Original Article

Clinical evaluation of the 3M Littmann Electronic Stethoscope Model 3200 in 150 cats

Journal of Feline Medicine and Surgery
15(10) 893–900

DOI: 10.1177/1098612X13485480
jfms.com
SAGE

Keith A Blass, Karsten E Schober, John D Bonagura, Brian A Scansen, Lance C Visser, Jennifer Lu, Danielle N Smith and Jessica L Ward

Abstract

Detection of murmurs and gallops may help to identify cats with heart disease. However, auscultatory findings may be subject to clinically relevant observer variation. The objective of this study was to evaluate an electronic stethoscope (ES) in cats. We hypothesized that the ES would perform at least as well as a conventional stethoscope (CS) in the detection of abnormal heart sounds. One hundred and fifty consecutive cats undergoing echocardiography were enrolled prospectively. Cats were ausculted with a CS (WA Tycos Harvey Elite) by two observers, and heart sounds were recorded digitally using an ES (3M Littmann Stethoscope Model 3200) for off-line analysis. Echocardiography was used as the clinical standard method for validation of auscultatory findings. Additionally, digital recordings (DRs) were assessed by eight independent observers with various levels of expertise, and compared using interclass correlation and Cohen's weighted kappa analyses. Using the CS, a heart murmur (n = 88 cats) or gallop sound (n = 17) was identified in 105 cats, whereas 45 cats lacked abnormal heart sounds. There was good total agreement (83–90%) between the two observers using the CS. In contrast, there was only moderate agreement (*P* <0.001) between results from the CS and the DRs for murmurs, and poor agreement for gallops. The CS was more sensitive compared with the DRs with regard to murmurs and gallops. Agreement among the eight observers was good-to-excellent for murmur detection (81%). In conclusion, DRs made with the ES are less sensitive but comparably specific to a CS at detecting abnormal heart sounds in cats.

Accepted: 14 March 2013

Introduction

Cardiac auscultation is an integral part of the physical examination of cats. However, auscultatory findings may be dynamic, transient, affected by ambient noise, and influenced by observer training and expertise, thus being subject to clinically relevant observer variation. The acoustic properties of the conventional stethoscope (CS) for the detection of heart sounds may be limited because they attenuate sound transmission proportional to frequency. The frequency response of the CS shows maxima and minima at very specific frequencies owing to tubular resonance effects.[1–4] Published studies in both humans and companion animals have reported only low-to-moderate interobserver agreement at detecting cardiac auscultatory abnormalities when using CSs.[5–10] The electronic stethoscope (ES) was designed to overcome these limitations by amplifying the acoustic signal with a more uniform frequency response, thus making it easier to detect faint heart sounds below the threshold of hearing for some observers.[1] Additionally, the ES offers the potential for generating a digital recording (DR) of heart sounds; such files could be useful for medical record documentation, distance diagnosis by remote consultants and teaching.

Although ESs have been available for years, they have not yet demonstrated a distinct advantage over the CS. Issues with ESs have included the introduction of artifacts and ambient background noise, expense, and an

Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, USA

This article was presented in abstract form via oral presentation at the American College of Veterinary Internal Medicine Forum in New Orleans, LA, USA on 31 May 2012

Corresponding author:
Karsten Schober DVM, PhD, Department of Veterinary Clinical Sciences, The Ohio State University, 601 Vernon L Tharp Street, Columbus, OH, 43210, USA
Email: schober.4@osu.edu

inability to interface with computers that would allow for fast off-line processing, storage and playback of recorded sounds.[1,11,12] Recent technological advances have attempted to overcome some of these problems.[12] While the current literature comparing conventional and newer-generation ESs is limited, two recently published studies showed favorable results for ESs compared with CSs when assessing subjective auscultation quality during in-flight medical transport in human patients.[13,14] Additionally, a study in dogs showed significant agreement between real-time auscultation using a CS and off-line retrospective analysis of heart sounds recorded using an ES.[15] However, to our knowledge, there are no reports evaluating the use of an ES in cats.

The 3M Littmann Electronic Stethoscope Model 3200 is a newer-generation ES that offers a number of features lacking in CSs, making it easier, potentially, to detect difficult-to-hear heart sounds. The features that seem most appealing for feline use include proprietary background and frictional noise reduction technology; a 15 mm diameter state of the art sound sensor located in the center of the diaphragm; up to 24× sound amplification designed to amplify faint heart sounds; and three filter modes that emphasize specific frequencies for optimal heart auscultation.

The objective of this study was to evaluate this fully electronic stethoscope in cats undergoing routine cardiac evaluation. We hypothesized that the 3M Littmann Electronic Stethoscope Model 3200 (3M) would be as good as, or better than, a commonly used CS at detecting murmurs and gallops in cats. An additional objective was to determine if the level of auscultation experience would influence an observer's ability to detect abnormal heart sounds using the CS.

Materials and methods

This study was approved by the Institutional Animal Care and Use Committee of The Ohio State University, Columbus, OH, USA.

Cats

Between 2010 and 2012, a total of 150 consecutive cats undergoing echocardiograpic examinations at The Ohio State University Veterinary Medical Center were enrolled prospectively in the study.

Study design

Cardiac auscultation was performed on all cats using a CS (Welch Allyn Tycos Harvey Elite Stethoscope, Welch Allyn) by two observers (KS and KB) with varying experience. observer A (KS) is a board-certified cardiologist with more than 20 years of experience with cardiac auscultation, while observer B (KB) is a cardiology resident with approximately 3 years of clinical experience. Immediately following auscultation with the CS, a maximum of 30 s of heart sounds were recorded from all cats over an area corresponding to the point of maximum intensity of abnormal heart sounds, or over the point of loudest intensity if no abnormal sounds were heard, detected by a single observer (KB) using a sensor-based ES (3M Littmann Electronic Stethoscope Model 3200, 3M) for later off-line analysis. Additionally, at the time of recording, subjective auscultation quality with the ES, based on real-time auscultation, was compared with that of the CS by a single observer (KB).

Off-line analyses of the digital heart sounds were assessed en bloc in a randomized order by eight blinded independent observers with various levels of experience in cardiac auscultation. Three observers (KS, BS, JB) were cardiology diplomates with a high level of experience, two observers (KB, LV) were cardiology residents with a moderate level of experience and three observers (JL, DS, JW) were small animal rotating interns with a low level of experience of cardiac auscultation.

Variables analyzed

Echocardiography In order to compare the results from auscultation to a clinical standard, echocardiographic examinations were performed in all cats immediately following auscultation using an ultrasound system (General Electric Vivid 7 Dimension Cardiac Ultrasound System, GE Healthcare) with transducers (General Electric Vivid 7 Dimension Cardiac Ultrasound System, GE Healthcare) operating at a nominal frequency of 7–10 MHz. Standard two-dimensional, M-mode and Doppler echocardiographic examinations[16] were performed by the attending cardiologist, analyzed by one observer (KB) and reviewed systematically by another observer (KS) for qualitative decision-making. Specific echocardiographic findings that could account for a cardiac murmur were noted, including: (i) regurgitant blood flow; (ii) dynamic left or right ventricular outflow obstruction; (iii) turbulent or accelerated blood flow; or (iv) aortic root dilation.[17–21] Specific echocardiographic abnormalities that would be associated with left ventricular diastolic dysfunction and a gallop sound included: (i) evidence of left ventricular hypertrophy; (ii) abnormal transmitral flow patterns; (iii) reduced pulse wave tissue Doppler velocity of mitral annular motion indicating delayed relaxation; or (iv) increased left atrial size in the absence of mitral regurgitation. The results of echocardiography were recorded without knowledge of the auscultatory findings.

Conventional cardiac auscultation Auscultation was performed using the CS over all cardiac valves and sternal borders on both sides of the chest wall for a maximum of 3 mins in an examination room free of ambient background noise, with recording of sound phenomena over any area of auscultation included in the final analysis. Variables recorded included heart rate (HR);

presence and grade of any murmur using a scale of 0–6/6;[22] presence of a gallop sound; and auscultation quality using an arbitrary scale of 1–3, with 1 being excellent, 2 being good and 3 being poor. Quality was considered to be excellent if heart sounds could be heard clearly with minimal respiratory or background noise; good if respiratory or background noise were present, but did not affect the ability to identify sound phenomena; and poor if respiratory or background noise was so severe that assessment of heart sounds could not be performed with confidence.

Digital auscultation and recordings Within 2 mins of auscultation using the CS, auscultation was performed in the same room using the ES for a maximum of 3 mins. Again, the stethoscope was allowed to be moved freely over both sides of the thoracic wall during auscultation, and any pertinent sound phenomena detected were used to assess subjective auscultation quality of the ES (by observer B). The auscultation quality of the ES was compared with that of the CS using an arbitrary scale of 1–3, with 1 indicating that the ES sounded better, 2 indicating equal sound quality and 3 indicating that the ES sounded poorer. Following auscultation, DRs (ES) (3M Littman Electronic Stethoscope Model 3200, 3M) were made and used for subsequent off-line analysis. For these, the ES chest piece was placed over a focal area of the thorax corresponding to the point of maximal intensity of the abnormal sound(s) identified. If abnormal sounds were not identified, the recording was obtained over the area of the cardiac apex.

DRs (ES) were transmitted from the ES to a personal computer running Windows XP via Bluetooth wireless transmission using the provided USB dongle (Bluetooth USB Wireless Dongle, Bluetooth SIG). Cardiac sounds were stored and played back using provided software (Zargis, StethAssist, Heart and Lung Sound Visualization Software, Zargis Medical). A training session of approximately 2 h was provided so that the eight observers could become familiar with the playback software. This included individual assessments of 12 digital sample recordings obtained from a different population of cats. The DRs (ES) were assessed in random order by all eight observers working independently in the same quiet room. The playback of stored DRs (ES) was directly through the ear buds of the ES following wireless transfer from the Zargis software. Following initial review using the diaphragm mode at the mid-range volume setting, observers could replay all digital recordings as often as needed at both normal and half-speed, using any volume setting and any of the three filter modes, which included a bell (20–200 Hz), diaphragm (100–500 Hz) and extended range filter (50–500 Hz), before recording their results. Variables recorded, in order, included HR, presence and timing of a murmur without assessment of murmur grade, and the presence of a gallop sound.

In the absence of intracardiac phonocardiography, no definitive gold standard was available to compare the auscultation findings. Therefore, interpretations of DRs (ES) were compared with two separate clinical standards — the first being echocardiography and the second the results using the CS by observer A, the more experienced observer. Two standards were chosen owing to possible shortcomings of either method alone in identifying murmurs and gallops, as echocardiography may not be able to identify the genesis of functional flow murmurs and some gallop sounds. Moreover, the CS has not been validated against a true gold standard and thus may, potentially, be inferior at detecting abnormal heart sounds in cats. However, both are used commonly in the clinical setting to identify cardiac disease in cats and were, therefore, selected as relevant standards for comparison.

Statistical analysis

Comparison of subjective auscultation quality for both stethoscopes, as assessed by a single observer (KB), was made based on overall frequencies of ratings for the CS using the arbitrary scale described previously and the direct comparisons between auscultation quality of the two stethoscopes. For comparison of agreement between observers A and B, Cohen's weighted kappa analysis was used to evaluate the inter-rater agreement beyond that occurring by chance.[23,24] Comparing the CS and DRs (ES) to the two clinical standards (echocardiography and auscultation with the CS by observer A), kappa values <0.20 indicated poor agreement, between 0.21 and 0.40 indicated fair agreement, between 0.41 and 0.60 indicated moderate agreement, between 0.61 and 0.80 indicated good agreement, and between 0.81 and 1.00 indicated very good agreement.[24] McNemar's test was used to compare diagnostic accuracy with each clinical standard for the identification of differences.[25] For comparison of the eight observers' DRs, Fleiss' kappa analysis was used to estimate inter-rater agreement beyond that occurring by chance,[26] with agreement cutoffs similar to that stated previously for Cohen's kappa.[27] Sensitivity and specificity were used to compare results between groups based on level of experience. P-values <0.05 were considered significant.

Results

Population characteristics and echocardiography

Of the 150 cats, 89 were male and 61 were female. Mean age (± SD) was 5.6 ± 3.9 years, ranging from 0.25 to 18 years, and mean body weight (± SD) was 5.1 ± 1.3 kg, ranging from 1.7 to 9.8 kg. Several breeds were represented, with the vast majority being domestic shorthair cats. Ninety-one cats had no evidence of structural cardiac

Table 1 Absolute frequencies of murmurs and gallop sounds obtained by observers A (board-certified cardiologist) and B (cardiology resident) using both stethoscopes and by echocardiographic findings that would support the presence of a murmur or gallop sound

	CS observer A	CS observer B	DRs (ES) observer A	DRs (ES) observer B	Echocardiography
Murmur	88	87	76	63	76
Gallop	17	16	13	8	18

CS = conventional stethoscope; ES = electronic stethoscope; DRs (ES) = digital recordings using the electronic stethoscope

Table 2 Comparison of subjective assessment of auscultation quality for the two stethoscopes assessed by observer B (cardiology resident) at the time of recording

Auscultation quality CS	CS vs ES (%)		
	ES better	Equivalent	ES worse
Excellent	6	56	4
Good	6	14	9
Poor	1	3	1
Total	13	73	14

CS = conventional stethoscope; ES = electronic stethoscope

disease based on echocardiography, while 50 of the 59 cats with cardiac disease were diagnosed with hypertrophic cardiomyopathy based on unexplained left ventricular end-diastolic wall thickness >6 mm in the absence of hyperthyroidism or systemic hypertension.[28] In 76 cats (51%), a putative echocardiographic reason for a murmur was identified, including dynamic left and right ventricular outflow tract obstruction (54 cats), dynamic mid-left ventricular obstruction (11 cats), mitral and tricuspid regurgitation (eight cats), aortic root dilation (three cats), ventricular septal defect (one cat) and valvular aortic stenosis (one cat). Of the three cats with aortic root dilation, two also had mid-left ventricular obstruction as a possible cause of a murmur, while the one cat with no other identifiable reason for a murmur had a 2/6 brief systolic murmur identified and quantified by both investigators with the CS. In 18 cats (12%), echocardiography identified a potential reason for a gallop sound.

Auscultatory findings

Table 1 summarizes the auscultatory findings using the CS and DRs (ES) for observers A and B, and compares their diagnosis to those obtained by echocardiography. Of the 88 cats identified with murmurs by observer A using the CS, 21 were determined to have grade 1/6 murmurs, 27 grade 2/6, 32 grade 3/6 and eight grade 4/6 murmurs. Of the 87 cats identified with murmurs by observer B using the CS, 21 were determined to have grade 1/6 murmurs, 27 grade 2/6, 33 grade 3/6 and six grade 4/6 murmurs. Table 1 illustrates differences between the examiners and putative diagnosis based on echocardiography. All cats determined to have a reason for a murmur using echocardiography had a murmur identified by observer A using the CS; however, 12 cats were categorized as having flow murmurs based on detection of a soft murmur by observer A (seven grade 1/6, five grade 2/6) using the CS with no echocardiographic explanation for the murmur. All murmurs were included in the final analysis comparing the DRs (ES) with the CS. Additionally, all cats determined to have gallops by observer A using the CS had an identifiable reason for a gallop during echocardiography; however, one cat with an echocardiographic explanation for a gallop (left ventricular hypertrophy and diastolic dysfunction) was not identified as having a gallop by observer A using the CS.

Auscultation quality

The results of the head-to-head comparison of subjectively perceived quality between the two stethoscopes, as assessed by observer B, are summarized in Table 2. Auscultation quality using the ES was considered to be excellent in 66% of the cats, good in 29% and poor in 5%, with quality considered to be equivalent between the two stethoscopes in 73% of the cats, while, for the remaining cats, superiority was divided equally between the two stethoscopes, with the ES considered superior in 13% of cats and the CS considered to be superior in 14% of cats (P >0.05).

Interobserver agreement

Table 3 illustrates the agreement between the assessment using the CS and echocardiography, the DRs (ES), and

Table 3 Cohen's kappa for agreement between observers A (board-certified cardiologist) and B (cardiology resident)

Observer	Echo vs CS		CS interobserver	CS vs DRs (ES)	
	A	B	A vs B	A	B
Murmur	0.84	0.77	0.90	0.57	0.64
Gallop	0.97	0.87	0.83	0.19	0.46

CS = conventional stethoscope; DRs (ES) = digital recordings using the electronic stethoscope

Table 4 Comparison between the two clinical standards and the two stethoscopes for both murmur and gallop detection and using sensitivity (Se) and specificity (Sp) in percent

			Clinical standard					
			Echocardiography			CS observer A		
			CS	DRs (ES)	*P*	CS	DRs (ES)	*P*
Se	Murmur	A	100	94	<0.0001	–	75	<0.0001
		B	96	83	<0.0001	96	69	<0.0001
	Gallop	A	82	28	0.02	–	24	<0.0001
		B	78	28	0.002	82	29	<0.0001
Sp	Murmur	A	84	81	0.81	–	84	0.001
		B	81	99	0.013	95	97	0.50
	Gallop	A	100	94	0.007	–	93	0.003
		B	95	98	0.50	99	98	0.25

A = observer A (board-certified cardiologist); B = observer B (cardiology resident); CS = conventional stethoscope; DRs (ES) digital recordings using the electronic stethoscope

the two main observers in identifying murmurs and gallops compared by Cohen's kappa. When comparing the CS to echocardiography, there was excellent agreement for observer A between the two for detection of both murmurs and gallops, while for observer B there was good agreement between the two for murmur detection and excellent agreement for gallop detection. Agreement between the two observers using the CS was excellent for detection of both murmurs and gallops.

When comparing the DRs (ES) to the CS, for observer A there was only moderate agreement for murmur detection and poor agreement for gallop detection, while for observer B there was good agreement for murmur detection and moderate agreement for gallop detection.

Comparison of stethoscopes to clinical standards

When compared with both clinical standards (observer A and echocardiography), the DRs (ES) exhibited lower sensitivity, but comparable specificity, at detecting murmurs and gallop sounds than the CS (Table 4). Sensitivity of the DRs (ES) for detecting murmurs compared with the CS was significantly lower for both observers when assessed against echocardiography (standard 1), which did not take flow murmurs into consideration. When assessed against the CS (standard 2) results from observer A, which did include flow murmurs in the analysis, similar findings were observed. Moreover, the DRs (ES) exhibited significantly lower sensitivity than the CS at detecting gallops for both observers compared with both clinical standards.

Specificity of the DRs (ES) for detecting murmurs compared with the CS was not significantly different for observer A and was significantly higher for observer B when assessed against echocardiography, which did not take flow murmurs into consideration. For observer B, there was no statistically significant difference in specificity for murmur detection when the two stethoscopes were compared against the CS results from observer A. Specificity of the DRs (ES) for detecting gallops compared with the CS was significantly lower for observer A, but was not significantly different for observer B when assessed against both clinical standards. Overall, specificity of the DRs (ES) was excellent for both murmurs and gallop sounds, averaging 90% and 96%, respectively.

Digital recordings

Table 5 illustrates the frequencies of murmurs and gallops obtained for all eight observers using the DRs (ES) and compares their overall agreement using Fleiss' kappa. Interobserver agreement was excellent for detection of murmurs, while agreement for detection of gallop sounds was fair.

Table 5 Absolute frequencies of murmurs and gallop sound detected by all eight observers using the digital recordings using the electronic stethoscope and their overall agreement using Fleiss' kappa

	Observer								*P*	Fleiss' kappa
	1	2	3	4	5	6	7	8		
Murmur	63	76	60	53	57	54	60	60	<0.001	0.81
Gallop	8	13	19	16	8	37	16	20	<0.001	0.31

Observers 2, 3 and 4 = board-certified cardiologists; observers 1 and 5 = cardiology residents; observers 6, 7 and 8 = rotating interns
Observer 1 is observer B listed previously and observer 2 is observer A listed previously

Table 6 Comparison among observers with different levels of auscultation experience using assessment of the digital recordings using the electronic stethoscope and echocardiographic findings as the clinical standard

Title	Clinical standard: echocardiography			
	Sensitivity (%)		Specificity (%)	
	Murmur	Gallop	Murmur	Gallop
Cardiologist (n = 3)	74	30	91	92
Resident (n = 2)	74	17	95	96
Intern (n = 3)	74	45	95	87
Average	74	31	94	92

Group comparison

Table 6 summarizes the results of observers grouped according to level of expertise using the DRs (ES) compared with the standard of echocardiography. Sensitivity for detecting murmurs was fair for all three groups, averaging 74%, with no statistical difference between the different levels of experience. Sensitivity for detecting gallop sounds was poor for all three groups, averaging 31%, with the least experienced observers performing slightly better than the more experienced groups (45% for interns vs 30% for board-certified cardiologists and 17% for residents). Specificity was excellent for all three groups at detecting murmurs, averaging 94%, with minimal difference between groups. Specificity at detecting gallop sounds was also excellent for all three groups, averaging 92% — again, with minimal difference between groups.

HR comparison

Comparison of the HR displayed on the user interface by the ES to the HR assessed manually by observer B while recording the heart sounds could not be performed owing to the inability of the ES to perform this computation at rapid feline HRs.

Discussion

To our knowledge, this is the first study evaluating a fully electronic stethoscope in cats. While previously published studies in both dogs and humans have shown favorable results when comparing newer generation ESs to either CSs or echocardiographic findings,[13–15] the results of this study suggest that electronic recordings made with the 3M ES Model 3200 were inferior to both a CS and echocardiography at detecting abnormal sounds or identifying cardiac hemodynamic alterations in cats. Only moderate agreement was seen between the two stethoscopes for detection of murmurs, while there was poor-to-fair agreement between the two stethoscopes for the detection of gallop sounds. When compared with both clinical standards, the DRs (ES) exhibited inferior sensitivity at detecting murmurs and gallop sounds, indicating that this stethoscope may underestimate the true prevalence of these auscultation abnormalities in cats. It should be noted, however, that subjective auscultation quality, as noted by observer B at the time of recording, was considered to be very good-to-excellent for the ES, and was comparable to that of the CS. The apparent discrepancy between these findings may be owing to the fact that the recordings were made over a very focal area corresponding to the point of maximum intensity of an abnormal sound and, as such, may not have captured non-radiating abnormalities if not recorded in the correct location. Additionally, the auscultation quality of recorded sounds may not be entirely comparable to that produced by the ES when listening in real time. Thus, playback of the recordings may not reflect the true ability of the ES to detect abnormal heart sounds, which may explain the lower sensitivity achieved in this study. Alternatively, the non-random order of auscultation by observer B may, potentially, have introduced bias, as this observer may have been expecting to hear specific abnormal heart sounds using the ES based on prior auscultation with the CS. Specificity, however, was comparable between the two stethoscopes at detecting both murmurs and gallops, and was considered excellent.

Interestingly, overall agreement among the eight independent observers was considered excellent for the detection of murmurs and fair for the detection of gallops using DRs, with comparable findings between all levels of experience, in contrast to previously reported studies using conventional and telephonic stethoscopy, respectively.[8,29] The comparisons among observers with different levels of experience depended on groups with only two or three observers; therefore, the performance of a single observer could have had a marked effect on the average agreement. However, the results were fairly consistent among all observers, suggesting that less experienced auscultators may benefit most from using the ES.

It also must be noted that all observers in this study had listened to a limited number of DRs prior to conduction of the study. Therefore, some degree of user inexperience related to the novel stethoscope may have contributed to the poorer performance achieved by the ES, especially when compared with the performance of the CS, which had been used for months-to-years by each observer prior to this study. Additionally, while each examiner had the opportunity to listen to DRs (ES) at half-speed and at different frequencies, there was no attempt to fully standardize how these modes and filters were used across observers.

Despite the apparent lack of sensitivity at detecting abnormal heart sounds, the 3M ES Model 3200 does offer advantages that may make it more attractive to a practitioner than a CS. All recordings can be downloaded, stored and linked to a medical record for subsequent review and comparison. Serial recordings can allow for the detection of auscultatory changes that may help follow disease progression. The provided software allows great flexibility in that recordings can be listened to repeatedly and compared among a number of different individuals with varying levels of experience, with manipulation of most variables possible post-recording. Additionally, listening repeatedly to cardiac sound recordings has been shown to increase auscultatory proficiency,[30] such that accuracy, inter-rater agreement and consistency can improve with experience alone, suggesting that multiple playbacks may increase user sensitivity to detecting abnormal heart sounds.

This study has several limitations. First, there was no definitive gold standard for comparison with the ES. We used echocardiography and an experienced examiner using a CS as standards, but both methods may be insufficient gold standards. Echocardiography may not reveal the origin of some audible murmurs and gallop sounds, while the CS, even with highly experienced examiners, has not been validated as a gold standard in cats. A future study comparing the ES to transthoracic or intracardiac phonocardiography may, perhaps, be a more reliable indicator of the ability of the ES to detect abnormal heart sounds than the present study. Moreover, there is still debate on whether or not aortic root dilation can explain the presence of a systolic heart murmur; as such, it is debatable whether aortic root dilation should have been included as an echocardiographic finding that could account for a murmur in this study. However, as only three of the 150 cats enrolled were determined to have aortic root dilation, of which only one had no other identifiable reason for a murmur, our results would not have been different had this cat been excluded from the study. Furthermore, this stethoscope was designed originally to detect auscultation abnormalities in people. Thus, owing to high HR, the inability to halt respiration, a thorax covered with fur and a different somatotype, this ES may not receive sounds as well in cats, which could, in part, account for the relatively poor sensitivity observed. An accurate HR could not be displayed on the stethoscope's display, again likely owing to the fact that the stethoscope was not designed to detect rapid HRs as commonly found in cats. As mentioned previously, recordings were only made from a small area of the chest wall corresponding to the point of maximum intensity of abnormal or normal sounds, and this may not reflect the true ability of the stethoscope to detect abnormal heart sounds in real time. In contrast, the CS could be moved freely over both sides of the chest wall, and all sound phenomena identified possibly originating from different loci were used for final data analysis. Furthermore, while the CS was objectively assessed instantaneously in this study, the ES was assessed objectively only with the DRs. That is, all results with the ES were related to the recorded digital signal, not the immediate ability of the observer to detect murmurs and gallops. Also, while in close temporal proximity, echocardiography and auscultation by both observers A and B were not simultaneous; therefore, the small time gap between methods and observers may be the cause of some differences observed, as murmurs and gallops are often labile in cats, with clinically relevant changes occurring in a very short time period. Furthermore, off-line analysis must be done using the DRs (ES) to play back recordings, as most computers' sound cards and speakers are not of high enough quality to accurately evaluate the recorded heart sounds. Lastly, as indicated above, the number of examiners at each experience level was small, making it difficult to compare levels of experience.

Conclusions

Assessment of DRs made with the 3M ES Model 3200 appears to be inferior for detection of murmurs and gallop sounds in cats compared with a CS. However, it may be particularly beneficial for auscultators with limited experience, as interobserver variability was not affected by observer experience. The ES may offer distinct practical advantages over a CS that may be attractive to clinicians. Further studies are needed to fully elucidate the diagnostic potential of ESs in the diagnosis of cardiac disease in cats.

Funding This study received financial support from 3M Corporation, Minneapolis, MN, USA.

Conflict of interest The authors do not have any potential conflicts of interest to declare.

References

1 Grenier MC, Gagnon K, Genest J, Jr, et al. **Clinical comparison of acoustic and electronic stethoscopes and design of a new electronic stethoscope**. *Am J Cardiol* 1998; 81: 653–656.

2 Abella M, Formolo J and Penney DG. **Comparison of the acoustic properties of six popular stethoscopes**. *J Acoust Soc Am* 1992; 91: 2224–2228.

3 Gavish B and Heller O. **A practical method for evaluating stethoscopes**. *Biomed Instrum Technol* 1992; 26: 97–102.

4 Kindig JR, Beeson TP, Campbell RW, et al. **Acoustical performance of the stethoscope: a comparative analysis**. *Am Heart J* 1982; 104: 269–275.

5 Ishmail AA, Wing S, Ferguson J, et al. **Interobserver agreement by auscultation in the presence of a third heart sound in patients with congestive heart failure**. *Chest* 1987; 91: 870–873.

6 Lok CE, Morgan CD and Ranganathan N. **The accuracy and interobserver agreement in detecting the 'gallop sounds' by cardiac auscultation**. *Chest* 1998; 114: 1283–1288.

7 Raftery EB and Holland WW. **Examination of the heart: an investigation into variation**. *Am J Epidemiol* 1967; 85: 438–444.

8 Pedersen HD, Haggstrom J, Falk T, et al. **Auscultation in mild mitral regurgitation in dogs: observer variation, effects of physical maneuvers, and agreement with color Doppler echocardiography and phonocardiography**. *J Vet Intern Med* 1999; 13: 56–64.

9 Hoglund K, French A, Dukes-McEwan J, et al. **Low intensity heart murmurs in boxer dogs: inter-observer variation and effects of stress testing**. *J Small Anim Pract* 2004; 45: 178–185.

10 Wagner T, Fuentes VL, Payne JR, et al. **Comparison of auscultatory and echocardiographic findings in healthy adult cats**. *J Vet Cardiol* 2010; 12: 171–182.

11 Hoyte H, Jensen T and Gjesdal K. **Cardiac auscultation training of medical students: a comparison of electronic sensor-based and acoustic stethoscopes**. *BMC Medical Education* 2005; 5: 14.

12 Tavel ME. **Cardiac auscultation: a glorious past – and it does have a future!** *Circulation* 2006; 113: 1255–1259.

13 Tourtier JP, Libert N, Clapson P, et al. **Auscultation in flight: comparison of conventional and electronic stethoscopes**. *Air Med J* 2011; 30: 158–160.

14 Tourtier JP, Fontaine E, Coste S, et al. **In flight auscultation: comparison of electronic and conventional stethoscopes**. *Am J Emerg Med* 2011; 29: 932–935.

15 Voros K, Nolte I, Hungerbuhler S, et al. **Sound recording and digital phonocardiography of cardiac murmurs in dogs by using a sensor-based electronic stethoscope**. *Acta Vet Hung* 2011; 59: 23–35.

16 Kienle RD and Thomas WP. **Echocardiography**. In: Nyland TG and Mattoon JS (eds). Small animal diagnostic ultrasound. 2nd ed. Philadelphia: WB Saunders, 2002, pp 354–424.

17 Leathem A. **Systolic murmurs**. *Circulation* 1958; 17: 601–611.

18 Perloff JK. **The physiologic mechanisms of cardiac and vascular physical signs**. *J Am Coll Cardiol* 1983; 1: 184–98.

19 Nerem RM and Seed WA. **An in vivo study of aortic flow disturbances**. *Cardiovasc Res* 1972; 6: 1–14.

20 Nerem RM, Seed WA and Wood NB. **An experimental study of the velocity distribution and transition to turbulence in the aorta**. *J Fluid Mech* 1972; 52: 137–160.

21 Vittal SB, Luisada AA and Rao DB. **Importance of aortic dilatation in the genesis of the innocent systolic ejection murmur of the aged**. *J Am Geriatr Soc* 1976; 8: 366–370.

22 Kvart C and Haggstrom J. Cardiac auscultation and phonocardiography in dogs, horses and cats. Uppsala: TK I Uppsala AB, 2002, pp 13–20.

23 Cohen J. **A coefficient of agreement for nominal scales**. *Educ Psychol Meas* 1960; 20: 37–46.

24 Altman DG (ed). Practical statistics for medical research. London: Chapman and Hall, 1991, p 404.

25 Agresti A (ed). Categorical data analysis. New York: Wiley, 1991, pp 59–66.

26 Fleiss JL. **Measuring nominal scale agreement among many raters**. *Psychol Bull* 1971; 76: 378–382.

27 Landis JR and Koch GG. **The measurement of observer agreement for categorical data**. *Biometrics* 1977; 33: 159–174.

28 Fox PR, Liu SK and Maron BJ. **Echocardiographic assessment of spontaneously occurring feline hypertrophic cardiomyopathy: an animal model of human disease**. *Circulation* 1995; 92: 2645–2651.

29 Belmont JM and Mattiolo LF. **Accuracy of analog telephonic stethoscopy for pediatric telecardiology**. *Pediatrics* 2003; 112: 780–786.

30 Keren R, Tereschuk M and Luan X. **Evaluation of a novel method for grading heart murmur intensity**. *Arch Pediatr Adolesc Med* 2005; 159: 329–334.