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Focused cardiac ultrasound examination in the emergency and critical care horse: Training for non-specialist veterinarians and evaluation of proficiency

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[Correction added on 15 Jul 2022, after the first online publication: article title has been changed to Focused cardiac ultrasound examination in the emergency and critical care horse: Training for non-specialist veterinarians and evaluation of proficiency.]

Abstract

Background: Focused cardiac ultrasound examination (FoCUS) is rapidly emerging for point-of-care cardiac assessment using hand-carried ultrasound (HCU) devices. A specific FoCUS protocol for horses and adequate training guidelines currently are not available.

Hypothesis: To gain knowledge about the training necessary to become proficient in performing FoCUS using a HCU device.

Animals: Three healthy Warmblood horses were used for practical training of veterinarians and veterinary students in equine focused cardiac ultrasound (eFoCUS).

Methods: Prospective educational study. An eFoCUS protocol and 1-day training course were developed. Pre- and post-course written tests were administered to participants to evaluate proficiency in knowledge of echocardiography and echocardiographic pathology. A post-course practical examination involved performing eFoCUS and storage of representative images. Images were evaluated using an image quality score and compared between participants with some practical experience and participants with no practical experience.

Results: Participants' knowledge of echocardiography increased significantly. Recognition of echocardiographic pathology pre-course ranged from 40% to 90% (mean score, 65.7%) and post-course from 85% to 100% (mean score, 92%). Eighteen of 21 participants were proficient in performing eFoCUS with a median image quality score of 79% (range, 42%-95%). Image quality did not differ between participants with some practical experience compared to participants with no experience.

Conclusions and Clinical Importance: Veterinarians and veterinary students independent of previous experience can become proficient in performing eFoCUS after completion of a 1-day training course.

Abbreviations: Ao, aorta; ASE, American Society of Echocardiography; eFoCUS, equine focused cardiac ultrasound; HCU, hand-carried ultrasound; LA, left atrium or left atrial; LV, left ventricle or left ventricular; LVOT, left ventricular outflow tract; PA, pulmonary artery; POCUS, point-of-care ultrasound; R-4C, right-parasternal long-axis 4-chamber view; R-AoSAX, right-parasternal short-axis view at the level of the aortic valve; R-LVOT, right-parasternal left ventricular outflow tract view; R-LVSAX, right-parasternal short-axis view of the left ventricle at the level of the chordae tendineae; R-RVOT, right-parasternal right ventricular outflow tract view; RV, right ventricle or right ventricular; RVOT, right ventricular outflow tract.

KEYWORDS
echocardiography, hand-carried, horse, level of competence, point of care

1 | INTRODUCTION

Focused cardiac ultrasound examination (FoCUS) is rapidly emerging as an important tool for point-of-care cardiac assessment in human medicine.[1-4] In contrast to comprehensive echocardiography performed by cardiologists with advanced training, the principal role of FoCUS is time-sensitive evaluation of the symptomatic emergency or critical care patient by the non-specialist clinician and initiation of emergency treatment.[3] It represents a qualitative or semiquantitative examination that typically includes only a limited number of echocardiographic views and addresses only a limited number of cardiac abnormalities. In horses, overt clinical signs of cardiac disease often only occur when severe cardiac dysfunction is present, whereas cardiac manifestation of systemic disease might remain undetected without further diagnostic testing.[5] In such cases, FoCUS may be valuable to identify horses with cardiac disease, understand underlying pathophysiology, narrow the list of differential diagnoses, assess the need for immediate therapeutic intervention, and trigger further diagnostic evaluation. Thoracic and abdominal point-of-care ultrasound (POCUS) examinations are increasingly performed in the veterinary emergency room, but a specific FoCUS protocol that allows for cardiac assessment of horses currently is not available.[6-10] Specific training in FoCUS, including image acquisition, recognition and interpretation of important echocardiographic pathologies, awareness of its scope and limitations and assessment of proficiency, is strongly emphasized in human medicine.[11-13] Veterinarians rarely are trained to perform echocardiographic examinations at the point of care, and trained specialists are often not available in an emergency or critical care setting. However, new and emerging technologies and the wide availability of portable hand-carried ultrasound (HCU) devices facilitate the use of POCUS in virtually any location.[14] Therefore, adequate training to gain basic competence for POCUS examinations will become necessary in veterinary medicine. A 4-step teaching approach consisting of demonstration, deconstruction, comprehension, and execution is becoming increasingly prevalent in medical education.[15] It is considered superior over traditional bedside teaching methods such as "see 1, do 1" in short- and long-term retention of practical medical skills and was shown to be effective in teaching focused echocardiography.[16-18] Data on adequate training for non-specialist practitioners to perform POCUS examinations are not available to date. Our purpose was to gain knowledge about the required training for veterinarians to become proficient in performing a specifically designed FoCUS protocol for horses (equine focused cardiac ultrasound, eFoCUS) using a HCU device. Our hypothesis was that with a 1-day training course employing the previously described 4-step approach, veterinarians with no previous experience in echocardiography would gain sufficient basic knowledge and practical skills to obtain echocardiographic views of sufficient quality to evaluate cardiac size and function subjectively and would correctly recognize clinically relevant echocardiographic pathologies.

2 | MATERIALS AND METHODS

2.1 | FoCUS for emergency and critical care patients

We developed a specific eFoCUS protocol. The following key elements determined the design of the eFoCUS approach: (a) Allows rapid (< 10 minutes), real-time cardiac assessment of horses; (b) rules in or out a limited number of potentially hemodynamically relevant cardiac abnormalities; (c) aids in time-sensitive decision-making and guides emergency treatment; (d) can be used by non-specialist clinicians with adequate basic training; (e) can be performed using a HCU device; and (f) Identifies when referral for comprehensive echocardiography is indicated.

The following steps combined with a narrow list of potential echocardiographic pathologies were included to allow for a systematic approach:

1. Exclude obvious pathologies: Pericardial effusion, extra-pericardial or pericardial mass lesions, obvious structural cardiac abnormalities, and obvious valvular thickening.
2. Subjectively assess chamber and great vessel dimensions: Enlargement of the left atrium (LA) including increased LA-to-aortic area ratio in short axis, enlargement or diminution of the left ventricle (LV), right ventricle (RV) or both, and dilatation of the pulmonary artery (PA) including decreased aorta (Ao)-to-PA diameter ratio.
3. Subjectively assess myocardial thickness and echogenicity: Focal and generalized hyper- or hypo-echogenicity and increased or decreased myocardial thickness.
4. Subjectively assess LV mechanical function: Hyperkinesis, decreased systolic function and impaired diastolic function.
5. Relate the findings to the clinical context.

Five standard right-parasternal long- and short-axis echocardiographic views as described previously were included in the proposed eFoCUS protocol.[19,20] The eFoCUS image planes were determined by 3 factors: (a) Application of only basic echocardiographic modalities, (b) visualization of each target structure in at least 2 different views as recommended by the American Society of Echocardiography (ASE), and (c) presumption that the required image acquisition skills can be obtained in a 1-day course.

1. Right-parasternal long-axis 4-chamber view (R-4C)
   This view is obtained first to achieve a broad overview of cardiac size and function. It allows for exclusion of obvious pathologies

such as pericardial effusion, extra-pericardial or pericardial mass lesions, abnormal or lack of anatomical structures and thickening of the mitral and tricuspid valves; assessment of obvious enlargement or diminution of all cardiac chambers; assessment of obvious myocardial abnormalities such as focal or generalized hyper- or hypo-echogenicity and increased or decreased thickness; assessment of abnormal LV mechanical function such as marked hyper- or hypo-kinesis and impaired diastolic function.

2. Right-parasternal left ventricular outflow tract view (R-LVOT)
   This view is obtained primarily to assess the size of both great vessels and the aortic valve. It allows for exclusion of obvious pathologies such as large perimembranous ventricular septal defect, large aorto-cardiac fistula, and aortic valve thickening; assessment of great vessel enlargement and Ao-to-PA diameter ratio for diagnosis of pulmonary hypertension (suspected if the PA appears larger than the Ao). This view also may identify extra-pericardial or pericardial mass lesions, but offers limited assessment of the ventricular myocardium and is not suitable for assessment of ventricular function.
3. Right-parasternal short-axis view of the left ventricle at the level of the chordae tendineae (R-LVSAX) and corresponding M-mode recording (R-LVSAX MM)
   This view complements assessment of ventricular size and mechanical function and assessment of the myocardium and pericardial space. It allows for additional assessment of ventricular chamber enlargement, assessment of obvious myocardial abnormalities such as increased or decreased thickness, and assessment of abnormal ventricular function such as marked hyperkinesis, decreased systolic function and impaired diastolic function. It may further help identify pericardial effusion and extra-pericardial or pericardial mass lesions.
4. Right-parasternal short-axis view at the level of the aortic valve (R-AoSAX)
   This view is obtained primarily to assess dimensions of the LA (including the LA appendage) in relation to the Ao (LA area should be < approximately 3 × the aortic area). In addition, it allows for assessment of obvious pathologies such as aortic valve thickening, ventricular septal defect, and aorto-cardiac fistula by moving the probe slightly dorsal or ventral.
5. Right-parasternal right ventricular outflow tract view (R-RVOT)
   This view is obtained primarily for additional assessment of right heart size and allows for evaluation of PA dilatation and pulmonic valve thickening. In addition, it allows for exclusion of extra-pericardial or pericardial mass lesions and pericardial effusion.

2.2 | Training course and participants

A 1-day training course was developed by the authors. The course was open to all equine internal medicine residents, interns, final-year veterinary students, and ambulatory veterinarians at the authors' institution. Twenty-one participants volunteered to complete the eFoCUS course including pre- and post-course tests. Participants were grouped based on their professional background and comprised 6 veterinarians enrolled in the American College of Veterinary Internal Medicine-Large Animal Internal Medicine (ACVIM-LAIM) or European College of Equine Internal Medicine (ECEIM) residency program, 5 veterinary equine interns, 5 ambulatory veterinarians, and 5 final-year veterinary students. It is recognized that the student-to-instructor ratio should be no higher than 5 to 1 to ensure appropriate POCUS skills training.[21] Five 1-day courses were held over a period of 2 months. Four courses enrolled 4 participants each (courses 2 to 5) and 1 course had 5 participants (course 1). Fourteen participants had no previous practical experience in echocardiography and 7 participants had some practical experience by exposure to clinical cases with cardiovascular disease. No previous practical experience was defined as never having performed any cardiac ultrasonography. Participants were assigned to courses independent of their professional background to achieve a heterogeneous setting.

The course consisted of 2 lecture-based sessions followed by 4 practical sessions (Data S1). The first lecture included the scope and limitations of eFoCUS and an introduction to acquisition of eFoCUS views including identification of normal echocardiographic anatomy. A second lecture covered recognition and interpretation of a limited number of cardiac abnormalities (Table 1). The 4 practical sessions including demonstration, deconstruction, comprehension, and execution were carried out using healthy privately owned Warmblood horses. The horses were unsedated and restrained by 1 of the participants.

A modified 4-step teaching approach was used to teach practical echocardiographic skills as described previously.[15,18] The following gives a brief overview of the modified 4 steps as used for practical training: (a) Demonstration (45 minutes): The course instructor demonstrated the eFoCUS protocol in real time with comments on image acquisition, identification of anatomical structures, and echocardiographic pathologies to be assessed. Questions were not allowed. (b) Deconstruction (45 minutes): The course instructor performed a second slower presentation of the eFoCUS protocol and gave a detailed overview for every eFoCUS view as in the demonstration. Questions were allowed at any time. (c) Comprehension (90 minutes): The course instructor performed the eFoCUS protocol and involved a participant, asking him or her to comment on adequate image acquisition and anatomical structures. This step was repeated multiple times until every participant had assumed the role of the instructor performing the eFoCUS protocol and every participant had commented on image acquisition and anatomical structures. A second round was carried out in the same manner but included comments on echocardiographic pathologies. (d) Execution (60 minutes): The participants simultaneously narrated and executed the eFoCUS protocol. During the practical sessions, participants were given the necessary time until an adequate quality view was achieved. During comprehension and execution, the instructor directed the participants by giving advice such as "turn the probe to the 1 o'clock position" or "angle more cranially."

TABLE 1 List of echocardiographic pathologies covered in lectures and tests

Echocardiographic pathology covered in lecture-based session	Number of participants (n = 21) that correctly identified the echocardiographic pathology in the test	
	Pre-course	Post-course
Obvious pathology		
Pericardial effusion	20	21
Paramembranous VSD	7	n/a
Valvular thickening	10	21
Pericardial mass lesion	n/a	n/a
Aorto-cardiac fistula	n/a	n/a
Complex congenital defect	8	n/a
Chamber and great vessel enlargement		
LA enlargement	20	19
LV enlargement	17	21
RV enlargement	n/a	n/a
Dilatation of the pulmonary artery	12	21
Dilatation of the aorta	n/a	n/a
Myocardial thickness and echogenicity		
Increased thickness	17	21
Decreased thickness	n/a	n/a
Focal lesion	16	20
Generalized abnormal echogenicity	n/a	18
LV function		
LV hyperkinesis	11	21
Decreased LV systolic function	n/a	19
Decreased LV diastolic function	n/a	8

Abbreviations: LA, left atrial; LV, left ventricular; n/a, included in the lectures but not in the respective test; RV, right ventricular; VSD, ventricular septal defect.

2.3 | Echocardiographic equipment

The Lumify S4-1 portable phased-array ultrasound transducer (Philips, Horgen, Switzerland) connected to a mobile device (Samsung Galaxy Tab S2 8.0, Samsung Electronics, Zurich, Switzerland) and operated with the corresponding application (Lumify App, Philips, Horgen, Switzerland) was used throughout the study. This HCU device provides 2-dimensional (2D) imaging, M-mode, and conventional color flow echocardiographic modalities; allows setting the image depth to a maximum of 30 cm; and provides adjustable time-gain compensation. Electronic calipers are available for measurements. All images can be frozen and scrolled for review and can be saved in digital still image or fixed-time cine-loop video format and exported as Digital Imaging and Communications in Medicine (DICOM) files. For the study, imaging depth was kept at 30 cm and the sector width was kept unchanged at 90° to achieve a recording frame rate of 18 Hz.

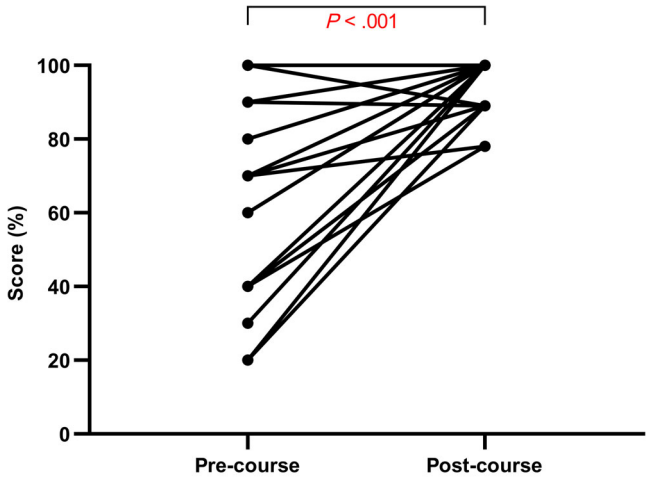

FIGURE 1 Scatter plot of the pre- and post-course test scores in percent, covering knowledge of echocardiography and echocardiographic anatomy. The dots and connecting lines represent individual participant paired scores

2.4 | Evaluation of proficiency

All participants completed 2 pre-course multiple choice tests on the morning of the 1-day training course. Knowledge of echocardiography and identification of normal echocardiographic anatomy were tested, followed by recognition of echocardiographic pathologies using normal echocardiograms and images of echocardiographic pathologies. In the evening after the course, all participants completed 2 similar tests. The first test included multiple choice questions on knowledge of echocardiography and identification of normal echocardiographic anatomy using different echocardiographic examples than used in the pre-course test. A second open answer test evaluated the participants' ability to correctly recognize specific echocardiographic pathologies using cine-loop recordings displayed on a screen. Pre- and post-course tests were similar in content and difficulty and included 10 echocardiograms each (Data S3 and Videos S1–S4).

The participants' ability to execute the entire eFoCUS protocol within 10 minutes and without guidance was assessed at the end of the course. Participants obtained and stored 5-second long cine-loops of every eFoCUS view digitally. Cine-loops of the R-4C view were recorded twice, 1 with focus on the LA and 1 with focus on the LV. The R-LVSAX and the R-LVSAX MM views were recorded as 1 cine-loop and 1 still image displaying 2 complete cardiac cycles, respectively. The R-LVOT, R-AoSAX, and R-RVOT views were recorded as 1 cine-loop each. Hence, 7 recordings per participant were obtained and stored. The recordings subsequently were evaluated by a blinded, independent observer with advanced training and competence in equine cardiology using a scoring sheet (Data S2). An image evaluation score was designed by the authors based on whether the respective cardiac structures were displayed adequately to be assessed subjectively and whether appropriate measurements would be feasible (Data S2). During the blinded evaluation process, the score also was applied to eFoCUS images produced by the course instructor, which were rated with a score of 100% by the blinded observer. The R-4C

with focus on the LA, R-4C with focus on the LV and R-LVOT views were evaluated based on 5 criteria and the R-LVSAX, R-LVSAX MM, R-AoSAX and R-RVOT views based on 4 criteria. Scores of 2, 1, and 0 were given for "perfect display for subjective evaluation and feasibility of measurement of cardiac dimensions," "acceptable display for subjective evaluation," and "not acceptable for subjective evaluation," respectively. A maximum score of 10 was attainable for each of the R-4C with focus on the LA, R-4C with focus on the LV and R-LVOT views and a maximum score of 8 was attainable for each of the R-LVSAX, R-LVSAX MM, R-AoSAX, and R-RVOT views. The maximum attainable total eFoCUS score was 62. Adequate image quality for subjective evaluation was defined as a minimum score of 1 for every criterion evaluated, excluding whether appropriate measurements would be feasible. Because of differences in the number of criteria evaluated in the different eFoCUS views, percent scores were reported and used for calculations. Participants were considered proficient in eFoCUS image acquisition when they achieved a mean score ≥ 65% with a maximum of 1 out of 7 views considered insufficient for subjective evaluation. The mean score was calculated as the sum of the individual eFoCUS view scores in percent divided by the number of views.

2.5 | Data analyses and statistics

All statistical and graphical analyses were performed using standard computer software (GraphPad Prism version 8.3.0; GraphPad Software, Inc, San Diego, California). Participants' pre- and post-course knowledge of echocardiography and echocardiographic pathologies as well as scores for eFoCUS views were assessed by descriptive statistics. To detect any differences between pre- and post-course

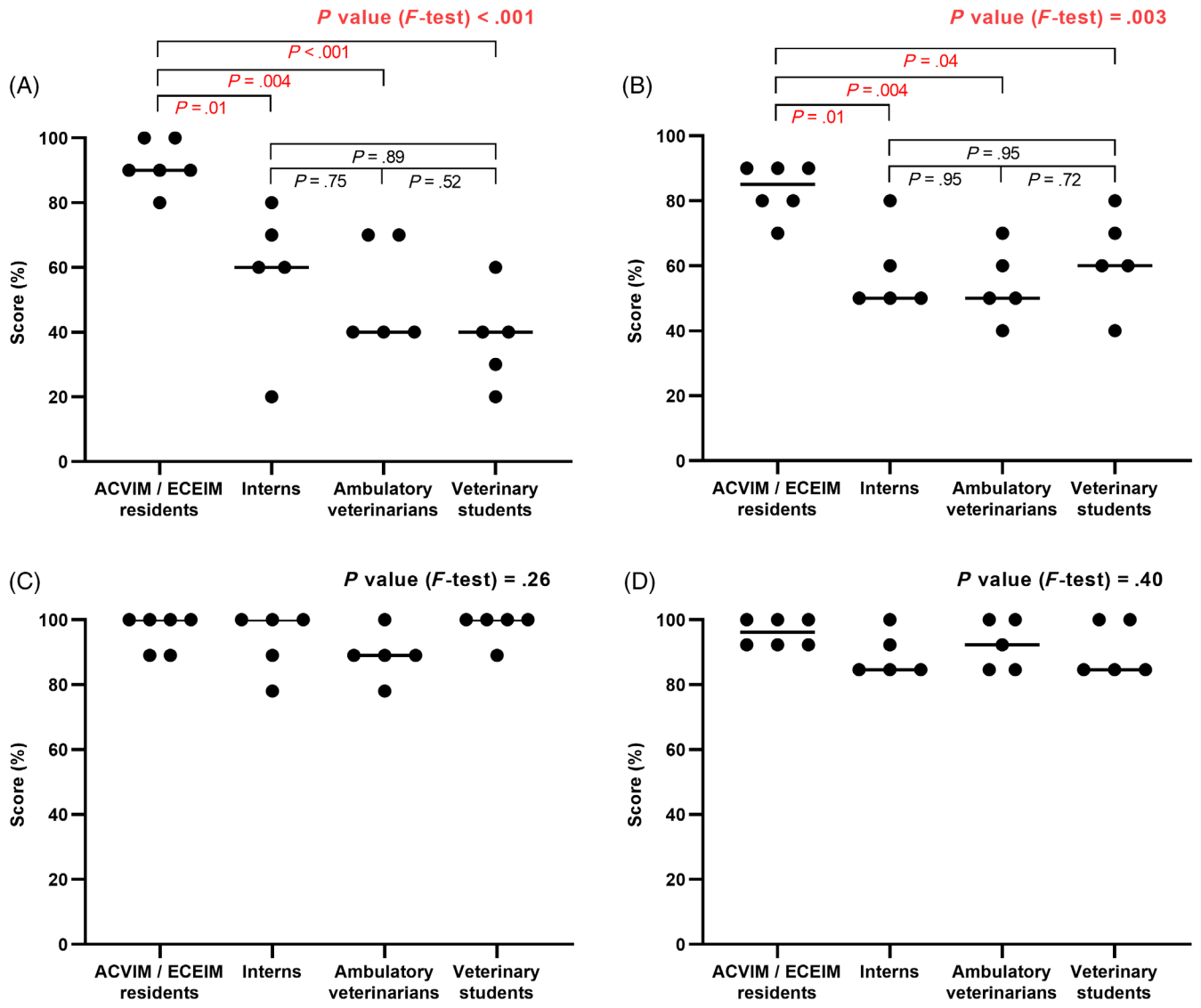

FIGURE 2 Scatter plots of pre- and post-course test scores in percent comparing results of different groups of participants. (A) Pre-course test on knowledge of echocardiography and echocardiographic anatomy. (B) Pre-course test on knowledge of echocardiographic pathology. (C) Post-course test on knowledge of echocardiography and echocardiographic anatomy. (D) Post-course test on knowledge of echocardiographic pathology. Dots represent individual participant scores and lines represent median scores

knowledge of echocardiography and echocardiographic anatomy, the appropriate scores were compared using a paired Student's *t*-test. To detect any differences among the 4 different groups of participants, the pre- and post-course test results of knowledge of echocardiography and echocardiographic pathology and the quality scores of eFoCUS view recordings, respectively, were compared among groups using a 1-way analysis of variance (ANOVA) with Tukey's post-hoc test. Similarly, a 1-way ANOVA with Tukey's post hoc test was performed to compare the quality of eFoCUS scores among the participants of the 5 different courses held. An unpaired Student's *t*-test was used to compare the quality scores of the eFoCUS view recordings of participants with previous practical experience in echocardiography to participants with no experience. The level of significance was set at $P < .05$.

3 | RESULTS

All 21 participants completed the entire course and the pre- and post-course tests.

3.1 | Proficiency in theoretical knowledge

The participants' knowledge of echocardiography and normal echocardiographic anatomy increased significantly from before to after the course (Figure 1). The participants achieved a mean score of 61.4% (range, 20%-100%) in the pre-course test compared to 94% (range, 78%-100%) in the post-course test. Recognition of echocardiographic pathology pre-course ranged from 40% to 90% with a mean score of 65.7%. After the course, participants achieved a mean score of 92% (range, 85%-100%) on recognition of echocardiographic pathologies displayed on cine-loops of different eFoCUS views. Table 1 summarizes the specific echocardiographic pathologies correctly identified by participants in the pre- and post-course tests. Scores achieved in the pre-course test on knowledge of echocardiography and echocardiographic anatomy and scores achieved in the pre-course test on echocardiographic pathology were significantly higher for residents compared to interns, ambulatory veterinarians, and veterinary students, respectively, but no differences among any of the other 3 groups were detected (Figure 2A,B). Results of the post-course tests indicated no remaining differences among any of the groups (Figure 2C,D).

3.2 | Proficiency in eFoCUS image acquisition

All participants successfully obtained and stored all eFoCUS views within the allocated time of 10 minutes. The portable ultrasound device produced images of sufficient quality and resolution for the study. No images had to be excluded from evaluation because of insufficient image resolution. Overall, 122 of 147 eFoCUS views (83%) obtained by the participants were at least of adequate quality for subjective evaluation (minimum score of 1 for every criterion evaluated, excluding whether appropriate measurements would be feasible). Of the 122 eFoCUS views considered adequate, 57 (46.7%) achieved a score of 100% (perfect display for subjective evaluation

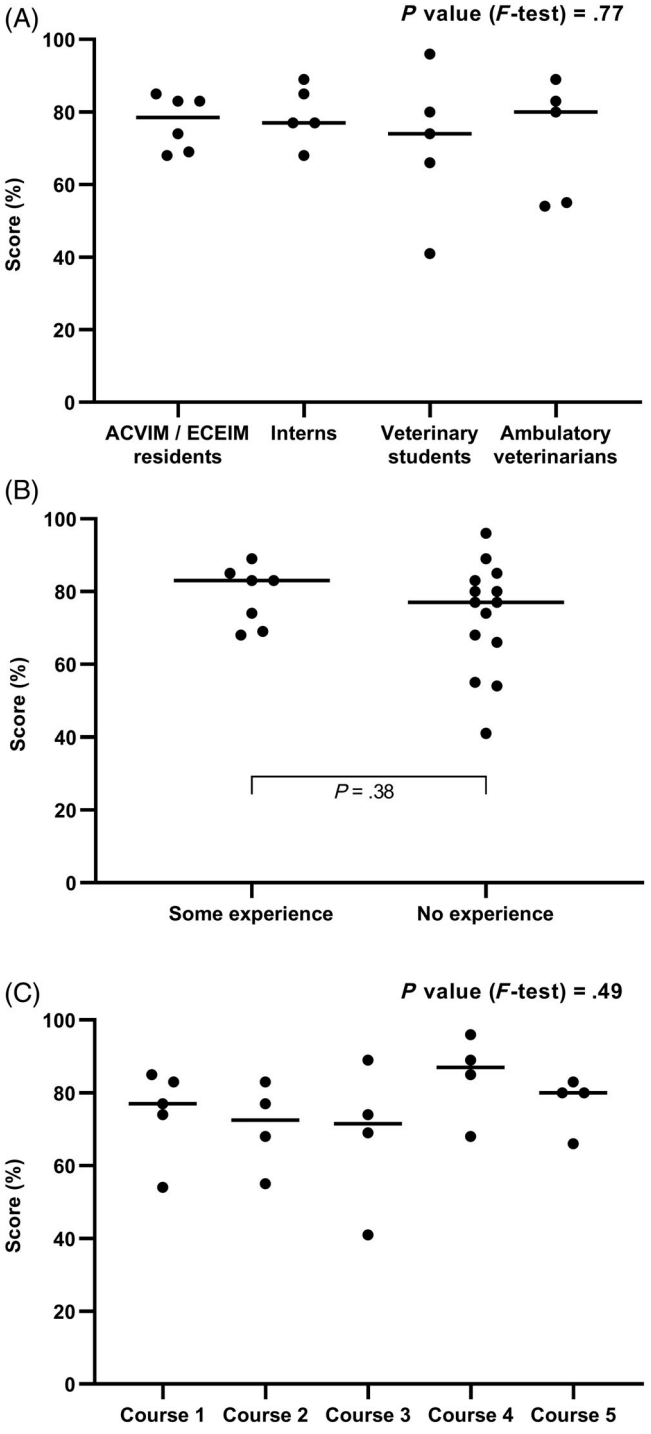

FIGURE 3 Scatter plots comparing total quality scores of eFoCUS views in percent, calculated as the mean of all single eFoCUS quality scores produced by 1 participant after the course. (A) Comparison of different groups of participants. (B) Comparison of participants with previous informal practical experience in echocardiography to participants with no previous experience. (C) Comparison of different courses. Dots represent individual participant scores and lines represent median scores

and feasibility of measurement of cardiac dimensions). The number of different eFoCUS views that were considered insufficient for subjective evaluation was as follows: 1 R-4C with focus on the LA view (4.8%), 5 R-4C with focus on the LV views (23.8%), 3 R-LVOT views (14.3%), 5 R-LVSAX views (23.8%), 7 R-LVSAX MM views (33.3%), 4 R-AoSAX views (19%), and no R-RVOT views.

Evaluation of all individual images by a blinded cardiologist indicated median quality scores of 100% for the R-4C with focus on the LA view (range, 40%-100%), the R-LVSAX view (range, 0%-100%) and the R-RVOT view (range, 50%-100%), followed by scores for the R-LVOT view (median, 90%; range, 30%-100%), the R-4C with focus on the LV view (median, 80%; range, 20%-100%), the R-AoSAX view (median, 62.5%; range, 0-100%), and the R-LVSAX MM (median 50%; range 12.5%-100%).

Eighteen of 21 participants achieved a total eFoCUS score ≥ 65% and were considered proficient in overall eFoCUS image acquisition. The median total eFoCUS score of all participants was 77% (range, 41%-96%). The quality of image planes did not differ among the groups (Figure 3A). Images obtained by participants with no previous practical echocardiographic experience were not inferior to images obtained by participants with some practical experience (Figure 3B). No difference was found in quality of image planes between the courses (Figure 3C).

4 | DISCUSSION

Echocardiography typically is performed by clinicians with comprehensive training. Although there are no guidelines for the training of ultra-sonographers performing cardiac examinations on horses to date, the ASE states that training, assessment, and continuous quality improvement are crucial components for all forms of cardiac ultrasound examination, from the most limited bedside examination to the most advanced comprehensive echocardiogram.[13] To our knowledge, the issue of basic competence in echocardiography on horses has not been addressed. In order to successfully implement the use of eFoCUS examinations, we focused on specific training requirements to achieve proficiency. A 1-day training course was developed that incorporated specific recommendations for FoCUS training published by the ASE.[3,13,22]

Because individuals learn at their own pace, no set number of trainings for emergency ultrasound examinations is recommended.[21] A study in small animals showed that house officers increased their knowledge significantly and were able to obtain echocardiographic images of fair quality after completion of a 6-hour teaching course in focused echocardiography in dogs.[23] A study in human medicine showed that a 5-hour didactic and 1-hour practical focused echocardiography training course significantly improved performance and interpretation skills of emergency medicine residents.[24] Others proposed that 12-hour combined didactic and practical focus transthoracic echocardiography training is suited to reach competence in FoCUS examinations, independent of previous experience.[25,26] However, FoCUS courses are only the starting point, and additional supervised practice is recommended to achieve full competence in performing a FoCUS examination.[12]

Except for residents, most participants in our study had marginal previous knowledge of echocardiography in horses as determined by the pre-course tests. This finding is not surprising because echocardiography usually plays a minor part in the veterinary education core curriculum. This result emphasizes the need for specific post-graduate training to perform eFoCUS and ensure best practice medicine.

The participants' knowledge of normal echocardiographic anatomy increased significantly with completion of the 1-day training course. Only 1 participant in the group of residents achieved a slightly higher score in the pre-course test compared to the post-course test. This finding might be the result of the nature of the multiple choice test format because both scores were still >80%, and therefore the difference was based on 1 question. All participants performed equally well (ie, no significant differences between groups) in the post-course test. This result compares to other studies that showed significant increases in written examinations after completion of a specific FoCUS training course.[23-25]

Most of the echocardiographic pathologies were correctly recognized by participants after the course. Although all participants correctly identified pericardial effusion, it can be challenging to differentiate pericardial from pleural effusion. Our study included only cardiac abnormalities, and the ability of the participants to differentiate between pleural and pericardial effusion was not assessed. In agreement with our study, a very high sensitivity of the FoCUS examination for the diagnosis of pericardial effusion also was demonstrated in human patients and in small animals.[3,23] Similarly, studies in humans and dogs that included different degrees of chamber enlargement and LV systolic function and hypertrophy in their post-course written examination indicated that such cardiac abnormalities can be correctly recognized by most trained clinicians.[3,23,24,26] Decreased diastolic function only was recognized by less than half of all participants in our study. However, evaluation of diastolic function is challenging without using more advanced echocardiographic methods such as tissue Doppler imaging or 2D speckle tracking echocardiography.[19,27-29] The results of the tests on echocardiographic pathology should be evaluated in light of the fact that obvious (moderate to severe) echocardiographic abnormalities were included. However, we propose that only horses with moderate to severe abnormalities and that present to the emergency service because of overt clinical signs indicating cardiovascular disease qualify for eFoCUS examination by non-specialist veterinarians. In the post-course test of echocardiographic pathologies, only abnormal echocardiograms were included and participants were asked to recognize the specific cardiac pathology. However, the first step of interpretation of an eFoCUS examination in a clinical setting would be to differentiate between normal and abnormal. Therefore, participants were not tested on their ability to differentiate between a normal and an abnormal echocardiogram. In addition, only good quality images were included in the tests, which might have influenced the results because the identification of pathologies on good quality images might be easier than on images obtained by an inexperienced clinician. Therefore, adequate training of non-specialist

veterinarians is needed to ensure good quality images can be obtained, which will facilitate identification of abnormalities and triage of patients.

Most eFoCUS image planes obtained by participants were considered of adequate quality to allow for subjective cardiac evaluation. However, lower scores were achieved for the R-LVSAX MM and R-AoSAX views. The main reason for the lower R-LVSAX MM score compared to the R-LVSAX score was the non-symmetrical bisection of the LV caused by inadequate placement of the M-mode cursor, resulting in non-representative images to assess ventricular size and function. However, the R-LVSAX MM view was recorded as a still image without simultaneous 2D cine-loop, making the assessment of cursor placement more difficult. Anatomical M-mode technology would help overcome this limitation but was not available in the HCU device used.[19] It is debatable whether M-mode imaging of the LV should be included in an eFoCUS protocol because visualization of the LV in the R-4C with focus on the LV view and R-LVSAX view already allows for assessment of LV size and function in 2 different image planes.

Difficulties obtaining high-quality R-AoSAX views mostly were attributed to interference of the ventral lung border with visualization of the entire LA. This difficulty is a known issue that prevents accurate measurements of LA size.[19] However, in cases of moderate to severe LA enlargement, visualization of the entire LA likely is not necessary to assess the ratio.

We allowed a 10-minute maximum for the acquisition of all eFoCUS views. This time limit might have influenced the results of image acquisition. However, we believed that 10 minutes would be the maximum time allotted to dedicated stall-side echocardiography in emergency settings.

The use of HCU devices for POCUS examinations is widely acknowledged.[30] However, appropriate user-specific training, including scope and limitations of HCU devices, is recommended. The HCU device produced images of sufficient resolution for our study, and settings were sufficiently adjustable for basic equine echocardiography. Therefore, the device was not considered a limiting factor regarding evaluation of image quality. Only Warmblood horses were included in our study, and all horses had lean body condition. Different breeds and higher body condition scores likely would influence image quality of the HCU device. In addition, horses presenting on emergency might not be standing still, might be sweating, or might even have a condition that precludes an eFoCUS examination. We used a device with standard settings throughout the entire study. Therefore, our results do not account for the effect of using different HCU devices or standard ultrasound machines with which the participant is not acquainted. Other devices may have additional more advanced settings and modalities available compared to the HCU device used in our study. However, the eFoCUS protocol involves only basic 2D and M-mode modalities, and the frame rate and depth (30 cm) was considered sufficient. Therefore, it is unlikely that a standard ultrasound machine would have resulted in better image quality. However, a different HCU device with a lower frame rate or insufficient depth to visualize the entire equine heart could have resulted in inadequate image acquisition.

After completion of the course, 18 of 21 participants were proficient in performing the eFoCUS protocol. This finding is important because proficiency in adequate image acquisition is a prerequisite to be able to perform a cardiac ultrasound examination.[4] Images obtained by participants with no previous practical experience in echocardiography were not inferior to images obtained by participants with some previous informal experience. However, the participants were assigned to the respective group based on the author's appraisal rather than a true baseline assessment of the participants' practical skills in echocardiography.

Our study included 4 courses of 4 participants each and 1 course of 5 participants. Although no statistical difference was found among participants of the 5 different courses, the inequality in participant numbers might have influenced the eFoCUS image quality scores. Participants in courses with 4 participants would have had more hands-on practical training per person. On the other hand, the participants in the course with 5 participants would have had the benefit of having the eFoCUS protocol narrated an additional time.

The lack of an a priori sample size analysis is a limitation of our study. However, other studies included similar numbers of participants.[23,24] Also, our results clearly indicate that veterinarians can become proficient in performing the proposed eFoCUS examination after completion of a 1-day training course. Comparison among the 4 subgroups of participants indicated no differences in any of the post-course tests, but may have lacked sufficient power to detect smaller differences among some of the groups.

We evaluated the participants' proficiency in image acquisition and their knowledge immediately after the 1-day training course. A second assessment after providing time for independent scanning and gaining more clinical experience would have provided valuable information about long-term retention. However, the majority of participants were not at the authors' institution over a long enough period of time to allow for follow-up, and the opportunity for all participants to practice eFoCUS on clinical patients after completion of the course was limited.

The horse used for practical training was the same horse used for assessment of proficiency at the end of each course. Using a different unknown horse would have strengthened our results. Furthermore, echocardiograms in our study were not performed on patients with pathological conditions. To become proficient in assessing clinical cases, ongoing continuing education programs and exposure to clinical patients with different conditions and body types are needed to maximize the sonographers' experience. Although we exposed the participants to a number of different examples of each echocardiographic pathology in the curriculum, different image planes and different grades of severity of 1 pathology were not included. Doing so would have strengthened our results. Furthermore, improvement of knowledge of cardiac pathologies could not be compared statistically between the pre- and post-course tests because of the different nature of the tests.

Because of the 1-day course design of our study, course content was limited. Although expert guided training is important for obtaining technical skills, it was shown that self-directed electronic modules are effective for teaching introductory FoCUS interpretation skills.[31] After

completion of the study, we designed a smartphone application (eFoCUS) that includes the content of the eFoCUS examination. It provides the user with information on eFoCUS image acquisition and includes lists of cardiac structures and pathologies that can be assessed. In addition, examples of normal and abnormal echocardiographic images and cine-loops are included. This application might serve as a self-directed learning tool and may assist the clinician in the evaluation of a clinical patient.

In conclusion, our results show that veterinarians and veterinary students, independent of previous experience, can become proficient in performing the proposed eFoCUS examination and recognize a limited list of clinically relevant, echocardiographic pathologies after completion of a 1-day training course using a 4-step approach. This course may serve as a good educational foundation for the performance of eFoCUS by practitioners. Further echocardiography training research is necessary to develop optimal training guidelines for the safe implementation of this technology in horses. The implementation of the eFoCUS protocol in emergency and critical care patients and its ability to aid in identification of primary and secondary cardiac disease will need to be assessed in a clinical setting.

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CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

The study was conducted within the scope of clinical teaching and covered by the respective IACUC license.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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