such constructs broke at the knot.

Table 1—Mean \pm SD values of mechanical variables for LTF surrogate constructs prepared with polyester sutures by use of standard (ST-PES; $n = 10$) or modified (MT-PES; 10) techniques and constructs prepared with polyethylene sutures by use of standard (ST-PET; 6) or modified (MT-PET; 6) techniques.

	Construct			
	ST-PES	MT-PES	ST-PET	MT-PET
Load at failure (N)	561 \pm 35	651 \pm 14*	1,182 \pm 113†	1,645 \pm 112‡
Elongation at failure (mm)	17.3 \pm 0.8	19.8 \pm 0.7§	12.0 \pm 1.6	16.1 \pm 1.9
Stiffness (N/mm)	31.3 \pm 1.7	31.2 \pm 1.0	95.4 \pm 19.6¶	116.7 \pm 16.6#

*Value is significantly ($P < 0.05$) different from the value for the ST-PES group for load at failure. †Value is significantly ($P < 0.001$) different from the value for the ST-PES, MT-PES, and MT-PET groups for load at failure. ‡Value is significantly ($P < 0.001$) different from the values for the ST-PES, MT-PES, and ST-PET groups for load at failure. §Value is significantly ($P < 0.001$) different from the values for the ST-PES, ST-PET, and MT-PET groups for elongation at failure. ||Value is significantly ($P < 0.001$) different from the values for the ST-PES, MT-PES, and MT-PET groups for elongation at failure. ¶Value is significantly ($P < 0.001$) different from the value for the ST-PES, MT-PES, and MT-PET groups for stiffness. #Value is significantly ($P < 0.001$) different from the value for the ST-PES, MT-PES, and ST-PET groups for stiffness.

Discussion

Results of the present study indicated that, for both evaluated techniques, constructs prepared with polyethylene sutures were stronger and stiffer and had less elongation than constructs prepared with polyester sutures prior to failure. These results were not surprising because the breaking strength of the polyethylene suture is approximately 2.5 times that of the polyester suture of similar size.^{14,15} The polyethylene suture used in the present study had a longitudinal core of ultrahigh molecular weight polyethylene, which gives this suture material higher strength and resistance to elongation than other polyester suture materials.¹⁴ In addition, results of this study indicated a slight modification of the standard LTF suture placement pattern increased the breaking strength and stiffness of the surgical constructs, which may decrease surgical failure attributable to suture breakage at the knot. During tensile load, the knot is the weakest part of a suture loop because of the high shear stress that develops at the interface between the suture loop and the first throw of the knot.^{14,16} The modification of the configuration of the knotted suture loops used in this study may have decreased stress at the suture knot by means of frictional dissipation, which might prevent suture knot failure after surgery in horses that have undergone an LTF procedure. This modification consisted of wrapping the suture around the transverse portion of the steel model basihyoid bone fixture near the knot, which likely decreased the shear stress at the level of the knot and changed the site of breakage of the suture loops. This was likely attributable to dissipation of load by friction of the suture across the transverse portion of the fixture adjacent to the knot and broad distribution of tension across the long knotted suture loops. However, the modified LTF surgical technique should be evaluated in vivo to ensure that sutures wrapped around the basihyoid bone would not cause adverse clinical effects and that the benefits detected in this study would benefit horses that undergo LTF procedures. The modification of the standard LTF surgical technique was performed in cadavers of the present study; that technique was simple to perform.

Results of this study indicated the evaluated polyethylene suture had significantly less elongation than the polyester suture during monotonic tensile loading; such properties of the polyethylene suture may provide a more secure and rostral laryngeal position versus the polyester suture in horses that undergo LTF procedures. We believe that minimizing loop elongation should be an important consideration when choosing a suture material for LTF procedures because a more dorsal position of the larynx achieved with the procedure is associated with an increased chance of racing after surgery.⁹ Furthermore, load and elongation at failure had a negative correlation for constructs prepared with polyethylene sutures, indicating this suture material may withstand higher in vivo loads with less elongation than the polyester suture in horses that have undergone LTF procedures; such properties of the polyethylene suture may reduce caudal movement of the larynx after LTF surgery. However, one of the limitations of this study was that elongation was measured at failure after application of a single load. Therefore, we did not determine the amount of suture loop elongation that would develop in sutures during repeated or cyclic loading; such elongation would allow caudal movement of the

larynx in a horse after performance of an LTF procedure. However, considering the stiffness of both tested suture materials,¹⁷ it is reasonable to expect that the polyethylene suture material would have less elongation than the polyester suture material during physiologic cyclic loading in horses.

Results of the present study should be interpreted with consideration of factors important for horses with clinical DDSP treated by means of LTF procedures. In this study, constructs were tested during single load to failure conditions, simulating the load conditions of LTF prostheses in horses during recovery from anesthesia. Determination of the mechanical performance of LTF constructs during cyclic loading would more accurately represent the stress on LTFs in horses during exercise. Accurate in vivo measurement of tension in LTF prostheses would be necessary to determine the clinical relevance of the results of the present study and to determine the appropriate loading variables for in vitro testing. Results of this study suggested that the tested polyethylene suture may have better mechanical performance than the tested polyester suture in horses with DDSP that undergo LTF procedures; however, the in vivo loads on sutures in horses that have undergone LTF procedures would likely be lower than the load at failure for both suture materials determined in this study. Therefore, without regard for differences in the biological reactivity of the tested sutures attributable to their material composition and braid characteristics,¹⁸ both suture materials might be sufficiently strong for LTF procedures in horses. In addition, the suture-holding capacities of the thyroid cartilage and basihyoid bone are important variables that may limit the overall strength of LTF constructs during tensile loading in horses.

An important consideration is that the methods used in the present study may not be applicable to mechanical variables in horses that have undergone LTF procedures. Therefore, the in vitro mechanical characteristics of the surrogate LTF constructs tested in this study may differ from those for LTF constructs in vivo. However, we considered that the surrogate constructs provided a consistent and objective model with which to determine the mechanical performance of suture materials and surgical techniques in single cycle load to failure testing; this method was intended to eliminate the potential confounding effects of variations in biomechanical properties of thyroid cartilages attributable to horse age and breed. Another important consideration is that the suture patterns used in this study may exert a moment of rotation of the basihyoid bone such that the lingual process would be rotated dorsally in vivo. We speculate that if the right and left sutures are placed around the basihyoid bone with 1 end dorsal and 1 ventral to the bone on either side of the lingual process, the moment of rotation of the basihyoid bone would be decreased, which would minimize rotation of the lingual process after surgery.

Results of the present study indicated the evaluated LTF surrogate constructs prepared with polyethylene suture were mechanically superior to those performed with polyester suture and that a slight modification of the surgical technique markedly increased the strength of the constructs. Use of polyethylene sutures with the modified suture application technique in horses with DDSP may increase the capacity of such surgical con-

structs to resist failure after surgery. However, because the in vitro methods used in the present study may not have accurately represented the in vivo mechanical environment in the laryngeal regions of horses, results of this study may not be applicable to horses with clinically detectable DDSP. Therefore, further research is warranted to determine the mode of failure and other mechanical characteristics of these suture materials and techniques in equine larynges and clinically affected horses.

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 - b. Ethibond Excel, Novartis Animal Health US Inc, East Hannover, NJ.
 - c. Instron model 880, Instron Corp, Norwood, Mass.
 - d. Phantom Miro eX4, Vision Research Inc, Wayne, NJ.
 - e. SAS, version 9.2 for Windows, SAS Institute Inc, Cary, NC.
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