Evaluation of learning curves for ovariohysterectomy of dogs and cats and castration of dogs

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OBJECTIVE
To define learning curves for fourth-year veterinary students performing ovariohysterectomy procedures in dogs and cats and castration in dogs.

DESIGN
Retrospective study.

SAMPLE
3,196 ovariohysterectomies or castrations performed in dogs and cats by 88 veterinary students during a spay-neuter surgery and animal shelter rotation (n = 3,056) or by 1 experienced general practitioner (n = 140).

PROCEDURES
Data collected from medical records included patient signalment, type and duration of procedure, and sequence (by date and time) of the procedure within a list of procedures of the same type generated for each student. For each procedure type, geometric mean surgery time and 95% confidence intervals were determined for each number of surgeries completed by ≥10 students. Median surgery times for the same procedure types were determined for the experienced practitioner. The learning curve for each procedure was modeled with nonlinear (3-factor exponential equation with a nonzero asymptote) and linear regression. For each procedure, the asymptote (optimal surgery time) for students was compared with the experienced practitioner’s median surgery time.

RESULTS
2,945 surgeries (mean, 33/student) performed by ≥10 students were analyzed. Surgery time decreased in a nonlinear manner as student experience increased for castration of adult or pediatric dogs and ovariohysterectomy of pediatric dogs and adult or pediatric cats. Surgery time decreased in a linear manner as experience increased for ovariohysterectomy of adult dogs.

CONCLUSIONS AND CLINICAL RELEVANCE
To the authors’ knowledge, this was the first study to map surgery times for common surgical procedures consecutively performed by veterinary students. Results clearly indicated the value of repetition to improve surgical skills (as measured by surgery time) during a 3-week period. (J Am Vet Med Assoc 2017;251:322–332)
scribed as a learning curve. Learning curves for surgical procedures in human medicine are portrayed as graphical representations, with surgery time on the vertical (y) axis and experience of the surgeon on the horizontal (x) axis. Other outcomes used to assess surgical learning curves include complication rates, conversion from laparoscopic to open procedures, amount of intraoperative blood loss, postoperative patient outcomes, and technical skills data. Through the use of statistical methods and large data sets, learning or performance curves can be mapped and monitored over time. In veterinary surgery, the application of learning curve methods has recently been used to evaluate surgical times and complications. Learning curve analysis of natural orifice transluminal endoscopic ovariectomy procedures in 20 dogs revealed that approximately 10 procedures were required for an experienced team to reach an asymptotic surgery time. Proot and Corr used cumulative sum analysis to evaluate the learning curve for 1 surgeon performing tibial tuberosity advancement procedures (167 procedures in 122 dogs) and, with a 9% complication rate within 12 months after surgery, showed that the learning curve continued until the 22nd procedure. In another study evaluating 116 total hip replacement procedures in dogs by 1 surgeon, there were 15 failures in the first 12 weeks after surgery, and cumulative sum analysis found that approximately 44 procedures comprised the learning curve. Similar analysis methods in a retrospective study of 4 different surgeons performing laparoscopic ovariectomy in 618 dogs indicated a learning curve of approximately 80 procedures. Models fitting with data from 27 dogs undergoing single-port ovariectomy by an experienced laparoscopic surgeon suggested that 8 procedures would be required for a comparable surgeon to reach 90% of the optimal surgery performance (where optimal performance was represented by completion within the predicted surgery time).

Kennedy et al retrospectively evaluated complications and outcomes for 513 animals (dogs and cats) that underwent ovariohysterectomy by third-year veterinary students in the teaching environment and identified 17 major complications, 15 of which involved dehiscence of the body wall incision. Median surgical times in that study were 105 and 180 minutes for ovariohysterectomy of cats and dogs, respectively. Burrow et al studied the records of 142 dogs that had ovariohysterectomy performed by fourth-year students in the veterinary hospital and found a mean surgery time of 79 minutes, with an overall complication rate of 20.6%. To the authors’ knowledge, there have been no studies evaluating time for elective surgical procedures performed in sequence by veterinary medical students. The purpose of the study reported here was to determine the durations of common surgical procedures performed sequentially by fourth-year veterinary students and to use these data to statistically model an asymptotic (optimal) surgery time, estimate the number of procedures that need to be performed to reach the asymptotic time, and compare the optimal surgical times with those of an experienced veterinary practitioner.

Materials and Methods

Procedures

The protocol for the present study was classified as exempt from review by the Purdue University Institutional Review Board because individual student data would not be disclosed. Veterinary students included in the study were participants in a fourth-year elective rotation in which each student spent 2 weeks with a mobile surgery unit performing ovariohysterectomy and castration procedures and 1 week volunteering in an animal shelter. A maximum of 3 students performed surgery at any given time (1 student/patient) under the supervision of a shelter medicine clinician, a general practitioner with extensive clinical experience in performing and teaching spay and neuter surgery, or a board-certified veterinary surgeon. The first procedure of each type for every group of students was demonstrated by the clinician. In subsequent procedures, the students took the lead role as surgeon but were assisted by the clinician when requested by the student or when deemed necessary by the clinician for safety or teaching purposes. There was no prescribed order of procedures, except that surgeries in pediatric patients were generally performed earlier in the day to minimize the duration of food withholding and facilitate rapid return to the shelter.

Electronic medical records of elective surgical procedures (a convenience sample of ovariohysterectomies of dogs or cats and castrations of dogs) performed by fourth-year veterinary students from July 30, 2012, to May 9, 2014, were extracted from the database used for the surgery and shelter rotation program. Feline castrations were excluded because the surgical times were too short to measure accurately. Dogs and cats > 5 months and ≤ 5 months of age were classified as adult and pediatric, respectively. Medical records were included in the study when the surgery was performed by a student or an experienced practitioner (NF), the required surgical times were recorded, and the student performing the surgery completed the rotation.

All procedures were performed aseptically following the published guidelines for elective surgery on shelter animals. The anesthesia protocol included premedication with acepromazine maleate (0.05 mg/kg [0.02 mg/lb], SC). A combination of tiletamine hydrochloride–zolazepam hydrochloride (100 mg/mL), butorphanol tartrate (5 mg/mL), and dexmedetomidine hydrochloride (250 µg/mL) was mixed in 1 vial (final concentrations for all drugs shown) and administered at a dosage of 0.03 mL/kg (0.01 mL/lb, IM) for induction of anesthesia. Each animal was intubated, and isoflurane (1% to 2% in oxygen) was
administered as needed to maintain a surgical plane of anesthesia. Heart rate and oxygen saturation of arterial hemoglobin as measured by pulse oximetry (with the monitoring probe placed lingually) were monitored continuously; values were recorded prior to surgery and at the end of surgery. An NSAID (carprofen, 2.2 mg/kg [1.0 mg/lb], SC; meloxicam, 0.1 mg/kg [0.045 mg/lb], SC; or firocoxib, 5.0 mg/kg [2.27 mg/lb], PO) was administered for postoperative analgesia. Antibiotic prophylaxis was not provided routinely; however, ceftazolin (22 mg/kg [10 mg/lb], IV) was administered if there was contamination during surgery or if surgical time exceeded 90 minutes. Each surgical site was prepared aseptically and draped for surgery. The surgical techniques used varied slightly among clinicians.

Ovariohysterectomy of dogs was performed through a midline celiotomy 1 to 3 cm in length; a stay hook was used to retrieve the uterine horns, and a 2-clamp technique, with a Carmalt clamp placed on the ovarian pedicle proximal to the ovary and a Kelly forceps placed across the utero-ovarian junction, was used. Each ovarian pedicle was transected between the ovary and Carmalt clamp prior to or following ligation; ovarian pedicles in adult dogs were double-ligated, and those in pediatric dogs were single-ligated. The uterine body and its vasculature were ligated with 1 or 2 ligatures prior to transection. If excessive bleeding from the broad ligament was anticipated, it was also ligated. Size 0, 2-0, or 3-0 monofilament absorbable suture was selected according to pedicle size at the discretion of the student and clinician. At the end of the procedure, the abdominal wall incision was closed with simple interrupted absorbable monofilament sutures at each end and ≥ 1 suture in a cruciate pattern in the middle. Closure of the subcutaneous tissue was performed with a simple continuous suture pattern, and skin closure was accomplished with a simple continuous pattern in the intradermal layer, with the same suture material. Surgical glue was applied to the closed incision.

Ovariohysterectomy of cats was performed through a midline celiotomy, 1 to 2 cm in length, and was similar to the procedure in dogs except that a pedicle tie (autoligation) of each ovarian pedicle was performed in lieu of suture ligatures. A single ligature of 3-0 monofilament absorbable suture was placed around the uterine body prior to excision, and surgical wound closure was performed with 3-0 monofilament absorbable sutures in 3 layers as described for dogs. Surgical glue was applied to the closed incision.

Adult dogs were castrated through a prescrotal incision. Closed castration was performed by excision of the testis with placement of a single ligature of 2-0 to 3-0 absorbable suture on each spermatic cord, and the surgical wound was closed in 2 layers (subcutaneous and intradermal) with the same suture material in a simple continuous pattern, followed by surgical glue application. Open castration of pediatric dogs was performed through a scrotal incision near the median raphe; a figure-8 cord tie was used for spermatic cord ligation, and surgical glue was used for skin closure.

All animals received a linear tattoo with green tattoo paste (identifying them as having been neutered) immediately after closure of the incision and removal of the drapes. Surgical glue was applied to the tattoo. Patients were monitored during postoperative recovery and extubated when they were able to swallow. When they were able to lift their heads, animals were returned to the shelter for further monitoring by trained shelter personnel.

Students were required to write a surgery report for each animal, and any intraoperative complications, such as unusual anatomy, excessive bleeding, or the need to extend the incision, were noted. Follow-up by telephone, email, or text message was made to the shelter supervisors 1 to 2 days after surgery to obtain information related to the health of the animals. Animals with incisional complications that required resuturing were seen by a local veterinarian or by the supervising clinician.

Data collection

Data collected from the records of each animal included patient species, age, and sex; identity of the experienced practitioner or student who performed the procedure; time of anesthetic administration; surgery start (initial skin incision) and end (completion of tattooing, approx 60 seconds after drape removal) times; and time of extubation. Surgery time was calculated as the difference in minutes between the start and end of surgery.

Statistical analysis

Data were sorted by student, procedure, date, and time. Each surgical procedure performed by each student was numbered sequentially according to the date and time performed. Data were then grouped by procedure type (ovariohysterectomy of an adult dog, ovariohysterectomy of a pediatric dog, ovariohysterectomy of an adult cat, ovariohysterectomy of a pediatric cat, castration of an adult dog, or castration of a pediatric dog) and sequence. Surgical times for the same types of procedures performed from July 30, 2012, to October 23, 2013, by the experienced veterinarian applying the Association of Shelter Veterinarians veterinary medical care guidelines for spay-neuter programs were used for comparison.

For each procedure type, data for student surgeons were expressed as the least squares geometric mean surgical time and 95% confidence interval for each sequential procedure completed by ≥ 10 students. The median time for each procedure type was calculated for the experienced surgeon. The geometric mean is the arithmetic mean of the logarithmically transformed values of a variable (ie, the arithmetic mean on the log scale) followed by exponentiation of the mean to return the value to the original scale. As such, geometric mean was a more appropriate sum-
mary measure than arithmetic mean because surgical time was positively skewed (skewed to the right) in that a small number of procedures took much longer than expected. As applied in this study, the geometric mean approximates the median, but log transformation facilitates the use of parametric procedures, such as ANOVA, provided that the remaining assumptions of the statistical analysis procedure are met.

Repeated-measures ANOVA with a mixed-models procedure was applied separately for each procedure type to generate least squares geometric mean surgical time for each procedure number that accounted for the effect of student. Surgical time was log transformed for the mixed-models analysis to ensure homogeneity of variances. To describe the association between time to complete the procedure and procedure number, nonlinear and linear regression analyses were then performed by use of the least squares geometric mean values for time determined from the mixed-models procedure and the number of students contributing to each geometric mean value as a weight. Nonlinear regression followed the Levenberg-Marquardt method and used the following 3-factor exponential equation with a nonzero asymptote as described previously:

\[ \text{Surgical time} = (t_o - t_w) \times e^{-(k \times \text{procedure number})} + t_w \]

where \( t_o \) is the intercept on the y-axis (initial starting point), \( e \) is a mathematical constant approximately equal to 2.71828, \( k \) is the rate of learning (unitless value), and \( t_w \) is the surgical time at infinite procedure number under the study conditions.

This surgical time–procedure number relationship included the 3 main features of a learning curve: an initial starting point, a change in the rate of learning that is likely to be exponentially related to the number of surgical procedures performed, and an asymptotic level at which surgical performance stabilizes (optimal surgical time). Major advantages of this modeling approach were that it provided an estimate of rate of learning and the asymptotic surgical time, and examining residual plots. The best learning curve model (nonlinear or linear) was determined on the basis of visual examination of residual plots and comparison of pseudo-\( R^2 \) values (nonlinear regression) and \( R^2 \) values (linear regression). The median

operative times of each procedure type for the experienced practitioner were subjectively compared with 95% confidence intervals of the \( t_w \) value for the same procedure when performed by students.

Values of \( P < 0.05 \) were considered significant for all statistical comparisons. A statistical software program\(^a\) was used for all analyses.

**Results**

Records of 5,231 elective procedures were identified in the accessions database for the surgery and shelter rotation program during the study period. Of these, 3,056 qualified for study inclusion and were performed by student surgeons, with the total number of the specified procedures they each performed ranging from 11 to 71. A mean of 34 procedures/student was captured in the data set (Table 1). Twelve records were excluded from statistical analysis because of missing values. The median numbers of procedures performed by individual students were as follows: ovariohysterectomies of adult dogs, 6 (range, 1 to 20); ovariohysterectomies of pediatric dogs, 3 (range, 0 to 12); castrations of adult dogs, 8 (range, 1 to 19); castrations of pediatric dogs, 2 (range, 0 to 10); ovariohysterectomies of adult cats, 7 (range, 0 to 20); and ovariohysterectomies of pediatric cats, 5 (range, 0 to 19). Data for each number of procedures of a given type performed by \( \geq 10 \) students (2,945 procedures in total) and the estimated values for variables used to define the learning curves for each procedure type were summarized (Table 2). Scatterplots of surgery time by procedure number were created to estimate the learning curves for sequentially performed surgeries completed by \( \geq 10 \) students and to determine the number of procedures required for the modeled surgery time to be within the 95% confidence interval for the calculated optimal surgical time (Figures 1–6).

Comparison of \( R^2 \) and pseudo-\( R^2 \) values for linear and nonlinear regression analysis, respectively, coupled with visual examination of residual plots indicated that the 3-factor exponential (nonlinear) equation with a nonzero asymptote provided the best description of the relationship between surgical time and procedure number for 5 of the 6 surgical procedures (Table 2). The 1 exception was the surgical time–procedure number relationship for ovariohysterectomy of adult dogs that was best described by a linear equation.

For ovariohysterectomy of adult dogs (n = 568), the (geometric) mean time required for the first procedure was 55 minutes (95% confidence interval, 40 to 78 minutes); surgery time decreased linearly with sequential performance of procedures in this category, but an asymptote was not detectable within 11 procedures (the highest number of procedures performed by \( \geq 10 \) students; Figure 1). After 6 procedures, the mean time for this procedure was \( \leq 45 \) minutes (95% confidence interval, 30 to 55 minutes). For 294 ovariohysterectomies of pediatric dogs, mean time for the first procedure was 44 minutes
Small Animals & Exotic

Table 1—Numbers of fourth-year veterinary students completing between 1 and 20 elective surgical procedures during 2 weeks of a 3-week spay-neuter surgery and shelter rotation program from July 30, 2012, to May 9, 2014.

<table>
<thead>
<tr>
<th>No. of procedures</th>
<th>Ovariohysterectomy of dogs</th>
<th>Castration of dogs</th>
<th>Ovariohysterectomy of cats</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of students</td>
<td>Adult</td>
<td>Pediatric</td>
<td>Adult</td>
</tr>
<tr>
<td>1</td>
<td>88</td>
<td>82</td>
<td>87</td>
</tr>
<tr>
<td>2</td>
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<td>—</td>
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</tr>
<tr>
<td>20</td>
<td>1</td>
<td>—</td>
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</table>

Data were summarized for 590 ovariohysterectomies of adult dogs, 309 ovariohysterectomies of pediatric dogs, 742 castrations of adult dogs, 239 castrations of pediatric dogs, 652 ovariohysterectomies of adult cats, and 524 ovariohysterectomies of pediatric cats. Castrations of cats were excluded from the study. Data for another 12 surgeries were excluded because of missing information (4 ovariohysterectomies of dogs [2 adult and 2 pediatric], 4 castrations of dogs [1 adult and 3 pediatric], and 6 ovariohysterectomies of cats [all adult]).

— = Not applicable.

Table 2—Estimated values for variables used to define the learning curves for a series of elective surgical procedures performed by 88 fourth-year veterinary students during 2 weeks of a 3-week spay-neuter surgery and shelter rotation program.

<table>
<thead>
<tr>
<th>Procedure type</th>
<th>No. of students</th>
<th>No. of procedures performed by &lt; 10 students</th>
<th>Nonlinear regression</th>
<th>Linear regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>t₀ (min)</td>
<td>tᵢ (95% CI; min)</td>
</tr>
<tr>
<td>Ovariohysterectomy of dogs</td>
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<td></td>
</tr>
<tr>
<td>Adult</td>
<td>88</td>
<td>568</td>
<td>0.940</td>
<td>ND</td>
</tr>
<tr>
<td>Pediatric</td>
<td>83</td>
<td>294</td>
<td>0.964</td>
<td>0.001</td>
</tr>
<tr>
<td>Castration of dogs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>88</td>
<td>721</td>
<td>0.955</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pediatric</td>
<td>73</td>
<td>225</td>
<td>0.759</td>
<td>0.12</td>
</tr>
<tr>
<td>Ovariohysterectomy of cats</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult</td>
<td>88</td>
<td>632</td>
<td>0.957</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pediatric</td>
<td>86</td>
<td>505</td>
<td>0.958</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Repeated-measures ANOVA with a mixed-models procedure was applied separately for each procedure type to generate least squares geometric mean values for each procedure number that accounted for the effect of student; surgery time was log-transformed for this analysis. Nonlinear and linear regression analyses were then performed by use of the least squares geometric mean values for time determined from the mixed-models procedure and the number of students contributing to each geometric mean value as a weight. Nonlinear regression used the following 3-factor exponential equation with a nonzero asymptote as described previously: surgery time = (t₀ – tᵢ) X e⁻(k X procedure number) + tᵢ, where t₀ is the intercept on the y-axis (initial starting point), e is a mathematical constant approximately equal to 2.71828, k is the rate of learning, and tᵢ is the surgery time at infinite procedure number under the study conditions (ie, optimal surgery time).

CI = Confidence interval. ND = Not determined.

(95% confidence interval, 32 to 66 minutes) and the calculated asymptote was 22 minutes (Figure 2).

For castrations of adult dogs (n = 721), the mean surgical time was 25 minutes (95% confidence interval, 16 to 36 minutes) for the first patient, and the calculated asymptote was 11 minutes (Figure 3). Castrations of pediatric dogs (n = 225) required a mean of 12 minutes (95% confidence interval, 6 to 25 minutes) for the first patient, and the calculated asymptote was 8 minutes (Figure 4). The probability for the nonlinear regression model fit was not significant (P = 0.12) for castration of pediatric dogs; however, estimated nonlinear regression values are included in the comparison with other surgical procedures (Table 2).

Ovariohysterectomy procedures in adult cats (n = 632) required 36 minutes (95% confidence interval, 21 to 62 minutes) for the first procedure and had a calculated asymptote of 21 minutes (Figure 5). The
same procedures for pediatric cats (n = 505) required a mean of 31 minutes (95% confidence interval, 20 to 45 minutes) for the first patient, and the calculated asymptote was 18 minutes (Figure 6).
For this group of 2,945 animals, all procedures were completed successfully, and there were no intraoperative deaths. There were 4 known postoperative complications; 3 animals (2 dogs and 1 cat) required additional surgery for treatment of incisional hernias. One animal died during recovery, and postmortem examination did not reveal the cause of death. Incisional complications (redness, swelling, self-trauma, or infection) were subjectively few but were not tracked specifically.

One hundred forty elective spay and neuter procedures performed by the experienced general practitioner were also studied. The median surgery times were 11 minutes for ovariohysterectomy of adult dogs (n = 48), 10 minutes for ovariohysterectomy of pediatric dogs (11), 5 minutes for castration of adult dogs (31), 4 minutes for castration of pediatric dogs (8), 6 minutes for ovariohysterectomy of adult cats (17), and 6 minutes for ovariohysterectomy of pediatric cats (25). Median surgery time for ovariohysterectomy of pediatric dogs by this practitioner was within the 95% confidence interval of the optimal surgical time (Table 2); however, the median surgery times for this individual were below the 95% confidence interval for this value (ie, times for the experienced practitioner were shorter) for ovariohysterectomy of adult and pediatric cats and for castration of adult and pediatric dogs. The median surgery time was also below the 95% confidence interval of the last (11th) ovariohysterectomy procedure performed in adult dogs by students.

Discussion

The present study was performed to attempt to map learning curves for small animal surgical procedures commonly performed by veterinary students. The initial surgery times for ovariohysterectomy and castration procedures performed by these 88 students compared favorably with previously published results. As expected, the learning curve analysis revealed an inverse relationship between student surgical experience and surgery time. The data were used to calculate optimal surgical times for each procedure type except for ovariohysterectomy of adult dogs: 22 minutes for ovariohysterectomy of pediatric dogs; 11 and 8 minutes for castration of adult and pediatric dogs, respectively; and 21 and 18 minutes for ovariohysterectomy of adult and pediatric cats, respectively. These optimal surgical times for students were longer than median times for the same procedure types performed by the experienced clinician (as determined by comparison with the 95% confidence interval for calculated surgical time at the infinite procedure number [ie, optimal surgical time]) except for ovariohysterectomy of pediatric dogs. Adult dogs undergoing ovariohysterectomy can vary substantially in size, conformation, stage of estrus, and body condition score. These factors, and the relatively few canine ovariohysterectomy procedures (median of 6 for adult dogs) performed by each student likely accounted for the inability to define an optimal surgical time for this patient category in the present study. The data revealed that students had to perform 2 ovariohysterectomies of pediatric dogs, 9 castrations of adult dogs, 2 castrations of pediatric cats, and 2 ovariohysterectomies of pediatric dogs.
ric dogs, 7 ovariohysterectomies of adult cats, and 8 ovariohysterectomies of pediatric cats for the modeled surgery times to be within the 95% confidence interval for the respective optimal surgical times. The reduction in time needed to complete various surgical procedures with repetition was expected, as students were expected to become familiar with the procedures, to gain more confidence, and to develop muscle memory, by which motor skills are performed with less conscious thought. In the present study, surgery time was used as 1 measure of surgical performance, considering that intraoperative complications such as inability to identify the linea alba, difficulty in retracting a uterine horn with a spay hook, slipped ligatures, dropped pedicles, or creation of an excessively long incision would increase surgery time. Other factors that can interfere with efficient performance such as inadequate depth of anesthesia or lack of instructor availability were minimized in this study by following a standard anesthesia protocol and having the supervising clinician immediately available.

The present study focused on evaluating students while they performed surgical procedures in real practice as a demonstration of competence. Monitoring surgical time provides 1 quantitative measure that tracks performance. Measurable feedback is crucial to improving performance. By calculating learning curves and optimal surgical times, measurable goals for improvement can now be set for students in our program, and this provides an example for other institutions to follow in setting goals for surgical education of veterinary students.

Other means to assess student performance could include error analysis, use of global rating scales, or procedure-specific checklists. Bowlt et al. studied competency in veterinary surgery with a combination of surgical time determination and a procedure-specific checklist. In that study, 11 final-year veterinary students each performed 5 ovariohysterectomy procedures in dogs, and 9 of 11 students were subjectively judged as competent after performing 4 procedures. A surgery time of < 120 minutes was used as a criterion for success, along with successful completion of a checklist. Our study did not include the use of procedure-specific checklists, but the clinician monitored the successful performance of each step and gave immediate feedback to ensure that the potential for postoperative complications was minimized.

The present study has several important limitations. First, learning was characterized by reduction in surgery time alone. Prolonged surgical time is an identified risk factor for surgical site infection; however, long-term information on postoperative complication rates was lacking in this study. Major complications of elective surgery are relatively uncommon, and postoperative complication data are not always immediately available. Each shelter involved in the student rotation program was contacted 1 to 2 days after surgery and visited every 3 to 4 weeks. Three patients were known to have postoperative complications, but additional data were not available. It is possible that some animals had dehiscence, incisional hernia, infection, or other complications that were not reported or recorded in the database.

Teaching veterinary surgery requires that the animals’ needs are appropriately balanced with the students’ educational needs. If an animal is severely hypothermic, unstable under anesthesia, or at risk of other major complications, assistance is provided to enable the student to complete the procedure. This so-called contingent instruction method enables faculty members to provide help when needed. Results of a study with third-year veterinary students showed that having a faculty member scrub in with students decreased overall anesthesia and surgery times for ovariohysterectomy and castration procedures in dogs. In the study reported here, faculty intervention could have impacted individual surgery times and may have reduced surgery times, especially in a student’s first few cases, but this could not be investigated owing to the retrospective study design. In addition, the impact on surgery time of verbal instruction or manual assistance from the supervising clinician could not be assessed.

In the study reported here, each student performed ovariohysterectomies in dogs and cats and castrations in dogs, and we observed that the surgery times decreased with the absolute number of procedures regardless of the procedure type. This finding suggested that more experience in performing any given procedure could be required to reduce surgery times if it is the only procedure being practiced by the student. Another limitation when considering application to other academic centers is that all of the procedures in the present study were performed during 2 weeks of a 3-week rotation. If procedures are being learned or practiced over a longer time period, a greater number of repetitions might be required to improve technical skills and surgery times. Another consideration is that only 3 faculty members were involved in teaching these 88 students, and uniform methods and procedures were followed. The procedures were performed in our mobile unit, and close supervision was maintained.

Close examination of the scatterplots revealed a wide variation in surgical times among students for each procedure sequence. This finding was in agreement with results of another study that included cumulative summation methods and found a wide variation in ability among 6 students in 60 attempts at placing IV catheters in a dog mannequin thoracic limb model. The authors of that study identified 4 steps for catheter placement and in-control limits for demonstration of proficiency. The advantages of the method used in that study are that a certain degree of failed catheterization is acceptable and that individual learning curves can be generated. In our study, surgery time was used to characterize learning of common surgical procedures performed to completion because it was simple to measure. The data

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from a large number of students, can be expressed by a mathematical function, and the resultant learning curve is a smooth line.

An extensive 2001 study on the statistical assessment of learning curves of health technologies resulted in a number of recommendations, including the following: the rate and length of learning and the final skill level are useful measures for describing learning, learning appears to follow a power or exponential model, the simplest models should be applied in a parsimonious manner, and the reliable assessment of learning is most likely to come from prospectively collected data for multiple operators. We therefore analyzed the surgery time–procedure number relationship with an exponential equation we developed in 2011 to model the learning curve for natural orifice transluminal endoscopic surgery in dogs. To the best of our knowledge, our 2011 study was the first to use this modeling approach to describe a surgical learning curve in veterinary medicine. This modeling approach was first used in human medicine in 1989 to model the cost of heart transplantation and in 1995 to model the learning curve for radiofrequency ablation of tachyarrhythmias. A minor variant of the exponential equation was used in a 2014 study evaluating the learning curve for performing laparoendoscopic single site ovariectomy in dogs.

The exponential equation in the present study included the 3 required features of any learning curve: an initial starting point, a change in the rate of learning that is likely to be exponentially related to the number of surgical procedures performed, and an asymptotic level at which experienced surgical performance stabilizes (optimal surgical time). Major advantages of this modeling approach are that it is based on our current understanding of learning theory, is parsimonious, and directly provides an estimate for the number of procedures that must be completed to be 95% confident of reaching the calculated optimal surgical time. This information can be used to estimate the potential costs and resources required to facilitate veterinary students in becoming proficient in the procedures assessed.

An interesting finding of the present study was that median surgery times for the experienced veterinary practitioner were below the 95% confidence interval for the calculated optimal surgical time for 5 of the 6 procedures investigated. This finding provides an important methodological note for future modeling related to the basic model parameters of the learning curve, in that extensive procedural experience may result in additional gains in performance. This suggests that inclusion of an empirically observed asymptote as a prior probability distribution in a nonlinear regression model might improve model fit in data sets where the number of cumulative procedures greatly exceed the maximum modeled (14 adult canine castration procedures performed by more than 10 students) in the study reported here. The cumulative sum analysis approach modeling surgery time instead of complication rate may also provide a fruitful modeling approach for investigating the effect of extensive procedural experience on surgery time.

The nonlinear regression equation used in this study provides an estimate of the rate of change in skill development or learning (represented as k). The relative value of this variable is relevant to our understanding of skill acquisition and performance. In general terms, a higher value for k indicates a faster rate of learning. Our finding that the value for k was numerically higher for ovariopexy of pediatric cats than for that of adult cats, and numerically higher for castration of pediatric dogs than for that of adult dogs, was consistent with the authors’ observations that the surgical approach and the change in relative anatomic size and tissue composition (particularly the amount of fat) associated with age impacted surgery time. Future studies investigating the effect of patient obesity on the value of k would therefore be of interest in further defining the learning curve.

One question that the present study did not answer is when a veterinary student should be considered competent (or proficient) in performing elective procedures. We have only begun to understand how surgery times may indicate competent performance, and this information was gained by comparing results for 1 group of students with results of an experienced veterinary clinician who had performed > 200,000 of these procedures overall. Comparing the student data with data from 1 experienced veterinary clinician set a very high standard for optimal surgical time, and that standard should not necessarily be considered a general standard for surgical competence. With limited time and an anesthetized animal, our opinion is that in our mobile teaching laboratory, demonstrating a decrease in surgery time is 1 acceptable measurement of technical skills competency when procedures are being performed under supervision and when a baseline for performance has been established. We have taken the initial steps to understand what the baseline for performance or optimal surgical times of common surgical procedures might be for our students. We strongly believe that veterinary students need ample opportunities to perform elective surgical procedures to ensure that surgical technical skills are obtained prior to graduation from veterinary school. In the present study, surgery time decreased as veterinary student experience increased for each type of elective surgery, indicating the value of repetition in improving technical skills. Further study is needed to define the optimal surgical times for ovariopexy of adult dogs.

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From this month’s AJVR

Effect of lidocaine on inflammation in equine jejunum subjected to manipulation only and remote to intestinal segments subjected to ischemia
Anje G. Bauck et al

OBJECTIVE
To examine effects of continuous rate infusion of lidocaine on transmural neutrophil infiltration in equine intestine subjected to manipulation only and remote to ischemic intestine.

ANIMALS
14 healthy horses.

PROCEDURES
Ventral midline celiotomy was performed (time 0). Mild ischemia was induced in segments of jejunum and large colon. A 1-m segment of jejunum was manipulated by massaging the jejunal wall 10 times. Horses received lidocaine (n = 7) or saline (0.9% NaCl) solution (7) throughout anesthesia. Biopsy specimens were collected and used to assess tissue injury, neutrophil influx, cyclooxygenase expression, and hypoxia-inducible factor 1α (HIF-1α) expression at 0, 1, and 4 hours after manipulation and ischemia. Transepithelial resistance (TER) and mannitol flux were measured by use of Ussing chambers.

RESULTS
Lidocaine did not consistently decrease neutrophil infiltration in ischemic, manipulated, or control tissues at 4 hours. Lidocaine significantly reduced circular muscle and overall scores for cyclooxygenase-2 expression in manipulated tissues. Manipulated tissues had significantly less HIF-1α expression at 4 hours than did control tissues. Mucosa from manipulated and control segments obtained at 4 hours had lower TER and greater mannitol flux than did control tissues at 0 hours. Lidocaine did not significantly decrease calprotectin expression. Severity of neutrophil infiltration was similar in control, ischemic, and manipulated tissues at 4 hours.

CONCLUSIONS AND CLINICAL RELEVANCE
Manipulated jejunum did not have a significantly greater increase in neutrophil infiltration, compared with 4-hour control (nonmanipulated) jejunum remote to sites of manipulation, ischemia, and reperfusion. Lidocaine did not consistently reduce neutrophil infiltration in jejunum. (Am J Vet Res 2017;78:977–989)