Development and validation of an ovine cesarean surgery model and rubric

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Abstract

Clinical skills are learned through deliberate practice with specific feedback. However, it is not possible to provide such experience to each student in food animal reproductive procedures (e.g., cesarean surgery). Aims of this study were to create an ovine cesarean surgery model to facilitate skill acquisition, to create a scoring rubric to assess performance, and to gather validation evidence for the model and rubric. A commercially available ovine manikin was modified using poured silicone to create suturable skin, muscle, and uterus containing a commercially available fetal lamb manikin that could be manipulated and delivered. A scoring rubric consisting of a 16-item checklist and 5 global rating scores (GRS) was created. Model was tested by veterinarians (n = 14, experts) and veterinary students (n = 16, novices) in a validation study that evaluated evidence in content, internal structure, and relationship with other variables (level of training). Most experts (93%) felt that the model would be helpful to teach procedural steps; also experts (100%) agreed that the model would improve students' skill in performing cesarean surgery. Novices scored lower than experts on the checklist and total GRS, and novices' surgical times were longer than experts' times. Content evidence and relationship with other variables evidence supported validation of the model and rubric. Checklist reliability (alpha = 0.58) could be improved by increasing the number of items and further refining them.

Keywords: Simulation, model, ovine, cesarean surgery

Introduction

Cesarean surgery is performed in ruminants when maternal/fetal characteristics make vaginal delivery difficult/impossible, or on an elective basis due to the value of the fetus or due to conditions other than dystocia (e.g., pregnancy toxemia). Cesarean surgery is frequently performed in an emergency and must be completed quickly and accurately to save lives of dam and fetus. Although small ruminant practitioners have not expressed competencies expected of new veterinary graduates, bovine practitioners expect new graduates to be able to perform bovine cesarean surgery independently with little supervision.[1] Performing a cesarean surgery requires accurate identification of tissue layers, fetal manipulation and delivery, and proficiency in suturing individual layers upon closure.[2] Complications from cesarean surgery can occur due to errors in surgical technique and may include trauma to the uterus, gastrointestinal organs, and abdominal wall; peritoneal cavity contamination; and inadequate uterine closure.[2]

Surgical training has slowly transitioned from the 'see one, do one, teach one' paradigm (a level of competence could be reached from observation of surgery)[3,4] to deliberate practice (skill is gained through repetitive practice with specific feedback).[5-7] Surgical practice can be acquired using live animals, cadavers, or models. However, the availability of live animals requiring cesarean surgery is limited and typically seasonal, making it challenging to provide every veterinary student with adequate educational opportunities utilizing live animals. Likewise, it is unusual to find cadavers with a full-term fetus to practice cesarean surgery, and if such cadavers are available, the typical drawbacks of cadavers still exist, including lack of bleeding, onset of rigor, and postmortem tissue changes.[8]

Model-based training permits students to repetitively practice their skills until reaching competence without any risk to animal welfare, and models have proven valuable in teaching other surgical procedures including canine castration,[9,10] canine ovariohysterectomy,[11,12] and bovine castration.[13] Studies have confirmed the superiority of veterinary surgical models compared to learning surgical skills using laboratory manuals and/or videos,[11,14] cadavers,[15] and live animals.[16] A meta-analysis of human medical education studies also demonstrated that for an array of medical and surgical skills, skills taught on models were learned more effectively than skills taught using traditional methods (e.g., observation, lectures, and other hands-off learning techniques).[17] A recent review of veterinary surgical models identified a scarcity of large animal surgical models and recommended further development in this area.[18]

Authors are unaware of a commercially available model for teaching ruminant cesarean surgery nor any privately constructed model that has been previously published. First aim of this study was to create a cost-efficient ovine cesarean surgery model that would serve as a model for ruminant cesarean surgery to improve veterinary students' proficiency with this procedure. Second aim was to create a rubric to score performance on the cesarean surgery procedure. Final aim was to validate the model and scoring rubric using a framework of evidence in content, relationship with other variables (level of training), and internal structure.[19-21] The validation framework stated that if the model and rubric are valid for use in teaching veterinary students to perform ovine cesarean surgery, then:

1) experienced veterinarians will rate the model as easy to use, reasonably realistic, and suitable for use in student training (content evidence),
2) experienced veterinarians will achieve higher scores and greater surgical efficiency while performing ovine cesarean surgery on the model than students (evidence of relationship with other variables – level of training), and
3) veterinarians' and students' checklist scores will demonstrate adequate reliability (internal structure evidence).

We hypothesized that an ovine cesarean surgery model could be created that had adequate features to be acceptable to experienced veterinarians and to differentiate the performances of students from those of veterinarians. Further, we hypothesized that checklist scores would attain at least an acceptable measure of reliability.

Materials and methods

Model development and content evaluation

Study was approved (# 969 V.0) by Lincoln Memorial University (LMU) Institutional Review Board. Large animal faculty at LMU College of Veterinary Medicine worked with college's model builder to create and test model prototypes in an iterative process. Final model is described here. For ovine body, a commercially available life size standing ovine artificial insemination model (Anatomoulds, Pretoria, South Africa) was used. A stiff copper cable was bolted to the metal frame to simulate spine, and a mock last rib of copper was added. Fabric over the left paralumbar fossa was cut to make a flap (~ 20 x 30 cm). Hook and loop tape was stitched to the inside of the fabric body wall. The body wall where the left paralumbar fossa incision would be performed was created by pouring 4 layers of different colored soft silicone rubber (Smooth-On, Easton, PA) to represent skin, external abdominal oblique, internal abdominal oblique, and transverse muscle layers. Perforated clear plastic food wrap was used between the silicone layers so that they could be differentiated and undermined. Hook and loop tape was glued around the edge of the suture pad to attach it to the ovine mannikin (Figure 1).

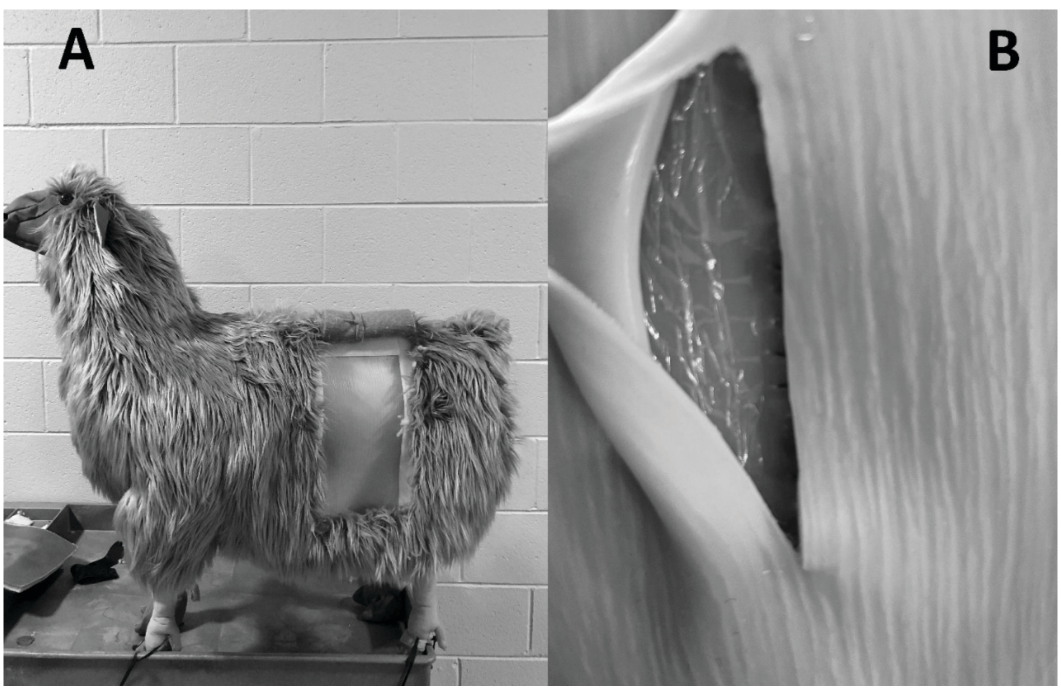

Figure 1. Ovine cesarean surgery model: A) ovine mannikin with silicone suture pad, B) clear plastic food wrap separates the skin layer from the subcutaneous layer below it

Uterus was made by pouring several layers of soft silicone rubber over a 27-cm diameter bowl. A strip of the uterus was designated as the greater curvature; this region had additional layers of poured silicone and a layer of 4-way stretch power mesh material to allow the uterus to be thick enough (3 - 4 mm) for partial thickness suturing. Placenta was made by pouring a thin layer of silicone over the same mold as the uterus, with thicker discs of silicone to imitate ovine cotyledonary placentation. Two fabric ties were included in the uterus to attach it to the metal frame dorsally so that it hung in the abdomen. For lambs, commercially available soft toys (Viahart Toy Company, Wills Point, TX) were used. For leg bones, 1.27 cm diameter polyvinyl chloride pipes were inserted into the lamb mannikin. Limbs were articulated using rivets so that the fore and hind-limb joints bent in the correct anatomical directions (Figure 2). Foam and poly-fill padding was placed into the abdominal cavity to represent other abdominal organs.

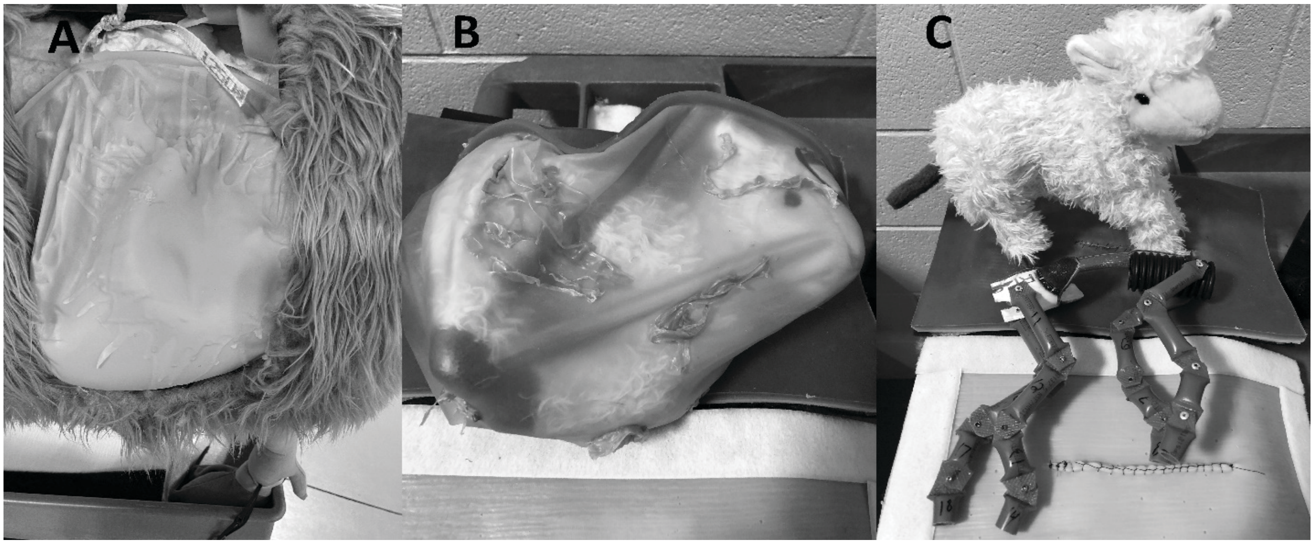

Figure 2. Ovine cesarean surgery model: A) the ovine mannikin with uterus installed in the abdomen, B) the lamb inside the uterus, C) the lamb mannikin with its spine and articulated limbs

After model's completion, a convenience sample of 14 veterinarians who were experienced in performing ruminant cesarean surgery tested the model and provided survey feedback about its features. These veterinarians were employed by 2 veterinary schools in the region; 6 were board-certified in a specialty (2 in theriogenology, 2 in surgery, and 2 in internal medicine), and 8 were general practice veterinarians. Data were collected using a series of 5-point Likert scales ranging from 'strongly disagree' to 'strongly agree' about ease of use, fidelity, and perceived ability to enhance student learning. Veterinarians were invited to provide written comments about the model (Appendix 1).

Novice to expert comparison

A convenience sample of third year veterinary students (n = 16) who had never performed a ruminant cesarean surgery was recruited from students enrolled in a food animal elective course (n = 31). Prior to using the model, students had a 50-minute lecture regarding ruminant cesarean surgery and read an article describing the procedure.[2] All students were enrolled in the LMU surgical skills training program, and their prior instruction included repetitive practice of surgical skills on the canine castration model, canine ovariohysterectomy model, and several suturing and ligation task trainers. Students were not exposed to the ovine cesarean surgery model prior to the start of the study.

Students, along with 14 veterinarians who had provided survey feedback, were recorded using wide angle action video cameras (GoPro HERO 6, GoPro, San Mateo, CA) while preparing for and performing cesarean surgery on the ovine model. Preparation included identifying landmarks and choosing where to make the incision. Although the model could simulate an inverted L-line block for anesthesia if desired, this feature was not used. Veterinarians performed the surgical procedure according to the technique were comfortable in using and not necessarily the standardized technique taught to the students. Ovine model was positioned standing on top of a low table to simulate an acceptable position for performing ovine cesarean surgery.[22] For the first 2 participants, veterinarians, cameras were worn on a head mount. After researchers observed that there was too much motion in these videos, cameras were subsequently attached to a nearby rod using a flexible arm. Cameras were oriented to exclude participant's identifying features whenever possible.

Recorded surgeries were scored and timed by 1 investigator who was experienced in performing ruminant cesarean surgery and in teaching students to perform the procedure. Rater was not involved in development of the model or rubric and was blinded to the identity and group of the person performing the procedure. Surgical time was recorded from the start of the incision to end of the final stitch. The video recordings were viewed on a computer monitor, and the rater could pause or replay the recordings as needed.

A rubric to score the video recordings was developed by faculty members who were experienced at performing, teaching, and assessing ruminant cesarean surgery and general surgical skills. Rubric consisted of 16 checklist items and 5 global rating scales. The 16 checklist items represented the steps for performing the procedure on a live animal and were each scored with 0 point awarded for unsatisfactory performance for that step and 1 point awarded for satisfactory performance of that step. Maximum checklist score was 16 points. Five global rating scores (GRS) were awarded independently from the checklist score and were awarded for tissue handling, instrument handling, efficiency of time and motion, suturing, and overall GRS.

Each GRS was scored on a 1 - 6 scale with 1 point awarded for a very poor performance, 2 for poor, 3 for borderline unsatisfactory, 4 for borderline satisfactory, 5 for good, and 6 for excellent (Appendix 2). Rubric was not shared with study participants.

Student Surveys

After performing simulated cesarean surgery, students completed a survey evaluating the model's features and ease of use on a 5-point Likert scale. Students were invited to write comments for its continued improvement (Appendix 3).

Data analyses

Data were analyzed using SPSS version 28 (IBM). Categorical and ordinal data (survey data, GRS, and scores from individual steps on the checklist) were compared using Mann-Whitney U-tests. A Shapiro-Wilk normality test was performed on continuous data (surgical time, checklist score, and total GRS); checklist score percentage and total GRS were normally distributed but not time. Performance scores were compared using Student's *t*-tests, and surgical time was compared using a Mann-Whitney U-test. For variables analyzed with a *t*-test, Levene's test was used to confirm homogeneity of variance. Hedge's *g* was used to evaluate effect sizes because the group sizes were unequal. Benchmarks suggested by Cohen were used for interpreting effect sizes; 0.2 was considered small, 0.5 medium, and 0.8 large.[23] Cronbach's alpha was used to assess internal consistency of checklist scores.

Results

Model development

To produce a model deemed acceptable by the teaching faculty, model developers went through 2 revisions of the lamb, 4 revisions of the abdominal closure pad, and 2 revisions of the uterus to get the correct thickness and texture. Entire manikin, including lamb, cost $732 to construct. Replacement parts for each use, including closure pad, uterus, and placenta, were $38 per use. If not ripped, uterus could be patched with silicone and reused for a second surgery for a $10 cost savings.

Content evaluation

Fourteen veterinarians provided survey feedback after using the model, providing content evidence for the model's validation. All veterinarians agreed to strongly agreed that the model was easy to use, and the majority of veterinarians (13/14, 93%) agreed that adequate landmarks were present and that the model felt realistic. Eleven veterinarians (79%) felt that the model's materials looked realistic. Nine veterinarians (64%) felt that the model adequately replicated the actual tactile experience; 1 veterinarian (7%) disagreed with this statement whereas remaining 4 veterinarians (29%) were neutral. Thirteen veterinarians (93%) felt that the model was able to teach preparation and skills required to perform the skill, and that the model would improve animal welfare by allowing students to first perform the skill on the model; 1 veterinarian (7%) was neutral on these statements. All veterinarians felt that the model would increase students' learning of the skill. Thirteen veterinarians (93%) felt that the model was adequate to prepare students for performing a live animal cesarean surgery; 1 veterinarian (7%) was neutral on this statement. One veterinarian (7%) felt a concern that the model could teach students poor technique; that veterinarian also left a comment explaining that the model's skin was not a good representation of the live animal, and that this could result in poor suturing technique. Survey item results are summarized (Table 1). Thirteen veterinarians left a total of 25 written comments about the model (Table 2).

Table 1. Veterinarians' survey responses after using the model

Question	**Strongly disagree n (%)**	**Disagree n (%)**	**Neutral n (%)**	**Agree n (%)**	**Between agree and strongly agree* n (%)**	**Strongly agree n (%)**
Model was easy to use*				5 (36%)	1 (7%)	8 (57%)
Adequate landmarks were present		1 (7%)		10 (71%)		3 (21%)
Materials looked realistic*		1 (7%)	2 (14%)	7 (50%)	1 (7%)	3 (21%)
Materials felt realistic*		1 (7%)		11 (79%)	1 (7%)	1 (7%)
I feel that students can safely utilize this model				3 (21%)		11 (79%)
Model was able to teach the preparation and steps required to perform this skill			1 (7%)	7 (50%)		6 (43%)
Model adequately replicates the actual tactile experience when performing this skill		1 (7%)	4 (29%)	8 (57%)		1 (7%)
Model will improve animal welfare by allowing students to first perform the skill on the model	1 (7%)			1 (7%)		12 (86%)
Model will increase students' learning ability by first performing the skill on the model				1 (7%)		13 (93%)
Model is adequate to prepare students for performing a live animal cesarean surgery		1 (7%)		4 (29%)		11 (79%)
Model could teach students poor technique	3 (21%)	10 71%)		1 (7%)		

*One veterinarian marked in between agree and strongly agree

Table 2. Veterinarians' comments about the model, paraphrased. Numbers in parentheses indicate how many veterinarians made that comment.

Add fluid in the uterus (6)
Very good model/very useful (4)
Skin should be tougher/suture pulls through (3)
Muscle layers should be tougher/puncture resistant (2)
Add peritoneal fluid (2)
Silicone material doesn't mimic live tissue very well; had more memory than typical small ruminant skin (2)
Add a peritoneum (2)
Add more landmarks – e.g., transverse vertebral wings, pin bone, etc. (2)
Tissue layers didn't open up like they would in real life (2)
Add a rumen
Good layers for suturing
Skin feel is excellent
Surprisingly life like
Shows all steps necessary
Sterility reminders will need to be provided by supervisor
Materials a bit sticky
Uterus should have same thickness throughout
Uterus should be thicker so students can do Utrecht as a partial thickness pattern
Fetus was outside of the uterus when I entered the abdomen.
Skin layer released from the model during my approach.
Uterus was a bit hard to identify. I thought it was possibly intestine or other tissue.
Ideally should bleed

Novice to expert comparison

Two expert videos were excluded because they were recorded using a head mount, and there was too much motion in the video recordings for accurate scoring. Six student videos were excluded from analysis because the video files were lost or incomplete. This left 12 expert videos and 10 student videos for scoring.

On average, experts received a checklist percentage score of 73.4% (SD = 12.5%); this was higher ($p = 0.042$) than the average checklist score achieved by students (mean = 62.4%, SD = 15.2%, $g = 0.88$). On average, although experts tended to receive an overall higher GRS of 3.67 (SD = 1.30) it was not different ($p = 0.058$) from the overall GRS awarded to students (mean 2.90, SD 0.88, $g = 0.59$). On average, the sum of experts' 4 GRS was 16.25 (SD = 3.67); this was higher ($p = 0.043$) than the sum of students' 4 GRS (mean = 13.50, SD = 3.44, $g = 0.75$). Experts spent a median of 42 minutes (IQR = 8.75) performing the surgery; this was less than ($p = 0.03$) the time spent by novices (median 69.00, IQR = 30.75). Although experts may have varied slightly in how they performed the procedure, the low IQR (8.75 minutes) suggested that these small variations did not have much impact on procedural time. Alpha for the 13-item checklist was 0.58.

Student surveys

Fifteen of the 16 students (94%) agreed or strongly agreed that the model was easy to use and had adequate landmark structures. Ten students (63%) agreed or strongly agreed that the materials looked and felt realistic; Although students had not previously performed ovine cesarean surgery and could not rate tissue realism specific to that surgery, they could rate tissue realism generally due to their experience performing small animal ovariohysterectomies and orchidectomies. All students agreed or strongly agreed that they could safely utilize the model. Student survey responses are summarized (Table 3). One student left a comment regarding the difficulty to suture deeper layer; it was unclear if this referred to the uterus or the abdominal transversus muscle layer. No other student comments were received.

Table 3. Students' survey responses after using the model

Question	Strongly disagree n (%)	Disagree n (%)	Neutral n (%)	Agree n (%)	Strongly agree n (%)
Model was easy to use			1 (6%)	6 (38%)	9 (56%)
Adequate landmarks were present			1 (6%)	7 (44%)	8 (50%)
The materials looked and felt realistic		1 (6%)	5 (31%)	7 (44%)	1 (6%)
I feel that I can safely utilize this model				1 (6%)	15 (94%)

Discussion

"Days of 'see one, do one, teach one' are long gone, and we are now in the era of evidence and outcome medicine; that is, 'see many, learn from the outcome; do many with supervision and learn from the outcome; and finally, teach many with supervision and learn from the outcome'".[24]

Learning to perform a surgical procedure takes practice and repetition,[5] and a well-designed model gives veterinary students the opportunity for repetitive practice and frees them from the necessity of animal or cadaver availability. In this study, the ovine cesarean surgery model and rubric were assessed using a validation framework of content evidence, relationship with other variables (e.g., level of training) evidence, and internal structure evidence. Experts rated the model's features and value for training students highly, offering content evidence in support of validation. Experts' comments indicated their desire for a rumen to be added to the model, and lubrication or fluid to simulate the slippery uterine environment. After completion of the study, the model was modified to include a rumen, simulated by a mostly deflated free-hanging rubber ball that must be pushed out of the way to access uterus. Lubrication or fluid in the uterine environment poses more of a logistical challenge and is being considered for future iterations of the model. Novices felt that the model was easy to use and possessed adequate landmark structures to orient them to the task.

Experts scored significantly higher than novices on the checklist and total GRS, which indicates that the model had adequate features to differentiate novice from expert performance. Experts also performed the procedure faster than novices, though the time to perform the procedure varied widely among novices. Other studies in veterinary education have also demonstrated that novices require longer time to perform simulated procedures.[25-28] Students performing ovine cesarean surgery on the model may have benefitted from the presence of a second surgeon or technician to assist during surgery. However, the design of the study required that the surgeon perform the procedure alone to limit the influence of the second person's skills, knowledge, and abilities. When included in the veterinary curriculum, the mock cesarean surgery could be performed by 2 students, allowing the primary surgeon to have the benefit of the assistant and granting students more training time with the model—once as assistant surgeon and once as primary surgeon.

Scores produced by the 16-item checklist had poor to questionable internal consistency ($\alpha = 0.58$), which indicates that performance among the various items was not closely correlated. This suggests that the steps performed during ovine cesarean surgery require a diversity of skills that are not necessarily closely related. These skills include knowledge-based items (e.g., leaving the feal membranes in the uterus rather than peeling it away and selecting appropriate suture patterns for closure). These skills also include technical items such as making a smooth incision and isolating muscle layers for incision. Modifying the checklist to contain more items would increase the internal consistency, as would including items that are more correlated with one another. Also, some of the individual skills contained within the cesarean surgery procedure may be able to be taught separately using task trainers (e.g., suture trainers for large animal skin and hollow organs).

Our study had some limitations. First, surgical performance was evaluated using video recordings rather than being observed in person. Although this allowed a single blinded scorer to score all performances, evaluating a 3-dimensional task using a 2-dimensional recording can potentially impact the accuracy of performance ratings.[29] Previous research has indicated that assessing surgical skills using video recordings is a useful way of improving study flexibility and allowing blinding.[30] Second, some participants' videos were either lost, incomplete, or unsuitable for scoring because of using a head mounted camera that impaired the rater's ability to evaluate performance. Other studies in veterinary education have also excluded some participants' videos from analysis due to technological malfunctions with cameras and video recordings.[9,29,31]

Statistical significance was observed despite lower number of participants. Third, surgical performance was evaluated by a single rater; this did not allow for the calculation of inter-rater reliability. Inter-rater reliability could be assessed in a subsequent study using the model and rubric. Fourth, the model was placed in standing rather than lateral recumbency that is more common for ovine cesarean surgery. Model accommodates either positioning. Finally, the study was performed with a relatively small cohort of veterinarians and veterinary students. Additional studies involving students from multiple institutions could generate further evidence for generalizability to other settings. Research comparing students' surgical performance on this model to their performance on the live animal procedure would provide further evidence in support of validation.

Conclusion

A cost-effective ovine cesarean surgery model has been created that met the content evidence and relationship with other variables evidence components of the validation framework. Reliability of scores produced by the checklist in this study could be further increased by adding more items and including items that are more correlated with one another. Model allowed students to practice cesarean surgery in a safe, standardized, low-stress environment. Teaching students to perform cesarean surgery on a model will allow them to perform the procedure repetitively to hone their skills while receiving instructor feedback, before performing the procedure on a live patient.

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Conflict of interest

Authors have no conflict of interest to report.

Author contributions

Philippa Gibbons: Conceptualization, Methodology, Investigation, Resources, Writing – Review & Editing, Supervision

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Dave Dutton: Formal analysis, Writing – Review & Editing

Tiffany Pulliam: Conceptualization, Methodology, Investigation, Writing – Review & Editing

Stacy Anderson: Conceptualization, Methodology, Resources, Writing – Review & Editing

Julie Hunt: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Supervision

Data availability statement

Data that support the findings of this study are available from the corresponding author (Julie Hunt) upon reasonable request.

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Appendix 1. Model evaluation survey* completed by veterinarians

Please rate the statements below using a scale of strongly disagree, disagree, neutral, agree, and strongly agree.

Adequate landmarks were present
Materials looked realistic
Materials felt realistic
Model was easy to use
Model was able to teach the preparation and steps required to perform the skill
Model will improve animal welfare by allowing students to first perform the skill on this model
Model will improve students' learning ability by first performing the skill on this model
Model is adequate to prepare students for performing a live animal caesarean surgery
Students can safely utilize this model
Model could teach students poor technique

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*Adapted from: Williamson JA: Construct validation of a small-animal thoracocentesis simulator. J Vet Med Educ 2014;41:384-389.

Appendix 2. Rubric used to score expert and novice performances on the model

Checklist (yes/no)

1. Palpates landmarks for appropriate placement of incision
2. Makes incision in the correct location on the paralumbar fossa
3. Creates skin incision of appropriate length (10 - 15 cm)
4. Makes smooth incision through skin
5. Isolates external abdominal oblique and either incises sharply or lifts and uses scissors
6. Isolates internal abdominal oblique and either incises sharply or lifts and uses scissors
7. Isolates transversus and lifts and uses scissors to incise
8. Makes similar length incisions through skin and muscle layers
9. Palpates and correctly identifies uterus
10. Brings fetus's hind limb to the body wall incision
11. Makes uterine incision approximately 10 cm in length (equal to fetal foot to hock length)
12. Leaves placenta in the uterus (unless it comes away with the lamb)
13. Uses inverting suture pattern to close uterus (Utrecht preferred; Cushing accepted if performed well)
14. Closes muscle layer using simple continuous pattern (either individual layers or all in one)
15. Closes skin using Ford interlocking pattern
16. Ends skin closure with 1 - 2 simple interrupted at ventral end of incision

Global Rating Scales (very poor, poor, borderline unsatisfactory, borderline satisfactory, good, excellent)

1. Tissue handling
2. Instrument handling
3. Efficiency of time and motion
4. Quality of suturing
5. Overall global rating score

Appendix 3. Model evaluation survey* completed by students

Please rate the statements below using a scale of strongly disagree, disagree, neutral, agree, and strongly agree.

Adequate landmarks were present
Materials looked/felt realistic
Model was easy to use
Model was suitable to teach the preparation and steps required to perform the skill
Model was suitable to give a general idea of the actual tactile experience when performing the skill
I feel the model will increase student learning ability by first performing the skill on this model
I feel students can safely utilize this model

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*Adapted from: Williamson JA: Construct validation of a small-animal thoracocentesis simulator. J Vet Med Educ 2014;41:384-389.