

Career racing performance in Thoroughbreds treated with prosthetic laryngoplasty for laryngeal neuropathy: 52 cases (1981–1989)

Eric Strand, DVM, MS, DACVS; George S. Martin, DVM, MS, MBA, DACVS;
Peter F. Haynes, DVM, MS, DACVS; J. Ray McClure, DVM, MS, DACVS; J. Donald Vice, DVM

Objective—To compare racing performance before and after prosthetic laryngoplasty for treatment of laryngeal neuropathy in inexperienced and experienced Thoroughbred racehorses.

Design—Retrospective study.

Animals—52 Thoroughbred racehorses treated with prosthetic laryngoplasty for laryngeal neuropathy.

Procedure—Lifetime race records were analyzed by use of a verified regression model. Individual race records and hospital records were also reviewed.

Results—Experienced horses had a decline in performance, as measured by performance index, earnings percentage, and mean prediction error, during the 6-month period before prosthetic laryngoplasty. Performance improved after surgery, relative to performance in 1 to 4 races immediately before surgery, but did not attain previous baseline values for performance index and earnings percentage, although racing speed was restored to baseline values. Factors associated with failure to attain baseline levels of performance included other racing-related injuries and disorders, major complications of surgery, and age. Individually, however, many horses had long and successful careers after surgery. Performance of inexperienced horses after surgery was at least equal to that of experienced horses.

Conclusions and Clinical Relevance—In addition to warning clients of the complications associated with prosthetic laryngoplasty, it may be prudent to provide a guarded prognosis for full restoration of racing performance in older horses, unless they are especially talented and are free of other racing-related problems. (*J Am Vet Med Assoc* 2000;217:1689–1696)

The importance of idiopathic laryngeal neuropathy as a cause of exercise intolerance and abnormal noise production in athletic horses is widely recognized.¹⁻⁴ In 1970, Marks et al⁵ described placing a prosthetic device for surgical improvement of this disorder. Prosthetic laryngoplasty remains the most commonly used surgical procedure for amelioration of the signs of the disease; however, the technique is not without sub-

From the Department of Veterinary Clinical Sciences, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803. Dr. Strand's present address is Department of Large Animal Surgery, Norwegian College of Veterinary Medicine, PO Box 8146 Dep, N-0033 Oslo, Norway.

Supported by a grant from Department of Veterinary Clinical Sciences, Louisiana State University, Baton Rouge, LA 70803.

Presented in part at the 8th Annual Scientific Meeting of the European College of Veterinary Surgeons, Brugge, Belgium, Jul 2-4, 1999.

stantial complications.^{6,7} Accordingly, neuromuscular grafts,^{8,9} nerve transplants,¹⁰ and nerve anastomosis¹¹ have been reported in recent years, although these techniques are not commonly used.

Results of 1 study¹² indicate that inspiratory impedance and transupper airway pressure during inspiration are increased, and inspiratory airflow and respiratory frequency are decreased, in horses moving at speeds ≤ 7.2 m/s on a treadmill set at an incline, after left recurrent laryngeal neurectomy. Prosthetic laryngoplasty restored these variables to baseline values. In another study, peak inspiratory upper airway pressure was substantially increased (> 40 cm H₂O) in Thoroughbreds after left recurrent laryngeal neurectomy, but only during maximum exercise efforts (heart rate, > 230 beats/min). Two horses with clinical signs of left recurrent laryngeal hemiplegia had similar pressures, compared with neurectomized horses exercised under the same conditions to the same degree of exertion¹³; prosthetic laryngoplasty nearly restored pressures to baseline values.¹⁴ In a Thoroughbred model of transient left recurrent laryngeal neuropathy,¹⁵ a substantial reduction in peak oxygen consumption, relative to baseline values, was detected. The metabolic cost of locomotion was not increased at exercise intensities at which oxygen consumption was less than peak oxygen consumption. The authors suggested that left recurrent neuropathy likely affects the performance of horses in races longer than 1 minute in duration, the time required to reach peak oxygen consumption.

The purpose of the study reported here was to compare racing performance before and after prosthetic laryngoplasty for laryngeal neuropathy in inexperienced and experienced Thoroughbred racehorses. A recently developed¹⁶ and validated¹⁷ statistical method of performance evaluation was used, to better understand how laryngeal neuropathy and its treatment affect racing ability.

Criteria for Selection of Cases

Medical records for all horses admitted to the Louisiana State University Veterinary Teaching Hospital that were treated with prosthetic laryngoplasty between 1981 and 1989 were reviewed to identify Thoroughbred racehorses.

Procedures

Fifty-two Thoroughbreds were identified and the records were examined for age at the time of surgery, sex, evidence of arytenoid paresis or paralysis during endoscopy performed at rest, degree of arytenoid abduction after surgery; complications that developed

during the period immediately after surgery, and any other potential performance-limiting problems that were evident at time of admission to the Veterinary Teaching Hospital. Whenever possible, horse owners or trainers were contacted by telephone in 1991 or 1992 for information regarding complications associated with surgery or other problems that may have shortened the racing careers of individual horses.

Surgery—The basic surgical technique for prosthetic laryngoplasty and ventriculectomy used in our study has been described.^{5,18} In all patients, a double-stranded abductor muscle prosthesis of size-5 polytetrafluoroethylene^a was used, and size-1 was used as the leader. The prosthesis sutures were tied under firm pressure, usually without endoscopic viewing of the degree of arytenoid cartilage abduction that was obtained immediately. Bilateral ventriculectomy was then performed through a ventral laryngotomy incision.¹⁸

Several days after surgery, nasopharyngeal endoscopy was performed to assess the degree of arytenoid cartilage abduction, prior to discharge from the clinic. Arytenoid cartilage abduction was deemed good if the affected arytenoid cartilage was positioned lateral to the intermediate or resting position. Abduction was considered excellent if the affected arytenoid cartilage was positioned laterally, well beyond the intermediate or resting position. Abduction was considered poor if the affected arytenoid was positioned more medially than the typical resting position.

Analysis of records—Lifetime race records for the 52 Thoroughbreds were purchased and organized for statistical analysis, as described.¹⁶ Horses raced between July 1976 and April 1992. Initially, individual race records for all horses were evaluated for the number of days after surgery to the first race, number of races run before and after surgery, and number of horses that returned to racing and won at least 1 race after surgery.

Association of age (2 years old vs > 2 years old) with likelihood of laryngeal paresis rather than laryngeal paralysis was determined by use of χ^2 analysis. Analysis of variance was used to determine association between age at the time of surgery and number of starts after surgery.

A published¹⁶ and verified¹⁷ regression model for standardizing racing performance of Thoroughbreds was also applied to this group of 52 horses to determine prediction error. The multiple regression model included terms for track surface (fast, good, and muddy), interaction between different racetracks and distance raced (furlongs), prize money, age of horse (years), season of the year, race number that day, number of horses in a race, weight carried by the horse (pounds), and starting position away from the rail. The model was created on the basis of race finish times, using data from 20,000 Thoroughbreds racing in Louisiana between 1981 and 1985, and accordingly is a model of typical horse performance. Prediction error of this regression model is actual finish time minus predicted finish time. A negative prediction error indicates superior performance (ie, the horse ran faster than predicted). A positive prediction error indicates

poor performance. The greater the positive prediction error, the slower the horse ran, compared with its predicted performance.

For certain analyses, horses were allocated into 2 groups on the basis of age and experience. Group A was composed of experienced horses that were ≥ 3 years old at the time of surgery and had ≥ 4 lifetime starts. Group B was composed of inexperienced horses that were either 2 years old at the time of surgery or were 3 years old at the time of surgery and had ≤ 2 race starts before surgery. None of the 3-year-old horses had 3 race starts before surgery.

Experienced racehorses

Because group-A horses had an established baseline record prior to surgery, comparisons could be made between performance measurements before and after prosthesis placement. Finish times for races of various distances run after surgery were compared with times of races run at the same distances before surgery. For a horse to have a personal best time after surgery at a certain race distance, that individual had to have competed at least twice before surgery at that same distance.

Other performance-related data evaluated in group-A horses included mean length of race, earnings percentage, performance index, and prediction error. Mean race distance after surgery for each horse was compared with mean race distance before surgery by use of a paired *t*-test. Earnings percentage represented the percentage of available first-prize money earned by a horse in each of its races.

Performance index was developed to compare the number of top-3 finishes in races before and after prosthetic laryngoplasty. First place was assigned 3 points, second place was assigned 2 points, and third place was assigned 1 point. To create the performance index, the total number of points for a given period were added together and divided by the total number of races run during that period.

Each group-A horse's race career was divided into 3 stages. Because it was unclear when or whether the prodromal stages of idiopathic left laryngeal hemiplegia began affecting racing performance, the 4 races before admission to the Veterinary Teaching Hospital were designated stage 2 (potentially disease-influenced). These 4 races had to have taken place within the 6-month period prior to surgery. If a horse competed in < 4 races during that time, then only those races were designated stage 2. The 10 races before stage 2 were designated stage 1 (unaffected by disease), and the first 10 races after surgery were designated stage 3 (recovery). The last race before admission to hospital was the race with the greatest likelihood of having been affected by idiopathic left laryngeal hemiplegia and was analyzed as a separate subset of stage 2.

Mean performance index, earnings percentage, and prediction error were determined for each horse in group A for stage 1, 2, and 3. Results of the Shapiro Wilks test indicated that performance index and prediction error data were normally distributed, but earnings percentage data were not normally distributed. Analysis of variance of the mean performance index was used to determine the effect of stage on this vari-

able. Earnings percentage was analyzed by use of non-parametric methods. Mean earning percentage for each horse was analyzed for differences between stages by use of Cochran-Mantel-Haenszel methods for repeated ranked data.

One-way ANOVA was used to test for differences among stages within the normally distributed variable, prediction error. The 4 races in stage 2, the first 10 races after surgery (stage 3), and all races after surgery were analyzed by use of simple linear regression with prediction error as the dependent variable and race order as the independent variable.

Inexperienced racehorses

Group B included inexperienced 2- and 3-year-old horses. Because of their inexperience, they were further subdivided by age and evaluated separately for variables determined after surgery, including mean race distance, percentage of horses that returned to racing and won at least 1 race, and performance index.

Comparisons of performance after surgery between group A and group B

The number of days from the time of surgery to the first start was compared between group A and group B by use of ANOVA. Performance in all races after surgery and in the first 10 races after surgery (stage 3) was compared between groups A and B for performance index and prediction error by use of ANOVA, and for earnings percentage by use of the Mann Whitney U test. For repeated measures ANOVA, the Scheffe test was used as the post hoc test for type-I error. The Shapiro-Wilks test statistic was used as a test of normality.

For all comparisons, differences were considered significant if $P < 0.05$. Data are reported as mean \pm SE. Computer software^{b,c} was used to perform the statistical tests.

Results

Median age at time of surgery was 3 years (Table 1). Sexually intact males and geldings represented 83% of horses treated with prosthetic laryngoplasty. Two-year-old horses most commonly had paresis of the left arytenoid cartilage (8/14 horses), whereas horses ≥ 3 years old more commonly had arytenoid paralysis (27/38 [71%] horses). χ^2 Comparison of paralysis versus paresis between the 2 groups indicated that the conditions were not equally distributed ($P = 0.043$). Paralysis was detected more commonly than expected in horses ≥ 3 years of age, and less commonly than

expected in 2-year-old horses. Two of 52 (3.8%) horses had paralysis of the right arytenoid cartilage.

Endoscopic evaluation of arytenoid abduction performed several days after surgery revealed that 45 of 52 horses had good to excellent lateral positioning of the affected arytenoid cartilage. One horse had poor abduction and hospital records were incomplete for this information for 2 horses. The remaining 4 horses had problems associated with prosthesis placement.

Eleven of 52 (21%) horses had complications associated with surgery; 3 of these horses had complications so severe that they did not return to racing. Five horses had complications that caused relatively short and winless race careers after surgery (range, 1 to 13 race starts), compared with other horses. Three horses had complications from which they recovered, and these horses had fairly long (range, 29 to 36 race starts) and successful race careers (range, 3 to 5 wins).

Complications identified in the study reported here varied among horses. One horse developed infection at the surgery site, necessitating removal of the implant. This horse had right-sided arytenoid cartilage paralysis that posed considerable challenge for prosthesis placement. The only other horse in our study that had right-sided paralysis was deemed to have good arytenoid cartilage abduction after surgery, without complications, but continued to race as poorly after surgery as it had prior to surgery, perhaps because the horse reportedly also had exercise-induced pulmonary hemorrhage. Three horses had signs suggesting that the prosthesis cut through the cartilage and loosened during surgery or the period immediately after surgery. One of these horses did not race after surgery and 1 horse had only 1 race start after surgery. The third horse with this complication raced 34 times after surgery, and won 3 of those races. This horse may have had a 2nd prosthetic laryngoplasty performed at another hospital, but this could not be determined definitively. Another possibility is that the arytenoid cartilage, although not positioned laterally as well as planned, may have been sufficiently stabilized to allow the horse to perform well. Chronic aspiration pneumonia, coughing, and dysphagia limited the racing careers of 5 horses (no wins in 0 to 13 race starts); however, 2 other horses had dysphagia that eventually resolved and these horses won 5 and 4 races, respectively. Four of these 7 horses had good arytenoid abduction after surgery, 2 had excellent abduction, and 1 lacked information in the medical record.

Nine (17%) horses developed other potentially performance-limiting problems after surgery that were not directly attributable to idiopathic left laryngeal hemiplegia or prosthetic laryngoplasty. These performance-limiting problems included fracture of metacarpal bone II ($n = 1$), ostochondral chip fractures of the carpal and metacarpophalangeal joints (2), fracture of the proximal portion of the sesamoid bone (1), degenerative joint disease (4), exercise-induced pulmonary hemorrhage (1), anemia (1), and aryepiglottic fold entrapment and dorsal displacement of the soft palate (1). Several horses had more than 1 problem.

Two-year-old horses had a median of 22.5 race starts after surgery (Table 2); 1 horse in this group had

Table 1—Sex distribution and results of endoscopic evaluation of arytenoid function (paralysis vs paresis; left [L] side vs right [R] side affected) in 52 Thoroughbreds of various ages, before undergoing prosthetic laryngoplasty

Age (years)	No. of horses	Sex distribution (M, G, F)	Paresis (L, R)	Paralysis (L, R)
2	14	6, 3, 5	8 (L)	5 (L), 1 (R)
3	15	7, 6, 2	5 (L)	9 (L), 1 (R)
4	9	2, 6, 1	3 (L)	6 (L)
5	8	0, 7, 1	0	8 (L)
6–9	6	0, 6, 0	3 (L)	3 (L)
Total	52	15, 28, 9	19 (L)	31 (L), 2 (R)

M = Sexually intact male. G = Gelding. F = Sexually intact female.

Table 2—Median No. (range) of race starts before and after prosthetic laryngoplasty in 52 Thoroughbreds of various ages

Age (years)	No. of horses	Before surgery	After surgery
2	14	1 (0–7)	22.5 (0–102)
3	15	4 (0–21)	8 (0–62)
4	9	18 (8–49)	17 (6–40)
5	8	41.5 (9–57)	13 (2–43)
6–9	6	60 (39–108)	11 (4–47)

102 race starts. As age at the time of surgery increased, the median number of races after surgery appeared to decrease, but not significantly ($P = 0.2775$).

Forty-five (86.5%) horses had at least 1 race start before prosthetic laryngoplasty. Of these, 34 (75.5%) had won at least 1 race before surgery. After surgery, 49 of 52 (94.2%) horses made at least 1 start. The 3 horses that did not start in a race after surgery had complications associated with the procedure. Thirty-one of 52 (59.6%) horses won at least 1 race after surgery. Twelve of 52 (23.1%) horses won at least 3 races after surgery. The most successful horse was a 2-year-old colt that won 16 races during a 52-month period.

Performance before and after surgery in group A—Thirty-one of 52 horses were considered experienced at the time of surgery. These 31 horses had 982 starts (mean, 31.7) before surgery, 114 starts in the last 4 races before surgery (mean, 3.7) and 586 starts (mean, 19.0) after surgery. Significant difference was not detected between mean race distance before surgery (6.42 ± 0.04 furlongs [$1,292 \pm 3.1$ m]) and mean race distance after surgery (6.34 ± 0.1 furlongs [$1,275 \pm 12.1$ m]; $P = 0.31$). After surgery, mean distance raced ranged from 920 m (11 races at a mean distance of 4.6 furlongs) to 1,660 m (47 races at a mean distance of 8.3 furlongs). Number of first, second, and third place finishes before surgery was 144, 126, and 97, respectively. Number of first, second, and third place finishes in the last 4 races before surgery was 5, 7, and 10, respectively. Number of first, second, and third place finishes after surgery was 53, 51, and 55, respectively.

Fourteen of these 31 (45%) horses ran a personal-best time at 1 or more race distances after prosthetic laryngoplasty, relative to their times at those distances during their entire career before surgery. The range of these distances was 4.5 to 8.5 furlongs (900 to 1,700 m).

Mean performance index, earnings percentage, and prediction error were determined for each stage for these horses (Table 3) and revealed a significant asso-

ciation between stage and performance index ($P < 0.001$). Stage-1 performance index was significantly greater than that of stage 2 and stage 3, but differences could not be detected between stages 2 and 3.

Comparison of earning percentage (percentage of available first-prize money earned per race) among the stages revealed significant ($P = 0.001$) differences (Table 3). Stage-1 earning percentage was greater than stage-2 and stage-3 earning percentage, whereas stage-2 and stage-3 earning percentages were not significantly different.

Significant differences were not detected between stages for mean prediction error ($P = 0.127$); however, when stage 2 was restricted to just the last race before admission to the hospital, significant differences ($P < 0.001$) were detected for mean prediction error among the 3 stages (Table 3). By use of the last race before admission, mean prediction error was 1.85 ± 0.54 for stage 2. Mean prediction error for stage 2 was significantly different (slower) from that of stage 1 and stage 3, whereas significant difference was not detected for this value between stages 1 and 3.

Regression analysis of prediction error as a function of career race number for the last 4 races before admission (stage 2) revealed a significant positive slope (career race number coefficient, 0.57; $P = 0.001$; $R^2 = 7\%$), thus indicating gradually slowing finish times as the date of admission approached. Regression analysis of prediction error as a function of career race number for the first 10 races after surgery (stage 3) revealed a significant negative slope (career race number coefficient, -0.11 ; $P = 0.003$; $R^2 = 2\%$). Regression analysis of prediction error as a function of career race number for the period past stage 3 (for those horses that raced > 10 times after surgery) revealed a significant positive slope (career race number coefficient, 0.03; $P = 0.006$; $R^2 = 2\%$).

Performance in group-B—Group B included 2-year-old horses ($n = 14$) and 3-year-old horses with 2 or fewer career race starts (7). Nine of the 14 two-year-old horses had at least 1 race start before surgery. Overall, only 3 of these 14 horses had won a race before surgery. After surgery, 12 of the 2-year-old horses returned to racing, and had a minimum of 6 and a maximum of 102 race starts. The 2 horses that did not return to racing had complications associated with surgery. Of the 12 that returned to racing, 10 won at least 1 race.

Five of the 7 group-B 3-year-old horses had raced

Table 3—Mean (\pm SE) performance index, earnings percentage, and prediction error values for 31 experienced racehorses during various stages before and after prosthetic laryngoplasty

Variable	Stage 1	Stage 2	Stage 3
Performance index	0.99 ± 0.10^a	0.30 ± 0.09^b	0.46 ± 0.05^b
Earnings percentage	$28.4 \pm 3.8\%^a$	$10.9 \pm 2.8\%^b$	$13.6 \pm 1.9\%^b$
Prediction error	-0.49 ± 0.25^a	0.30 ± 0.28^b	-0.09 ± 0.29^a

Stage 1 = 10 races immediately preceding stage 2. Stage 2 = Last 1 to 4 consecutive races run during the 6-month period preceding prosthetic laryngoplasty. Stage 3 = First 10 races after prosthetic laryngoplasty.

^{a,b}Within rows, different superscript letters indicate mean values that are significantly ($P < 0.05$) different.

at least once before surgery. Only 1 horse had won a race during that period. After surgery, 6 of the 7 horses in this group raced at least once (range, 1 to 28 races). The horse that raced only once and the horse that did not have any races after surgery had complications associated with surgery. Of the 6 horses that returned to race after surgery, 3 won at least 1 race.

The 12 two-year-old horses that returned to racing ran a total of 364 races after surgery (mean, 30.3 races) at an overall mean distance of 6.41 ± 0.05 furlongs ($1,282 \pm 9.7$ m). This distance is identical to the mean distance of races entered by the experienced racehorses (group A) after surgery. The 6 inexperienced 3-year-old horses that returned to racing had a total of only 66 race starts (mean, 11 races) at a mean distance of 5.42 ± 0.12 furlongs ($1,084 \pm 23.5$ m). This is approximately 1 furlong (200 meters) shorter in distance than that raced by the other 2 groups of horses. For all group-B horses, total number of career races after surgery was 430. Numbers of first, second, and third place finishes after surgery were 39, 51, and 48, respectively.

Comparisons of performance after surgery between group-A and group-B racehorses—The rest period (from the time of prosthetic laryngoplasty to the first race start after surgery) for the 31 experienced horses in group A was significantly ($P = 0.05$) shorter than for the 21 inexperienced horses in group B; mean time to first start was 120 ± 11 days (range, 26 to 331 days) for group A and 165 ± 23 days (range, 59 to 386 days) for group B.

In the first 10 races after surgery, there were no significant differences between groups A and B regarding performance index ($P = 0.47$), earnings percentage ($P = 0.852$), or prediction error ($P = 0.91$). Mean performance index was 0.46 ± 0.05 for group A and 0.57 ± 0.09 for group B. Mean earnings percentage was $13.6 \pm 1.9\%$ for group A and $14.8 \pm 2.5\%$ for group B. Mean prediction error was -0.09 ± 0.29 for group A, and -0.11 ± 0.18 for group B.

When all races after surgery were used for comparisons, significant differences between group A and B were not found for performance index ($P = 0.68$) and earnings percentage ($P = 0.65$), whereas there was a significant difference between groups regarding prediction error ($P < 0.001$). Mean performance index was 0.47 ± 0.05 for group A and 0.51 ± 0.08 for group B. Mean earnings percentage was $12.8 \pm 1.5\%$ for group A, and $12.6 \pm 2.1\%$ for group B. Mean prediction error was -0.06 ± 0.10 for group A and -0.75 ± 0.11 for group B.

Discussion

Median age at the time of prosthetic laryngoplasty in the study reported here was 3 years; however, a considerable number of older racehorses (maximum age, 9 years) were also referred for surgical treatment and included in the study. Sex distribution among all age groups revealed a disproportionate number of male horses and this finding was even more pronounced among older horses. In another study,¹⁹ a similar sex distribution was reported (79% males, 21% females) in a population composed predominantly of Thorough-

bred horses that underwent prosthetic laryngoplasty. We feel that a selection process had taken place whereby male Thoroughbreds were treated for the condition, whereas females were probably retired as broodmares. Results of a study of Quarter Horses²⁰ indicated a similar selection bias that resulted in changes in the sex distribution of older racehorses.

Interestingly, 2-year-old Thoroughbreds were referred more commonly for laryngeal hemiparesis, whereas 3-year-old horses and older horses were usually referred because of complete laryngeal paralysis. This may reflect a time interval during which the disease progresses. A subclinical form of this disease has been reported to affect $> 70\%$ of all horses > 145 cm in height^{21,22}; however, the clinical form of the disease only develops in 3 to 9% of horses.^{23,24} The 2-year-old horses in our study may have had a higher incidence of laryngeal paresis because there had not been sufficient time to develop complete laryngeal paralysis. At our clinic some horses have been evaluated because of suspicion of early laryngeal hemiplegia, based on detection of an asymmetrical aditus laryngis, but the horses' ability to fully abduct the arytenoid cartilages could be seen after deglutition or during treadmill endoscopy. Surgery was not performed, but the horses were reevaluated several months later for more severe laryngeal hemiplegia. This clinical observation seems to support data from the study reported here that indicate that most affected horses develop poor performance during a period of < 6 months.

Results of a retrospective study¹⁹ indicate that horses with maximally abducted arytenoid cartilages have a lower success rate and higher incidence of complications, compared with horses with less optimal lateral positioning of the cartilages. Results of another research study indicate that stabilization of the affected arytenoid, to prevent dynamic collapse, is more important in reducing inspiratory resistance and preventing flow limitation than achieving full arytenoid abduction.²⁵ In our study, an objective grading system was not used to evaluate the lateral positioning of the arytenoid cartilages, so correlation between arytenoid position and racing success after surgery or complications could not be accurately determined. In most of 52 horses reported here, the prosthesis sutures were tied under firm tension without using intraoperative endoscopic evaluation of the degree of arytenoid abduction that was immediately achieved. The degree of abduction obtained was evaluated several days after surgery, prior to discharge.

Overall, 45 of the 52 horses in our study were considered to have adequately abducted arytenoid cartilages after surgery. Of the 7 horses that developed transient or long-term aspiration pneumonia, coughing, and dysphagia, 4 were considered to have good cartilage abduction after surgery, 2 had excellent abduction, and 1 lacked this information in the medical record. Thus, a clear correlation between degree of abduction and complications associated with the surgery was not apparent.

The 3 horses in which the prosthesis failed, either by apparently loosening shortly after surgery or by apparently cutting through cartilage when tied, were 2

years of age ($n = 2$) and 3 years of age (1). There has been controversy whether cartilage retention strength in 2-year-old horses is adequate to prevent the prosthesis from cutting through the muscular process of the arytenoid cartilage or the dorsocaudal aspect of the cricoid cartilage.^{26,27} Results of 1 study²⁸ indicate that cartilage retention strength is similar in 2-, 3-, and 4-year-old horses. Despite the fact that the 3 horses with prosthesis failure in our study were all young and inexperienced as racehorses, our results indicate that inexperienced racehorses had racing success after surgery that was at least equal to that of older, experienced horses.

Nine (17%) horses were identified as having other potential performance-limiting problems after surgery that were not directly attributable to idiopathic laryngeal neuropathy or prosthetic laryngoplasty. Because of the difficulty of obtaining accurate follow-up information on horses that competed as long as a decade before the study, more horses than the 9 we detected probably had racing-related physical problems that limited their performances or led to premature retirement. Thus, the acquirement of other racing-related problems and injuries in this population after prosthetic laryngoplasty clearly influenced postoperative performance, as measured by the variables used in the study reported here.

The long-term effect of prosthetic laryngoplasty on racing performance is not well documented.²⁹ One goal of our study was to follow the entire race careers of all 52 horses to determine racing longevity. Many horses that did not develop complications associated with surgery or other racing-related problems had long and relatively successful careers. In every age group were horses that competed ≥ 40 times after surgery, which represented ≥ 3 years of racing for many horses. Approximately 60% of all the horses in our study won at least 1 race after surgery, and nearly 25% won at least 3 races. This should indicate that prosthetic laryngoplasty is more than just a salvage procedure, as has been suggested by some surgeons.

Among experienced racehorses, mean performance index during stage 1 was 0.99. During stage 2, their mean performance index declined significantly to 0.30. After prosthetic laryngoplasty, mean performance index improved to 0.46 in their first 10 races. This was still significantly lower than that of the baseline period (stage 1) and not significantly greater than the disease period (stage 2). Mean performance index after surgery was obviously substantially decreased by those horses that had complications or other racing-related problems.

For comparisons of performance before and after surgery in group-A horses, the authors decided not to compare purse money, earnings per start, or total earnings, but instead to use the earnings percentage. This was done for several reasons. The prize money available to 2- and 3-year-old horses is in general greater than for older horses of comparable racing ability, or for the same horses later in their careers. Two-year-old horses also have not established their competitive level, so trainers will select the highest reasonable entry-level prize money. Another consideration is that trainers were likely more aware of the horse's disease history during the period after surgery, and may have

intentionally sought out easier, less competitive races for these horses, especially in the first races after returning from surgical treatment; less competitive races have lower prize money. A final consideration was that these horses raced during a period from 1976 to 1992. Purses awarded during the latter years of this period were inflated relative to earlier purses, and the purse structures have changed at the racetracks during this period. Although we could account for inflation, we had no definitive method to account for change in purses. The earning percentage is a ratio of earnings to first-place prize money. Fortunately, the ratio compensates for inflation and the influence of purse fluctuation over time. Earnings after surgery, expressed as earning percentage, were still significantly less than earnings before surgery for the experienced racehorses.

Significant differences were not detected between mean race distance before or after surgery for the experienced racehorses, suggesting that no conscious adjustment (shortening) in race length had been made by trainers after surgery. Although the mean race distance of 6.4 furlongs is considered a sprint distance, this is approximately the mean and median distance for all Thoroughbred races in the United States.¹⁶ Fourteen of these 31 (45%) horses ran a best time at 1 or more race distances, ranging from 4.5 to 8.5 furlongs, after surgery. To qualify for a personal-best time they had to have run the same distance at least twice before surgery. We set this strict criteria to eliminate horses that may have had 1 poor race performance at a particular distance before surgery. These results also suggest that under American racing conditions, prosthetic laryngoplasty may restore performance ability in many horses and some may even improve their running times relative to their baseline period.

Prediction error is another time-based method of evaluating performance. In our analysis, only when stage 2 was restricted to the last race before admission to the hospital could significant differences in prediction error be detected among the 3 stages for experienced horses. Prediction error for stage 2 was then significantly greater than for stage 1 (baseline) or stage 3 (after surgery), indicating that racing speeds during stage 2 were significantly slower. We could not, however, detect a difference in prediction error between stage 1 and 3, which indicates that racing speed after surgery was approximately equal to that during the baseline (disease-free) period before surgery.

The short duration of poor performance in horses with idiopathic laryngeal neuropathy may be a reasonable, although unexpected, finding. Idiopathic laryngeal neuropathy creates upper airway stridor, which will be noticed by exercise riders and trainers as an important problem. Trainers understand that the clinical signs of this disease represent a potentially substantial impairment to athletic capability and will quickly seek veterinary help. These horses are then removed from training, and are retired or undergo surgery. It is rare for these horses to continue to race after respiratory noise and severe exercise impairment become apparent. Further evidence of this is the fact that only 2 of the horses in our study failed to finish a race prior to surgery. Thus, we had not expected to find evidence

in the records of racing performance that the effects of the disease were prolonged. The high prediction error (+1.85) found for the restricted stage 2 (final race prior to surgery), and the progressively slowing finish times during all of stage 2 (final 4 races prior to surgery), appear to be evidence of the prodromal effects of idiopathic laryngeal neuropathy.

Regression analysis of prediction error as a function of career race number for the first 10 races after prosthetic laryngoplasty (stage 3) revealed a significant negative slope, suggesting that surgery had helped the horses and that they were improving in fitness. Regression analysis of prediction error as a function of career race number for the period after stage 3 (for those horses that raced > 10 times after surgery) revealed a significant positive slope. This indicated that those horses that had long careers had gradual slowing of race times, suggesting that there is an age and time-in-training effect on performance. This probably represents accumulated musculoskeletal damage from training and racing, but could also represent gradual failing (loosening) of the prosthesis.

Inexperienced racehorses required significantly more time to return to racing (mean, 165 days), relative to experienced horses (mean, 120 days). This is probably related to a greater baseline level of fitness and seasoning in the experienced horses at the time of surgery, compared with the lightly raced inexperienced horses.

Inexperienced racehorses had equal success during the first 10 races after surgery and during their entire career after surgery, compared with older experienced racehorses, determined on the basis of earning percentage and performance index. Because inexperienced horses had few race starts before surgery, it was not possible to do a meaningful comparison of race finish times for various distances before and after surgery, as was done for the experienced racehorses. However, a statistical difference was not detected between groups for another time-based variable, prediction error, for the first 10 races after prosthetic laryngoplasty. Interestingly, for horses' entire careers after surgery, prediction error values indicated that the inexperienced horses had significantly faster times than predicted, compared with experienced horses. Because horses in the experienced group were older at the time of diagnosis and treatment, they were closer to the end of their competitive careers, compared with the inexperienced horses, and likely did not perform as well because of accumulated injuries. The practical meaning of the differences in prediction error between groups is also interesting and indicates that in head-to-head competition, inexperienced horses would finish 0.69 seconds (approx 3.5 lengths) ahead of experienced horses.

Mean distance raced after surgery for 2-year-old horses was almost identical to that of the experienced horses. Two-year-old Thoroughbreds are reported to be among the most successful of age groups receiving prosthetic laryngoplasty as treatment for idiopathic left laryngeal hemiplegia.^{19,30} Again, part of the reason for this observation is probably that these horses are at the beginning (rather than the latter portion) of their

careers and have not accumulated the effects of other injuries and problems.

On a practical basis, it may be prudent to suggest a more guarded prognosis for restoration of racing performance in older horses receiving prosthetic laryngoplasty, unless they are especially talented and free of musculoskeletal and other racing-related problems. Nevertheless, results of the study reported here indicate that many horses may have long, successful careers after prosthetic laryngoplasty, and return to approximately the same racing speed they had before developing laryngeal neuropathy.

The measures we used to evaluate performance (earnings percentage, performance index, and prediction error) are similar and correlated; however, only prediction error is based on race finish times and can be related to relative finish position in terms of seconds or lengths. Prediction error appeared to be the most sensitive variable because it could detect subtle changes in performance during the final races prior to referral for surgery in the experienced racehorses. From a statistical standpoint, prediction error has the advantage of being a normally distributed, continuous variable, which allows application of more powerful parametric statistical tests.

^aPolydek (Deknatel), Genzyme Surgical Products, Fall River, Mass.

^bStatistix 2.0, Analytical Software, Tallahassee, Fla.

^cSAS, SAS Institute, Cary, NC.

References

1. Fleming G. Laryngismus paralytica ("roaring"). *Vet J Ann Comp Pathol* 1882;14:1-12.
2. Liautard A. *Manual of operative veterinary surgery*. New York: Sabiston and Murray, 1892:462-467.
3. Williams WL. Clinical observations on roaring. *Am Vet Rev* 1901;25:811-815.
4. Cook WR. A comparison of idiopathic laryngeal paralysis in man and horse. *J Laryngol Otol* 1970;84:819-835.
5. Marks D, Mackay-Smith MP, Cushing LS, et al. Use of a prosthetic device for surgical correction of laryngeal hemiplegia in horses. *J Am Vet Med Assoc* 1970;157:157-163.
6. Raker CW. Complications related to the insertion of a suture to retract the arytenoid cartilage to correct laryngeal hemiplegia in the horse. *Arch Vet Surg* 1975;4:64-66.
7. Greet TRC, Baker GJ, Lee R. The effect of laryngoplasty on pharyngeal function in the horse. *Equine Vet J* 1979;11:153-158.
8. Ducharme NG, Horney FD, Partlow GD, et al. Attempts to restore abduction of the paralyzed equine arytenoid cartilage I. Nerve-muscle pedicle transplants. *Can J Vet Res* 1989;53:202-209.
9. Fulton IC, Derksen FJ, Stick JA, et al. Treatment of left laryngeal hemiplegia in Standardbreds, using a nerve muscle pedicle graft. *Am J Vet Res* 1991;52:1461-1467.
10. Ducharme NG, Horney FD, Hulland TJ, et al. Attempts to restore abduction of the paralyzed equine arytenoid cartilage II. Nerve implantation (pilot study). *Can J Vet Res* 1989;53:210-215.
11. Ducharme NG, Viel L, Partlow GD, et al. Attempts to restore abduction of the paralyzed equine arytenoid cartilage III. Nerve anastomosis. *Can J Vet Res* 1989;53:216-223.
12. Shappell KK, Derksen FJ, Stick JA, et al. Effects of ventriculectomy, prosthetic laryngoplasty, and exercise on upper airway function in horses with induced left laryngeal hemiplegia. *Am J Vet Res* 1988;49:1760-1765.
13. Williams JW, Meagher DM, Pascoe JR, et al. Upper airway function during maximal exercise in horses with obstructive upper airway lesions: effect of surgical treatment. *Vet Surg* 1990;19:142-147.
14. Williams JW, Pascoe JR, Meagher DM, et al. Effects of left recurrent laryngeal neurectomy, prosthetic laryngoplasty, and subtotal arytenoidectomy on upper airway pressure during maximal exertion. *Vet Surg* 1990;19:136-141.

15. Ehrlich PJ, Seeherman HJ, Morris et al. The effect of reversible left recurrent laryngeal neuropathy on the metabolic cost of locomotion and peak aerobic power in Thoroughbred racehorses. *Vet Surg* 1995;24:36–48.
16. Martin GS, Strand E, Kearney MT. Use of statistical models to evaluate racing performance in Thoroughbreds. *J Am Vet Med Assoc* 1996;209:1900–1906.
17. Martin GS, Strand E, Kearney MT. Validation of a regression model for standardizing lifetime racing performances of Thoroughbreds. *J Am Vet Med Assoc* 1997;210:1641–1645.
18. Haynes PF. Surgery of the equine respiratory tract. In: Jennings PB, ed. *The practice of large animal surgery*. Philadelphia: WB Saunders Co, 1984;388–487.
19. Russell AP, Slone DE. Performance analysis after prosthetic laryngoplasty and bilateral ventriculectomy for laryngeal hemiplegia in horses: 70 cases (1986–1991). *J Am Vet Med Assoc* 1994;204:1235–1241.
20. Buttram ST, Willham RL, Wilson DE, et al. Genetics of racing performance in the American Quarter Horse: 1. Description of the data. *J Anim Sci* 1988;66:2791–2799.
21. Duncan ID, Griffiths IR, McQueen A, et al. The pathology of equine laryngeal hemiplegia. *Acta Neuropath (Berl)* 1974;27:337–348.
22. Cook WR. Diagnosis and grading of hereditary recurrent laryngeal neuropathy in the horse. *J Equine Vet Sci* 1988;8:432–455.
23. Baker GJ. Laryngeal asynchrony in the horse: definition and significance. In: Snow DH, Persson SGB, Rose RJ, eds. *Equine exercise physiology*. Cambridge: Granta, 1983;46–50.
24. Hillidge CJ. Prevalence of laryngeal hemiplegia on a Thoroughbred horsefarm. *Equine Vet Sci* 1985;5:252–254.
25. Derksen FJ, Stick JA, Scott EA, et al. Effect of laryngeal hemiplegia and laryngoplasty on airway flow mechanics in exercising horses. *Am J Vet Res* 1986;47:16–20.
26. Johnson JH. Laryngeal surgery techniques and results, in *Proceedings*. Am Coll Vet Surg Form 1985;13:60.
27. McAllister ES. Obstructive respiratory disease. In: Mansmann RR, McAllister ES, eds. *Equine medicine and surgery*. 3rd ed. Vol 2. Santa Barbara, Calif: American Veterinary Publications, 1982;738–770.
28. Dean PW, Nelson JK, Schumacher J. Effects of age and prosthesis material on in vitro cartilage retention of laryngoplasty prostheses in horses. *Am J Vet Res* 1990;51:114–117.
29. Speirs VC, Tulleners EP, Ducharme NG, et al. Larynx. In: Auer JA, ed. *Equine surgery*. Philadelphia: WB Saunders Co, 1992:472.
30. Speirs VC. A retrospective survey of racing performance of Australian horses after surgery for carpal injuries and laryngeal hemiplegia, in *Proceedings*. 26th Annu Meet Am Assoc Equine Pract 1980;26:335–344.