UNIVERSIDADE FEDERAL DE LAVRAS

ADRIANA CRISTINA DA SILVA

STRAIN E *STRAIN RATE* LONGITUDINAL POR MEIO DO *SPECKLE TRACKING* BIDIMENSIONAL EM GATOS DOMÉSTICOS SADIOS E NÃO SEDADOS

LAVRAS – MG

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Dissertação apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ciências Veterinárias, área de concentração em Clínica, Cirurgia e Patologia Veterinária, para a obtenção do título de Mestre.

Orientadora

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Ficha Catalográfica Preparada pela Divisão de Processos Técnicos da Biblioteca da UFLA

Silva, Adriana Cristina da.
Strain e *strain rate* longitudinal por meio do *speckle tracking* bidimensional em gatos domésticos sadios e não sedados / Adriana Cristina da Silva. – Lavras : UFLA, 2012.
58 p. : il.

Dissertação (mestrado) – Universidade Federal de Lavras, 2012.
Orientador: Ruthnéa Aparecida Lázaro Muzzi..
Bibliografia.

1. Felinos. 2. Cardiopatia. 3. Ecocardiografia. 4. Strain. I. Universidade Federal de Lavras. II. Título.

CDD – 636.08961207543

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APROVADA em 28 de fevereiro de 2012.

Prof. Dr. Gregório Corrêa Guimarães	UFLA
Prof. Dr. Rodrigo Bernardes Nogueira	UFLA
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Orientadora

LAVRAS – MG

2012

Aos meus pais, José e Rosa,
por me ensinarem o valor
das pequenas coisas,

DEDICO

AGRADECIMENTOS

Agradeço a Deus, por me permitir vencer mais esta etapa e conquistar, durante o caminho, amigos de quem jamais me esquecerei.

A meus irmãos e irmãs, que partilharam comigo muitas felicidades e dificuldades encontradas.

Ao meu amor, amigo e companheiro, Guilherme, que esteve comigo em todos estes momentos, com muita paciência e carinho, partilhando cada conquista e temor, me incentivando sempre a buscar meus sonhos. E à sua família, que também considero como minha, pelo apoio e consideração.

À professora Ruthnéa, a quem considero mais do que uma orientadora e sim uma amiga e um exemplo, como pessoa e como profissional, pela confiança, apoio e por partilhar conosco seu conhecimento.

Aos amigos que sempre estiveram presentes em algum momento e que torceram para que tudo fosse perfeito, em especial meus companheiros de mestrado, Gisele, Rosane e Matheus, por estarem ao meu lado, mesmo nos arranhões e miados, pelos risos e lágrimas que juntos partilhamos. E aos colegas residentes do HV UFLA e alunos, que se mostraram sempre prontos a nos ajudar.

Aos membros da banca examinadora, professores Gregório, Rodrigo, Leonardo e Lacreta, por aceitarem o convite, pela disponibilidade e por compartilharem seu conhecimento.

Ao Departamento de Medicina Veterinária e ao Programa de Pós-Graduação em Ciências Veterinárias, por propiciarem o desenvolvimento do projeto e pela oportunidade de aprendizado.

À Universidade Federal de Lavras, por sempre acolher seus alunos com braços de mãe.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), pelo suporte financeiro durante a realização do projeto.

Aos proprietários dos gatos, que prontamente se dispuseram a nos ajudar E a todos os gatos que participaram do projeto. Todos foram “gracinhas” para mim.

Aos meus gatos, Pretinha, Batata, Toninho e Neném, por estarem em minha vida e ajudarem a despertar o imenso amor que tenho pelos felinos.

“Um gato vive um pouco nas poltronas, no cimento ao sol, no telhado sob a lua. Vive também sobre a mesa do escritório, e o salto preciso que ele dá para atingi-la é mais do que impulso para a cultura. É o movimento civilizado de um organismo plenamente ajustado às leis físicas, e que não carece de suplemento de informação. Livros e papéis beneficiam-se com a sua presteza austera. Mais do que a coruja, o gato é símbolo e guardião da vida intelectual."

Carlos Drummond de Andrade

RESUMO

A ecocardiografia tem se tornado um dos métodos diagnósticos mais importantes em cardiologia veterinária. Dessa forma, novas ferramentas incorporadas à ecocardiografia, como o Doppler tecidual e, mais recentemente, o *speckle tracking* bidimensional, têm auxiliado no diagnóstico definitivo assim como na determinação do prognóstico das alterações cardíacas. O *speckle tracking* é uma ferramenta já consolidada e validada em medicina humana, sendo utilizada em diversas cardiopatias. Em medicina veterinária, o uso dessa ferramenta já foi demonstrado em cães e equinos. No entanto, por ser recente, ainda não abrange várias espécies, havendo poucas informações ou, mesmo, ausência delas em felinos domésticos. Diante disso, o presente trabalho foi realizado com o objetivo de demonstrar o uso da ferramenta *speckle tracking* bidimensional em gatos, de forma a estabelecer valores de referência e padronizar a técnica em felinos domésticos saudáveis não sedados. Para isso, foram utilizados 30 gatos clinicamente saudáveis e não sedados, dos quais foram obtidos pressão arterial sistólica, eletrocardiograma (ECG) e ecoDopplercardiografia. Três a cinco ciclos cardíacos consecutivos utilizando ECG contínuo foram armazenados em formato digital para posterior avaliação *off-line*. Os c*ine loops* foram obtidos a partir da vista apical quatro câmaras esquerda e seis mensurações, utilizando o *software* do *speckle tracking*, foram obtidas em dois diferentes *cine loops* (três medidas para cada *cine loop*) ao final da sístole para todas as variáveis estudadas e, então, a média foi calculada. A função miocárdica longitudinal foi avaliada e as variáveis *strain* (%), *strain rate* (1/s), velocidade (cm/s) e deslocamento (mm) longitudinais foram obtidas, demonstrando os seguintes valores -15,65±5,46, -1,80±0,59, 1,41±0,87, 1,27±0,80, respectivamente. Dessa forma, o presente estudo auxilia na melhor compreensão da função miocárdica em felinos domésticos.

Palavras-chave: Cardiopatia. Ecocardiografia. Felinos. *Strain*.

ABSTRACT

Echocardiography has become one of the most important diagnostic methods in veterinary cardiology. Thus, new tools incorporated into echocardiography such as tissue Doppler and, more recently two-dimensional speckle tracking has been assisting in the definitive diagnosis, as well as in determining the prognosis of cardiac diseases. The speckle tracking is a well-established and validated tool in human medicine and is used in several heart diseases. In veterinary medicine its use has been demonstrated in dogs and horses. However, its use is recently applied to veterinary, given that, there is little species being studied with speckle tracking. Regarding felines, there is little or even absence of information about the use of this tool in domestic cats. Thus, the present work aimed to demonstrate the use of the two-dimensional speckle tracking echocardiography, in order to establish preliminary reference range and the technique in healthy non-sedated cats. For this purpose, were used 30 clinically healthy non-sedated cats, which were obtained the systolic blood pressure, electrocardiogram (ECG), and Doppler echocardiography. Three to 5 consecutive heart cycles using a continuous monitoring ECG were stored in digital format on a workstation for off-line analysis. Cine loops were acquired from left apical four chamber view and 6 measurements using speckle tracking software were obtained in two different Cine loops (3 measurements for each Cine loop) at end-systole for all studied variables and then average was calculated. Myocardial longitudinal function was evaluated and the variables longitudinal Strain (%) Strain Rate (1/s), velocity (cm/s) and displacement (mm) were obtained, showing the values -15.65 ± 5.46, -1.80 ± 0.59, 1.41 ± 0.87, 1.27 ± 0.80, respectively. Thus, the present study helps in the better understanding of myocardial function in cats.

Keywords: Cardiopathy. Echocardiography. Felines. Strain.

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LISTA DE ABREVIATURAS	
DT	Doppler tecidual
ECG	Eletrocardiograma
ROI	Região de interesse
ST	*Speckle tracking*
St	*Strain*
StR	*Strain rate*
VE	Ventrículo esquerdo
2D	Bidimensional

LISTA DE SÍMBOLOS	
%	Porcentagem
1/s	Um dividido por Segundo
cm/s	Centímetros por Segundo
mm	Milímetros
±	Mais ou menos

SUMÁRIO

PRIMEIRA PARTE

1 INTRODUÇÃO

O felino doméstico (*Felis catus*) vem se tornado um dos animais de companhia mais populares no mundo. Este fato leva a uma demanda crescente por atendimento veterinário especializado para a espécie. Além disso, há um aumento na longevidade destes animais e, com isso, o surgimento de doenças até recentemente pouco diagnosticadas na rotina.

As cardiopatias em felinos têm recebido grande interesse, uma vez que estes são modelos experimentais para algumas alterações que ocorrem em humanos. Assim, o entendimento da fisiopatologia dessas afecções nesta espécie corrobora para o desenvolvimento não apenas da cardiologia veterinária, mas também da área cardiológica humana.

Neste contexto, a ecocardiografia tem se tornado um dos métodos diagnósticos mais importantes na cardiologia veterinária. O desenvolvimento de novas ferramentas, como o *speckle tracking* (ST), tem auxiliado tanto no campo clínico quanto experimental, uma vez que pode fornecer o diagnóstico definitivo, de forma não invasiva e muitas vezes precoce, das alterações cardíacas.

Em nosso país, a medicina de felinos ainda é uma área em ascensão e que cada vez mais pesquisas em torno desta espécie têm sido desenvolvidas.

O presente estudo foi realizado com o objetivo de avaliar, por meio da ecocardiografia bidimensional (2D) ST, a deformação miocárdica ventricular esquerda pela mensuração do *strain* (St) e do *strain rate* (StR) longitudinal, obtidos em diversos segmentos miocárdicos em felinos clinicamente saudáveis e não sedados, uma vez que não há dados semelhantes relatados na literatura.

2 REFERENCIAL TEÓRICO

2.1 Ecocardiografia

Durante os últimos anos, a ecocardiografia transtorácica tem se tornado uma das ferramentas de imagem mais importantes para o diagnóstico não invasivo e o manejo clínico adequado das doenças cardiovasculares em pequenos animais. Avanços mais recentes em ultrassonografia como o Doppler tecidual (DT) e o ST, têm acrescentado novos parâmetros para a avaliação da função miocárdica, incluindo velocidade regional e deformação, torsão ventricular e sincronia mecânica (CHETBOUL, 2010).

Em relação aos felinos, o exame ecocardiográfico é essencial para a avaliação de doenças cardíacas, especialmente animais com suspeita de doença miocárdica adquirida. Este exame é também indicado em casos suspeitos de doenças cardíacas congênitas ou, mesmo, quando alterações são observadas à auscultação, no eletrocardiograma (ECG) ou em outros exames auxiliares (BONAGURA, 2000).

Várias modalidades ecocardiográficas são utilizadas nas doenças cardíacas em felinos (BONAGURA, 2000), como a ecocardiografia convencional (modo-M, 2D, Doppler clássico espectral e mapeamento de fluxo a cores) e novas modalidades do Doppler (tecidual, St e StR) (ABBOTT; MACLEAN, 2006; BOON, 2011a, 2011b, 2011c; WESS; SARKAR; HARTMANN, 2010).

O modo-M e o 2D são utilizados para se obter o diâmetro das câmaras cardíacas e a espessura do septo interventricular e parede ventricular, além da avaliação qualitativa do movimento e função. Estes métodos, associados ao Doppler, podem fornecer uma mensuração mais detalhada do miocárdio (BONAGURA, 2000).

O DT é uma técnica ecocardiográfica que permite a quantificação da função miocárdica global e regional por meio de medidas de velocidade miocárdica em tempo real (CHETBOUL, 2002, 2010; SIMPSON et al., 2007). As modalidades do DT pulsado e modo-M em cores têm demonstrado serem ferramentas sensíveis para se detectar doença miocárdica em felinos (KOFFAS et al., 2006, 2008; MACDONALD et al., 2006).

Em gatos com cardiomiopatia hipertrófica, em alguns estudos foi demonstrado que o DT foi capaz de fornecer o diagnóstico precoce da doença, mesmo na presença de hipertrofia em grau leve ou ausente (CHETBOUL et al., 2006a, 2006b; SIMPSON et al., 2007). Por sua vez, em cães com doença crônica da valva mitral, Schober et al. (2010) demonstraram que novos índices obtidos a partir do DT foram capazes de predizer a ocorrência de insuficiência cardíaca congestiva nos animais estudados.

Segundo Pavlopoulos e Nihoyannopoulos (2008), St e StR miocárdico são definidos como a magnitude de encurtamento ou alongamento das fibras cardíacas (%) e a taxa em que esta deformação ocorre (1/s). Estes são considerados novos índices incorporados à medicina veterinária (CHETBOUL, 2010). St e StR obtidos a partir do DT foram capazes de demonstrar alterações miocárdicas em felinos com cardiomiopatia hipertrófica, mesmo quando os índices ecocardiográficos convencionais estavam dentro da normalidade (WESS et al., 2010). No entanto, entre as limitações desta técnica está a dependência da translação cardíaca e do ângulo de insonação, uma vez que o alinhamento incorreto do feixe ultrassônico com a parede miocárdica pode influenciar os resultados obtidos (CHETBOUL et al., 2007). Além disso, incorporação de ruídos, reverberação de artefatos, limitação relativa à resolução lateral, *aliasing* e inadequada taxa de repetição de quadros (*frame rate*) constituem os principais desafios da técnica (PAVLOPOULOS; NIHOYANNOPOULOS, 2008).

2.2 Ecocardiografia *speckle tracking* bidimensional

A ecocardiografia 2D ST é uma das mais recentes ferramentas de ultrassonografia que permitem o acesso à função miocárdica, utilizadas em medicina veterinária (CHETBOUL, 2010). Esta técnica de imagem é baseada no rastreamento de pontos criados pela interferência entre o feixe ultrassonográfico e o miocárdio em imagens ecocardiográficas 2D em escala de cinza. Estes s*peckles* aparecem como elementos (pontos) pequenos e brilhantes dentro do miocárdio e representam marcadores acústicos teciduais naturais que podem ser monitorados (*tracking*) momento a momento, durante todo o ciclo cardíaco (Figura 1) (CHETBOUL, 2010; HOOGE, 2007).

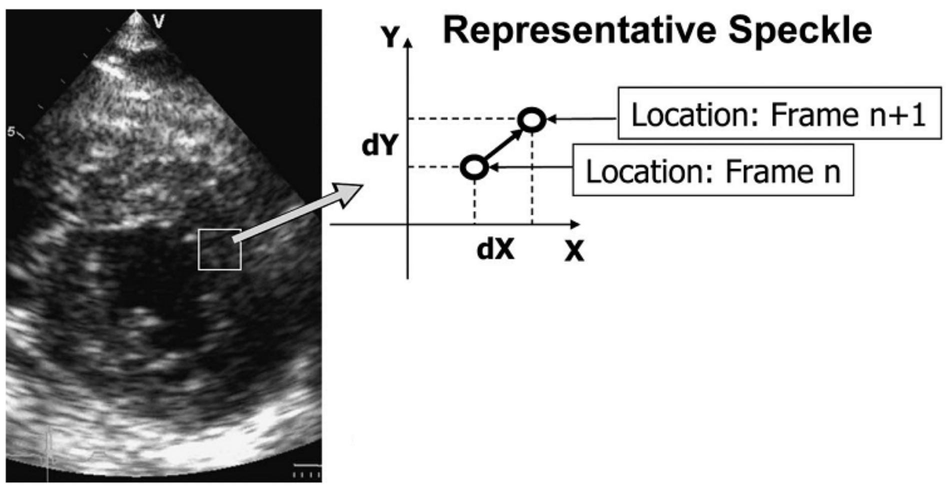

FIGURA 1 Padrão de *speckles* em escala de cinza em imagem bidimensional. Pontos acústicos (*speckles*) são identificados na região de interesse. A posição relativa dos pontos é, então, rastreada quadro a quadro (taxa de frames/s), de acordo com a movimentação do miocárdio. dY: deslocamento dos pontos; dX: tempo de deslocamento. Fonte: Suffoletto e Herszkowicz (2006)

Ao contrário do DT, a ecocardiografia 2D ST permite a mensuração das deformações miocárdicas em sentido longitudinal e circunferencial pelos cortes apical quatro câmaras e paraesternal eixo curto do ventrículo esquerdo (VE), uma vez que não há restrições quanto ao ângulo de insonação. Além disso, os pontos acústicos rastreados são representados por vetores de velocidade, que permitem observar a direção e a intensidade do movimento (DEL CASTILLO; HERSZKOWICZ, 2008). No entanto, este método ecocardiográfico também possui algumas limitações, como resolução lateral em regiões miocárdicas distantes, pontos fora do plano miocárdico, reverberações e, sobretudo, a qualidade da imagem 2D, que deve ser acima da média (PAVLOPOULOS; NIHOYANNOPOULOS, 2008).

Nos últimos anos, a técnica 2D ST tem sido aplicada intensamente em medicina e seus resultados validados com a ressonância magnética marcada e sonomicrometria, técnicas consideradas padrão para a obtenção da deformação miocárdica. Foi demonstrado que os valores encontrados eram semelhantes aos obtidos através do 2D ST (AMUNDSEN et al., 2006; GOFFINET et al., 2009). Esta ferramenta tem sido empregada na obtenção de valores de referência em humanos saudáveis (HURLBURT et al., 2007) e em portadores de diversas alterações cardíacas, como cardiomiopatia hipertrófica ou dilatada, embolismo pulmonar, torção ventricular, sincronia e avaliação da resposta à terapia de re-sincronização cardíaca (DELGADO et al., 2008; MELUZIN et al., 2011; OPDAHL et al., 2008; SERRI et al., 2006; SUFFOLETTO et al., 2006; TAKAMURA et al., 2011).

Em medicina veterinária, a ecocardiografia 2D ST tem sido utilizada em cães, para se obter o St e StR, assim como a torção e a sincronia miocárdicas, tanto em animais saudáveis para se estabelecer valores de referência e padronizar a técnica (CHETBOUL et al., 2007, 2008; GRIFFTHS; FRANSIOLI; CHIGERWE, 2011; WESS et al., 2011), como em animais cardiopatas (TAKANO et al., 2011). Em equinos, esta ferramenta tem sido aplicada na avaliação miocárdica, obtendo-se valores de referência em repouso e em exercício (DECLOEDT et al., 2011; SCHEFER et al., 2010). No entanto, há pouca informação na literatura sobre o uso desta ferramenta em gatos domésticos (RIESEN et al., 2011), assim como valores de referência para St, StR longitudinal, radial ou circunferencial, além de torsão ventricular, sincronia e outras aplicações já validadas em outras espécies.

2.2.1 *Strain* e *strain rate* bidimensional

Vários trabalhos têm sido desenvolvidos utilizando-se as variáveis St e StR obtidas pela ecocardiografia 2D ST, em humanos (DELGADO et al., 2008; OPDAHL et al., 2008; SERRI et al., 2006; SUFFOLETTO et al., 2006; TAKAMURA et al., 2011) e na área da cardiologia veterinária (CHETBOUL et al., 2007; TAKANO et al., 2011; WESS et al., 2011). Estas variáveis têm grande importância, uma vez que podem ser consideradas novos índices sistólicos que podem, muitas vezes, predizer alterações miocárdicas, mesmo antes de serem observadas na ecocardiografia convencional (ARTIS et al., 2008).

As variáveis de deformação miocárdica St e StR são diretamente dependentes da disposição das fibras miocárdicas e esta deformação ocorre no sentido destas, podendo ser longitudinal, radial, circunferencial ou em cisalhamento (DEL CASTILLO; HERSZKOWICZ, 2008).

O St longitudinal é representado pela deformação que ocorre no miocárdio entre o anel mitral e o ápice cardíaco, ou seja, no eixo longitudinal. Por sua vez, o St radial é aquele que ocorre pelo espessamento da parede ventricular e septal durante a sístole. O St circunferencial ocorre devido à rotação do miocárdio em torno de seu eixo longitudinal. E, por último, o St de cisalhamento é aquele formado pelo deslocamento do endocárdio em relação ao epicárdio (Figura 2) (GEYER et al., 2010).

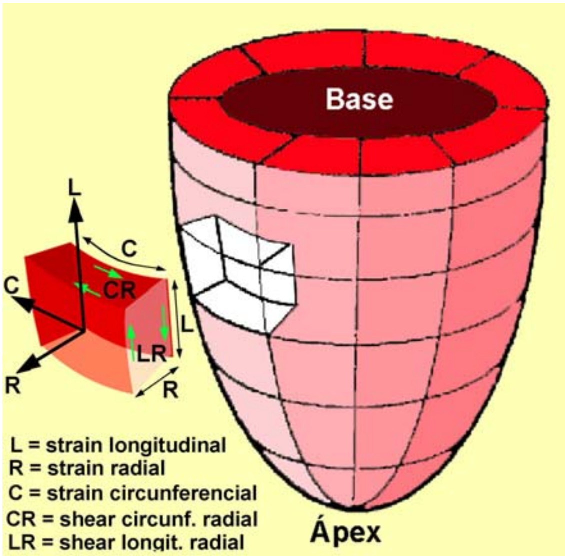

FIGURA 2 Esquema demonstrando a deformação miocárdica longitudinal, radial, circunferencial e cisalhamento (*shear strain*). Fonte: Dell Castilho e Herszkowicz (2008)

Em cães, Wess et al. (2011) demonstraram que os valores St e StR longitudinais, obtidos tanto pela ecocardiografia 2D ST quanto pelo DT, são semelhantes e com pouca variação inter e intraobservador. Dessa forma, os dois métodos podem ser utilizados alternadamente, de acordo com a disponibilidade destas ferramentas na rotina da clínica cardiológica. No entanto, o 2D ST apresenta a vantagem de maior facilidade e rapidez em sua execução, além de menor influência de fatores, como o ângulo de insonação nos resultados.

Em eqüinos, a ecocardiografia 2D ST demonstrou ser uma técnica confiável para se obter o St e o StR longitudinal, além de velocidade e deslocamento (DECLOEDT et al., 2011). Por sua vez, em humanos, o St longitudinal demonstrou ser mais adequado como índice prognóstico em várias alterações como em doenças valvares, além de auxiliar como indicativo de disfunção ventricular esquerda (LANCELLOTTI et al., 2008; MARCINIAK et al., 2009; MIZUGUCHI et al., 2008).

Em cães, a técnica do 2D ST foi padronizada para o corte paraesternal eixo curto por Chetboul et al. (2007), que quantificaram o St e StR radial em cães saudáveis e não sedados, além de comparar os valores obtidos com o DT, tendo sido observada semelhança entre eles. Além disso, em humanos, foi demonstrado, por Delgado et al. (2008), que o St radial é o melhor método para se avaliar a resposta em pacientes submetidos à terapia de ressincronização cardíaca, quando comparado ao St longitudinal e circunferencial.

Quanto às variáveis St e StR circunferenciais, em um estudo em paciente humano tratado para insuficiência cardíaca com marcapasso, foi demonstrado que, apesar de o DT mostrar velocidade radial e longitudinal sincronizada, o St e o StR mostraram uma disparidade persistente, fato que poderia ser justificado como uma possível melhora não sustentada do desempenho sistólico do VE no paciente em questão (VANNAN et al., 2005).

Em outro estudo em humanos, identificou-se significante correlação entre o St circunferencial e a fração de encurtamento na região média miocárdica, obtida pela ressonância magnética cardíaca ou modo-M, podendo atuar, dessa forma, como um índice prognóstico em casos de doença cardíaca hipertensiva e disfunção sistólica intramural, assim como a fração de ejeção (HURLBURT et al., 2007).

3 CONSIDERAÇÕES GERAIS

Diante do exposto, a ecocardiografia 2D ST tem demonstrado ser de grande utilidade no diagnóstico das cardiomiopatias, tanto em humanos quanto em medicina veterinária. Diversos estudos demonstram a importância de St e StR como novos índices sistólicos para a avaliação da função miocárdica ventricular esquerda. No entanto, sua viabilidade e sensibilidade ainda não foram demonstradas em gatos domésticos. Dessa forma, o presente estudo atua de modo a colaborar para o melhor entendimento desta ferramenta e suas variáveis e seu papel na cardiologia de felinos, além de padronizar a técnica e fornecer valores de referência para o St e o StR obtidos por meio do 2D ST nesta espécie.

REFERÊNCIAS

ABBOTT, J. A.; MACLEAN, H. N. Two-dimensional echocardiographic assessment of the feline left atrium. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 20, n. 1, p. 111-119, Jan./Feb. 2006.

AMUNDSEN, H. et al. Noninvasive myocardial strain measurement by speckle tracking echocardiography: validation against sonomicrometry and tagged magnetic resonance imaging. **Journal of the American College of Cardiology**, San Diego, v. 47, n. 4, p. 789-793, Feb. 2006.

ARTIS, N. J. et al. Two-dimensional strain imaging: a new echocardiographic advance with research and clinical applications. **International Journal of Cardiology**, Amsterdam, v. 123, n. 3, p. 240-248, Jan. 2008.

BONAGURA, J. D. Feline echocardiography. **Journal of Feline Medicine and Surgery**, London, v. 2, n. 3, p. 147-151, Sept. 2000.

BOON, J. A. Evaluation of size, function, and hemodynamics. In: ______. **Veterinary echocardiography**. 2nd ed. Iowa: Wiley-Blackwell, 2011a. p. 153-266.

______. The M-mode and Doppler examination. In: ______. **Veterinary echocardiography**. 2nd ed. Iowa: Wiley-Blackwell, 2011b. p. 101-152.

______. The two-dimensional echocardiographic exam. In: ______. **Veterinary echocardiography**. 2nd ed. Iowa: Wiley-Blackwell, 2011c. p. 37-100.

CHETBOUL, V. Advanced techniques in echocardiography in small animals. **Veterinary Clinics Small Animal**, Philadelphia, v. 40, n. 4, p. 529-543, July 2010.

CHETBOUL, V. Tissue Doppler imaging: a promising technique for quantifying regional myocardial function. **Journal of Veterinary Cardiology**, Bern, v. 4, n. 2, p. 7-12, Nov. 2002.

CHETBOUL, V. et al. Noninvasive assessment of systolic left ventricular torsion by 2-dimensional speckle tracking imaging in the awake dog: repeatability, reproducibility, and comparison with tissue Doppler imaging variables. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 22, n. 2, p. 342-350, Mar./Apr. 2008.

______. Radial strain and strain rate by two-dimensional speckle tracking echocardiography and the tissue velocity based technique in the dog. **Journal of Veterinary Cardiology**, Bern, v. 9, n. 2, p. 69-81, Nov. 2007.

______. Tissue Doppler imaging for detection of radial and longitudinal myocardial dysfunction in a family of cats affected by dystrophin-deficient hypertrophic muscular dystrophy. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 20, n. 3, p. 640-647, May/June 2006a.

______. Two-dimensional color tissue Doppler imaging detects myocardial dysfunction before occurrence of hypertrophy in a young Maine coon cat. **Veterinary Radiology & Ultrasound**, Raleigh, v. 47, n. 3, p. 295-300, May/June 2006b.

DECLOEDT, A. et al. Quantification of left ventricular longitudinal strain, strain rate, velocity, and displacement in healthy horses by 2-dimensional speckle tracking. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 25, n. 2, p. 330-338, Mar./Apr. 2011.

DEL CASTILLO, J. M.; HERSZKOWICZ, N. Strain bidimensional (X-Strain): utilização do método para avaliação de cardiopatias. **Revista Brasileira de Ecocardiografia**, São Paulo, v. 21, n. 3, p. 29-35, jul./set. 2008.

DELGADO, V. et al. Assessment of left ventricular dyssynchrony by speckle tracking strain imaging comparison between longitudinal, circumferential, and radial strain in cardiac resynchronization therapy. **Journal of the American College of Cardiology**, San Diego, v. 51, n. 20, p. 1944-1952, May 2008.

GEYER, H. et al. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. **Journal of the American Society of Echocardiography**, Morrisville, v. 23, n. 4, p. 351-359, Apr. 2010.

GOFFINET, C. et al. Assessment of subendocardial vs. subepicardial left ventricular rotation and twist using two-dimensional speckle tracking echocardiography: comparison with tagged cardiac magnetic resonance. **European Heart Journal**, Oxford, v. 30, n. 5, p. 608-617, Mar. 2009.

GRIFFITHS, L. J.; FRANSIOLI, J. R.; CHIGERWE, M. Echocardiographic assessment of interventricular and intraventricular mechanical synchrony in normal dogs. **Journal of Veterinary Cardiology**, Bern, v. 13, n. 2, p. 115-126, June 2011.

HOOGE, J. d'. Principles and different techniques for speckle tracking. In: MARWICK, T. H.; YU, C. M.; SUN, J. P. (Ed.). **Myocardial imaging:** tissue doppler and speckle tracking. Massachusetts: Blackwell, 2007. p. 17-25.

HURLBURT, H. M. et al. Direct ultrasound measurement of longitudinal, circumferential, and radial strain using 2-dimensional strain imaging in normal adults. **Echocardiography**, Gardendale, v. 24, n. 7, p. 723-731, Aug. 2007.

KOFFAS, H. et al. Colour M-mode tissue Doppler imaging in healthy cats and cats with hypertrophic cardiomyopathy. **Journal of Small Animal Practice**, Oxford, v. 49, n. 7, p. 330-338, July 2008.

______. Pulsed tissue Doppler imaging in normal cats and cats with hypertrophic cardiomyopathy. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 20, n. 1, p. 65-77, Jan./Feb. 2006.

LANCELLOTTI, P. et al. Importance of left ventricular longitudinal function and functional reserve in patients with degenerative mitral regurgitation: assessment by two-dimensional speckle tracking. **Journal of the American Society of Echocardiography**, Morrisville, v. 21, n. 12, p. 1331-1336, Dec. 2008.

MACDONALD, K. A. et al. Tissue Doppler imaging and gradient echo cardiac magnetic resonance imaging in normal cats and cats with hypertrophic cardiomyopathy. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 20, n. 3, p. 627-634, May/June 2006.

MARCINIAK, A. et al. Myocardial deformation abnormalities in patients with aortic regurgitation: a strain rate imaging study. **European Journal of Echocardiography**, Oxford, v. 10, n. 1, p. 112-119, Jan. 2009.

MELUZIN, J. et al. Estimation of left ventricular filling pressures by speckle tracking echocardiography in patients with idiopathic dilated cardiomyopathy. **European Journal of Echocardiography**, Oxford, v. 12, n. 1, p. 11-18, Jan. 2011.

MIZUGUCHI, Y. et al. The functional role of longitudinal, circumferential, and radial myocardial deformation for regulating the early impairment of left ventricular contraction and relaxation in patients with cardiovascular risk factors: a study with two-dimensional strain imaging. **Journal of the American Society of Echocardiography**, Morrisville, v. 21, n. 10, p. 1138-1144, Oct. 2008.

OPDAHL, A. et al. Apical rotation by speckle tracking echocardiography: a simplified bedside index of left ventricular twist. **Journal of the American Society of Echocardiography**, Morrisville, v. 21, n. 10, p. 1121-1128, Oct. 2008.

PAVLOPOULOS, H.; NIHOYANNOPOULOS, P. Strain and strain rate deformation parameters: from tissue Doppler to 2D speckle tracking. **International Journal of Cardiovascular Imaging**, Boston, v. 24, n. 5, p. 479-491, June 2008.

RIESEN, S. C. et al. Comparison of the effects of ivabradine and atenolol on heart rate and echocardiographic variables of left heart function in healthy cats. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 25, n. 3, p. 469-476, Jan. 2011.

SCHEFER, K. D. et al. Quantitative analysis of stress echocardiograms in healthy horses with 2-dimensional (2D) echocardiography, anatomical M -mode, tissue Doppler imaging, and 2D speckle tracking. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 24, n. 4, p. 918-931, July/Aug. 2010.

SCHOBER, K. E. et al. Detection of congestive heart failure in dogs by Doppler echocardiography. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 24, n. 6, p. 1358-1368, Nov./Dec. 2010.

SERRI, K. et al. Global and regional myocardial function quantification by two-dimensional strain application in hypertrophic cardiomyopathy. **Journal of the American College of Cardiology**, San Diego, v. 47, n. 6, p. 1175-1181, Mar. 2006.

SIMPSON, K. E. et al. Assessment of the repeatability of feline echocardiography using conventional echocardiography and spectral pulse wave Doppler tissue imaging techniques. **Veterinary Radiology & Ultrasound**, Raleigh, v. 48, n. 1, p. 58-68, Jan./Feb. 2007.

SUFFOLETTO, M. S. et al. Novel speckle-tracking radial strain from routine black-and-white echocardiographic images to quantify dyssynchrony and predict response to cardiac resynchronization therapy. **Circulation**, Dallas, v. 113, n. 7, p. 960-968, Feb. 2006.

TAKAMURA, T. et al. Reversible left ventricular regional non-uniformity quantified by speckle-tracking displacement and strain imaging in patients with acute pulmonary embolism. **Journal of the American Society of Echocardiography**, Morrisville, v. 24, n. 7, p. 792-802, July 2011.

TAKANO, H. et al. Assessment of left ventricular regional function in affected and carrier dogs with duchenne muscular dystrophy using speckle tracking echocardiography. **BMC Cardiovascular Disorders**, London, v. 11, n. 23, p. 1-8, May 2011.

VANNAN, M. A. et al. Effect of cardiac resynchronization therapy on longitudinal and circumferential left ventricular mechanics by velocity vector imaging: description and initial clinical application of a novel method using high-frame rate B-mode echocardiographic images. **Echocardiography**, Gardendale, v. 22, n. 10, p. 826-830, Nov. 2005.

WESS, G. et al. Comparison of longitudinal myocardial tissue velocity, strain, and strain rate measured by two-dimensional speckle tracking and by color tissue Doppler imaging in healthy dogs. **Journal of Veterinary Cardiology**, Bern, v. 13, n. 1, p. 31-43, Mar. 2011.

WESS, G.; SARKAR, R.; HARTMANN, K. Assessment of left ventricular systolic function by strain imaging echocardiography in various stages of feline hypertrophic cardiomyopathy. **Journal of Veterinary Internal Medicine**, Philadelphia, v. 24, n. 6, p. 1375-1382, Nov./Dec. 2010.

SEGUNDA PARTE

ARTIGO

Longitudinal strain and strain rate by two-dimensional speckle tracking in non-sedated healthy cats

Artigo segue as normas e formato do periódico *Journal of Veterinary Internal Medicine* (JVIM)* ao qual foi submetido.

*Este artigo é uma versão preliminar, considerando que o conselho editorial da revista poderá sugerir alterações para adequá-lo ao seu próprio estilo.

Longitudinal Strain and Strain Rate by Two-dimensional Speckle tracking in non-sedated healthy cats

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Short Title: Longitudinal Function by 2D-STE in Cats

Keywords: Echocardiography, Cardiomyopathy, Felines, Myocardial function.

Abbreviations:

2D-STE	Two-dimensional speckle tracking echocardiography
St	Strain
StR	Strain Rate
LSt	Longitudinal Strain
LStR	Longitudinal Strain Rate
Lvel	Longitudinal Velocity
Ldisp	Longitudinal Displacement
2D	Two-dimensional
LVDd	Left ventricular diastolic diameter
RVDd	Right ventricular diastolic diameter
LVDs	Left ventricular systolic diameter
PWd	Posterior wall at diastole
PWs	Posterior wall at systole
IVSd	Interventricular septum at diastole
IVSs	Interventricular septum thickness at systole
FS	Fractional shortening

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Partial data of this study were accepted to be presented as a research report at the American College of Veterinary Internal Medicine Forum (ACVIM), New Orleans, Louisiana, USA, May 30-June 2, 2012.

Acknowledgments

The authors wish to thank to Fundação de Amparo a Pesquisa do Estado de Minas Gerais (FAPEMIG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for the financial support.

Background: 2D speckle tracking is a new tool that has been used in humans and veterinary medicine to quantify myocardial longitudinal function. However, there is an absence of information about the use of this tool in healthy non-sedated cats to obtain myocardial longitudinal strain, strain rate, velocity and displacement.

Objectives: To evaluate myocardial longitudinal strain and strain rate in awake clinically healthy cats, as well as, longitudinal velocity and displacement by means of 2D speckle tracking echocardiography.

Animals: The study population consisted of 30 clinically healthy no-sedated cats, weighting 4.11 ± 0.94 kg and mean age 36.00 ± 33.43 months.

Methods: All cats were examined physically, were obtained systolic blood pressure and performed electrocardiography and echocardiography to assess the healthy status. During conventional echocardiography 2D images were obtained and evaluated off line at speckle tracking software.

Results: Speckle tracking echocardiography demonstrated to be feasible and reliable to obtain left ventricular longitudinal function. The global mean obtained for strain and strain rate were -15.65 ± 5.46 (%), -1.80 ± 0.59 (1/s), respectively. Regarding velocity and displacement were observed 1.41 ± 0.87 (cm/s), 1.27 ± 0.80 (mm), respectively.

Conclusions and Clinical Importance: 2D speckle tracking echocardiography was found to be a reliable technique for measuring LV myocardial LSt, LStR, Lvel and Ldisp. These measurements offer new insights into feline ventricular deformation and motion. In addition, based on our results, preliminary reference values for healthy non-sedated cats could be formulated.

Two-dimensional Speckle Tracking (2D-STE) is a new tool that has been used in veterinary medicine to evaluate myocardial strain (St) and strain rate (StR).[1] St is expressed as a percentage (%) and it is the magnitude of myocardial fibers lengthening or shortening. On the other hand, StR is the rate at which deformation occurs, it describes the velocity of deformation (1/s).[2]

This technique was already validated for dogs, showing to be useful in the diagnosis of cardiomyopathies.[3–6] In humans, several studies demonstrated the efficacy of 2D-STE in the diagnosis of various cardiac diseases and hemodynamic conditions, as myocardial infarctation, hypertrophic cardiomyopathy, coronary disease, ventricular dyssyncrony, among others.[7–9]There is some studies in horses, which were obtained some 2D-STE variables, such as St and StR.[10–13]

In veterinary medicine longitudinal strain (LSt) and strain rate (LStR) were obtained in dogs[6] and in horses[11] and its reliability and feasibility were demonstrated for these species. Although, there are little information regarding 2D-STE variables, such as St and StR in cats,[14,a] being that its feasibly has not yet clarified for this species. In addition, to our knowledge, there is no data about LSt and LStR obtained by 2D-STE in non-sedated clinically healthy cats, as well as, longitudinal velocity (Lvel) and displacement (Ldisp).

Thus, the aim of this study was to evaluate myocardial LSt and LStR in non-sedated clinically healthy cats, as well as, myocardial Lvel and Ldisp by means of 2D-STE.

Material and Methods

Study Population

The study population consisted of 30 healthy cats of different breeds and origins (companion animals presenting for vaccinations or cardiac screening programs, as well as ,student- or faculty-owned cats). Owner consent was obtained before enrollment into the study. The study protocol was in compliance with the institutional Animal Care and Use Committee under the protocol number 052/11. In this study none of the animals were under any type of treatment. In all cats, clinical examination, electrocardiography, echocardiography, and indirect systolic blood pressure measurements were performed to exclude cardiovascular disease.

Conventional Echocardiography

Echocardiographic studies were performed using an ultrasound unit equipped with a 4-10 MHz phased-array transducer.[b] All examinations were performed without sedation in gently restrained cats in lateral recumbency. Standard echocardiographic views were obtained in right and left lateral recumbence.[17,18] Conventional echocardiographic variables, included ventricular measurements taken from the right parasternal short-axis view by two-dimensional (2D) guided M-mode, such as the left ventricular diastolic diameter (LVDd), right ventricular diastolic diameter (RVDd); left ventricular systolic diameter (LVSd), posterior wall at diastole (PWd) and systole (PWs) interventricular septum at diastole (IVSd) and at systole (IVSs) and fractional shortening (FS %). Were also included measurements of the aorta (Ao) and left atrial (LA) diameter by 2D mode and was calculated the LA/Ao ratio. All valves were examined using color Doppler and velocities over the valves were measured using pulsed wave Doppler examinations. At least 3 measurements were performed for all echocardiographic variables and the mean value of the measurements was calculated for each variable.

Speckle Tracking Echocardiography

The 2D echocardiographic loops used for STE analysis were acquired and recorded in all cats using the same ultrasound unit as for the standard examinations. Three to five consecutive heart cycles using a continuous monitoring ECG were stored in digital format on a workstation for off-line analysis. Cine loops were acquired from left apical four chamber view with sampling rates from 56.10 ± 23.49 (38 to 159) frames/s and 6 measurements were obtained in two different Cine loops (3 for each Cine loop) at end-systole for all studied variables and then average was obtained. Semi-automatic tissue tracking and analysis for 2D-ST was performed using a commercially software.[c] For myocardial tracking, endocardial border was marked manually and then, epicardial border was marked automatically by the software, which performed myocardial wall tracking process and velocity vectors were displayed at the region of interest (Fig 1A). Manual adjustment of the myocardial wall borders was performed when necessary. Graphics and curves of studied variables were automatic displayed and myocardium was divided in six segments by the software (Fig 1B) and the values of peak systolic of LSt, LStR, Lvel and Ldisp were shown for each segment at endocardial and epicardial region.

Statistical Analysis

All data were tested for normality by the Kolmogorov-Smirnov test ($P>0.05$). Statistical and graphical analyses were performed by computer software.[d] Summary statistics for the different measurements (mean ± standard deviation-SD; n= 30 cats) were calculated using the average measurement of 6 consecutive heart cycles per cats obtained of two different cine loops (3 consecutive cycles for each cine loop). The data demonstrated not be normally distributed and therefore the Mann-Whitney and Kruskal-Wallis test were applied to compare the cardiac regions (Endocardium and Epicardium) and segments (Bas Sept, Mid Sept, Apic Sept, Bas Lat, Mid Lat and Apic Lat), respectively. These data were displayed as boxplots, and each segment, the median and spread of the peak value or timing were indicated by a boxplot, based on the averaged measurement values for each cat. A value of $P<0.05$ was considered statistically significant.

The intra-observer repeatability was obtained from 3 echocardiograms that were randomly selected to be subjected to 6 repeated analyses at 3 different days for the same recorded loops, to determine intra-observer between-day measurement variability for LSt, LStR, Lvel and Ldisp. Each variable was measured 6 times on 6 consecutive cardiac cycles in 2 different cine loops (3 consecutive cardiac cycles for each cine loop), and the between-day intra-observer variability was determined based on the analysis of variance results of all measurements.

Results

Demographic data (Table 1) and conventional echocardiography (Table 2) are displayed as mean and standard deviation. In this study were observed a higher number of males than females and the mean age of cats were about 36 months. The study population was compounded by mixed breed, Persian and Siamese cats. Regarding to weight a minimal variation was present. The mean of systolic blood pressure was into normal ranges (< 150 mmHg). Regarding conventional echocardiography was observed that all variables were into the normal range described at literature.[19-21]

The 2D STE demonstrated to be feasible in cats, using apical four chamber view to obtain longitudinal variables. A total of 8,640 measurements were obtained for all segments of all STE variables analyzed and 77% of measurements could be considered with adequate tracking quality.

The values of endocardial and epicardial variables are displayed on Table 3 and global endocardial values were lower than epicardial for LSt, Ldisp and Lvel. Table 4 shows the peak values of global, average and segmental measurements of 2D STE variables of all cats studied and significant differences among regions were observed. Heterogeneity was observed at different myocardial segments analyzed, but LV posterior wall regions demonstrated no significant difference. Apical regions of variables Ldisp and Lvel demonstrated significant lower values than other regions for these same variables. Regarding, other variables were observed lower variability, despite significant differences among segments (Fig 2).

The Table 5 displays the between-day intra-observer variability, demonstrating that the variables LSt and LStR had higher values than the others, despite these values were considered with low variability. Endocardial region presented higher variability than epicardial for the variables LSt, Lvel, Ldisp. Regarding the global average Lvel and Ldisp demonstrated to be similar and have lower variability than LSt and LStR.

Discussion

The present study describes the technique of the 2D STE to obtain LV longitudinal myocardial function and its feasibility in non-sedated healthy cats. The left apical four chamber view demonstrated to be adequate to obtain measurements of LSt, LStR, Lvel and Ldisp in felines.

In this study was observed a larger number of males than females, this fact were also observed in a study with cats presenting hypertrophic cardiomyopathy.[22] In our study it can be justified by the fact that cats were selected randomly and gender was not controlled.

Regarding conventional echocardiography, to be included in this study cats must be in the normal range for all variables, excluding any cardiac alteration.

The 2D-STE demonstrated to be feasible to obtain longitudinal function in all cats evaluated, despite some measurements had to be excluded of the analyzes because inadequate tracking. This fact was mentioned before by others studies in dogs[3,6] and could be justified by the difficulty of obtain an optimal quality image compatible with STE software. In our study another fact that could be added is the higher heart rates that non-sedated cats can present at echocardiographic examination which could to interfere in the adequate tracking. The frame rate presented in our study were in accordance with previous data demonstrated in studies in dogs,[3,6] humans,[15,16] horses[11,13] and sedated cats (radial St and StR).[14]

In this study, epicardial and endocardial LSt demonstrated to be significantly different, being epicardial values higher than endocardial one. This fact is different of data reported in a previous study with humans, in which endocardial region presented higher strain values.[23] In our study the global mean of LSt were similar to previous data for the same variable obtained in dogs[6] and in human fetus[24] and much lower than data from horses.[11] This result could be justified by the species differences, as heart size, which is expected higher values of St, proportionally to the size, and heart rate, that may influence the quality of the image.

Heterogeneity was observed at different myocardial segments analyzed, but for the variable LSt there was no significant difference among the segments of the LV posterior wall (Apic Lat, Mid Lat and Bas Lat). In dogs was also demonstrated no significant difference among these segments for LSt.[6] This fact was also observed in a study with horses[11] and in humans.[25] In humans was demonstrated that apical values of LSt were higher than in other segments,[25] and in the present study we observed that basal segments of septum and posterior wall demonstrated higher values. In a study with cats using tissue Doppler to obtain the variable St,[22] were demonstrated values of basal segments of septum and posterior wall a little higher than values of our study. This difference could be justified due to the data of studies were obtained using different techniques, and also was reported at literature the fact that tissue Doppler can be influenced by the insonation angle.[1] Another explanation to these differences is the fact that the cats of the tissue Doppler study were sedated and in the present study the animals were awake, which could influence the results of measurements.

Regarding the variables Lvel, Ldisp and LStR, were observed differences among the segments, despite the middle and basal segments of IVS and LV posterior wall demonstrate no significant differences for the LStR. In dogs, were observed no significant differences in the segments for LStR, however, for the variable Lvel were observed that the values were different and increasing from the apex to the base,[6] as were demonstrated in our study in cats for this same variable.

Regarding the between-day intra-observer the values of variability could be considered with low variability due to all values were lower than 15%. It was also observed at a study with dogs, which were found similar values for the variable LStR.[6] Although, in this same study lower values for LSt were observed than in our study. Lower variability was shown for the variables Ldisp and Lvel in the present data.

Limitations of the present study must be clarified. Firstly, it is a noninvasive study design, performed on companion animals without any invasively obtained hemodynamic data to corroborate with the healthy status of the cats. Another limitation is the high dependency of STE of image quality, which is difficult to obtain in non-sedated cats, given that they can present high heart rates at the examination.

Another limitation of this study is the fact that data obtained may not be applicable to all clinical situations due to differences in machine settings, software, equipment, observer experience and image quality, which may influence the values and variability of the data.

Our study was performed on 30 non-sedated healthy cats and mixed breeds were over represented, being only Persians and Siamese cats presented in small number. Then, a larger study population would be performed in order to determine if there is an influence of breed, gender and age over the 2D-STE variables in cats. Despite the limitations, the study provide preliminary reference values of LSt, LStR, Lvel, Ldisp for non-sedated healthy cats, as well as the feasibility of the technique in this specie.

In conclusion, 2D STE can be considered a reliable technique for measuring left ventricular myocardial LSt, LStR, Lvel and Ldisp in cats. These measurements provide new prospects into feline ventricular deformation and motion, allowing a more complete quantification and understanding of longitudinal myocardial function in this specie. However, more studies should be carried out in order to evaluate the role and reliability of this technique in cats with cardiomyopathies.

Footnotes

[a]Takano H, Isogai T, Aoki T, Wakao Y, Fujii Y: 2D speckle tracking echocardiography in clinically healthy cats and cats with hypertrophic cardiomyopathy. J Vet Int Med 2011;25:971 (Abstract)

[b]Esaote Mylab 40, Italy

[c]Xstrain software version 10.1, Esaote

[d]SPSS Statistics 17.0, Rel. 17.0.1. 2008, SPSS Inc, Chicago, IL

References

1. Chetboul V. Advanced techniques in echocardiography in small animals. Vet Clin North Am Small Anim Pract 2010;40:529–543.

2. Pavlopoulos H, Nihoyannopoulos P. Strain and strain rate deformation parameters: From tissue Doppler to 2D speckle tracking. Int J Cardiovasc Imaging 2008;24:479–491.

3. Chetboul V, Serres F, Gouni V, et al. Radial strain and strain rate by two-dimensional speckle tracking echocardiography and the tissue velocity based technique in the dog. J Vet Cardiol 2007;9:69–81.

4. Chetboul V, Serres F, Gouni V, et al. Noninvasive assessment of systolic left ventricular torsion by 2-dimensional speckle tracking imaging in the awake dog: repeatability, reproducibility, and comparison with tissue Doppler imaging variables. J Vet Int Med 2008;22:342–350.

5. Takano H, Fujii YO, Yugeta N, et al. Assessment of left ventricular regional function in affected and carrier dogs with duchenne muscular dystrophy using speckle tracking echocardiography. BMC Cardiovasc Disord 2011;11:2–8.

6. Wess G, Keller LJM, Klausnitzer M. et al. Comparison of longitudinal myocardial tissue velocity, strain, and strain rate measured by two-dimensional speckle tracking and by color tissue Doppler imaging in healthy dogs. J Vet Cardiol 2011;13:31–43.

7. Amundsen H, Helle-Valle T, Edvardsen, T, et al. Noninvasive myocardial strain measurement by speckle tracking echocardiography: Validation against sonomicrometry and tagged magnetic resonance imaging. J Am Coll Cardiol 2006;47:789–793.

8. Delgado V, Ypenburg C, Van Bommel RJ, et al. Assessment of left ventricular dyssynchrony by speckle tracking strain imaging comparison between longitudinal, circumferential, and radial strain in cardiac resynchronization therapy. J Am Coll Cardiol 2008;51:1944–1952.

9. Meluzin J, Spinarova K, Hude P, et al. Estimation of left ventricular filling pressures by speckle tracking echocardiography in patients with idiopathic dilated cardiomyopathy. Eur J Echocardiogr 2011;12:11–18.

10. Schwarzwald CC, Schober KE, Berli A-SJ, et al. Left ventricular radial and circumferential wall motion analysis in horses using strain, strain rate, and displacement by 2D speckle tracking. J Vet Int Med 2009;23:890–900.

11. Decloedt A, Verheyen T, Sys S, et al. Quantification of left ventricular longitudinal strain, strain rate,velocity, and displacement in healthy horses by 2-dimensional speckle tracking. J Vet Int Med 2011;25:330–338.

12. Schefer KD, Bitschnau C, Weishaupt MA, et al. Quantitative analysis of stress echocardiograms in healthy horses with 2-dimensional (2D) echocardiography, anatomical M-mode,tissue Doppler imaging, and 2D speckle tracking. J Vet Int Med 2010;24:918–931.

13. Decloedt A, Verheyen T, Sys S, et al. Two-dimensional speckle tracking for quantification of left ventricular circumferential and radial wall motion in horses. Eq Vet J 2012; DOI: 10.1111/j.2042-3306.2012.00549.x.

14. Riesen SC, Schober KE, Cervenec RM, et al. Comparison of the effects of ivabradine and atenolol on heart rate and echocardiographic variables of left heart function in healthy cats. J Vet Int Med 2011;25:469–476.

15. Suffoletto MS, Dohi K, Cannesson M, et al. Novel speckle-tracking radial strain from routine black-and-white echocardiographic images to quantify dyssynchrony and predict response to cardiac resynchronization therapy. Circulation 2006;113:960–968.

16. Gjesdal O, Hopp E, Vartdal T, et al. Global longitudinal strain measured by twodimensional speckle tracking echocardiography is closely related to myocardial infarct size in chronic ischaemic heart disease. Clin Sci 2007;113:287–296.

17. Thomas WP, Gaber CE, Jacobs GJ, et al. Recommendations for standards in transthoracic two-dimensional echocardiography in the dog and cat. Echocardiography Committee of the Specialty of Cardiology, American College of Veterinary Internal Medicine. J Vet Int Med 1993;7:247–252.

18. Boon JA. The two-dimensional echocardiographic exam. In: Boon, JA, ed. Veterinary Echocardiography. 2nd ed. Iowa, USA: Wiley-Blackwell; 2011:37–100.

19. Campbell FE, Kittleson MD. The effect of hydration status on the echocardiographic measurements of normal cats. J Vet Int Med 2007;21:1008–1015.

20. Disatian S, Bright JM, Boon J. Association of age and heart rate with pulsed-wave Doppler measurements in healthy, nonsedated cats. J Vet Int Med 2008;22:351–356.

21. Boon JA. Appendix four feline. In: Boon, JA, ed. Veterinary Echocardiography. 2nd ed. Iowa, USA: Wiley-Blackwell; 2011:569–580.

22. Wess G, Sarkar R, Hartmann K. Assessment of left ventricular systolic function by strain imaging echocardiography in various stages of feline hypertrophic cardiomyopathy. J Vet Int Med 2010;24:1375–1382.

23. Leitman M, Lysiansky M, Lysyansky P, et al. Circumferential and longitudinal strain in 3 myocardial layers in normal subjects and in patients with regional left ventricular dysfunction. J Am Soc Echocardiogr 2010;23:64–70.

24. Ishii T, McElhinney DB, Harrild D. M, et al. Circumferential and longitudinal ventricular strain in the normal human fetus. J Am Soc Echocardiogr 2012;25:105–111.

25. Hurlburt HM, Aurigemma GP, Hill, JC, et al. Direct ultrasound measurement of longitudinal, circumferential, and radial strain using 2-dimensional strain imaging in normal adults. Echocardiography 2007;24:723–731.

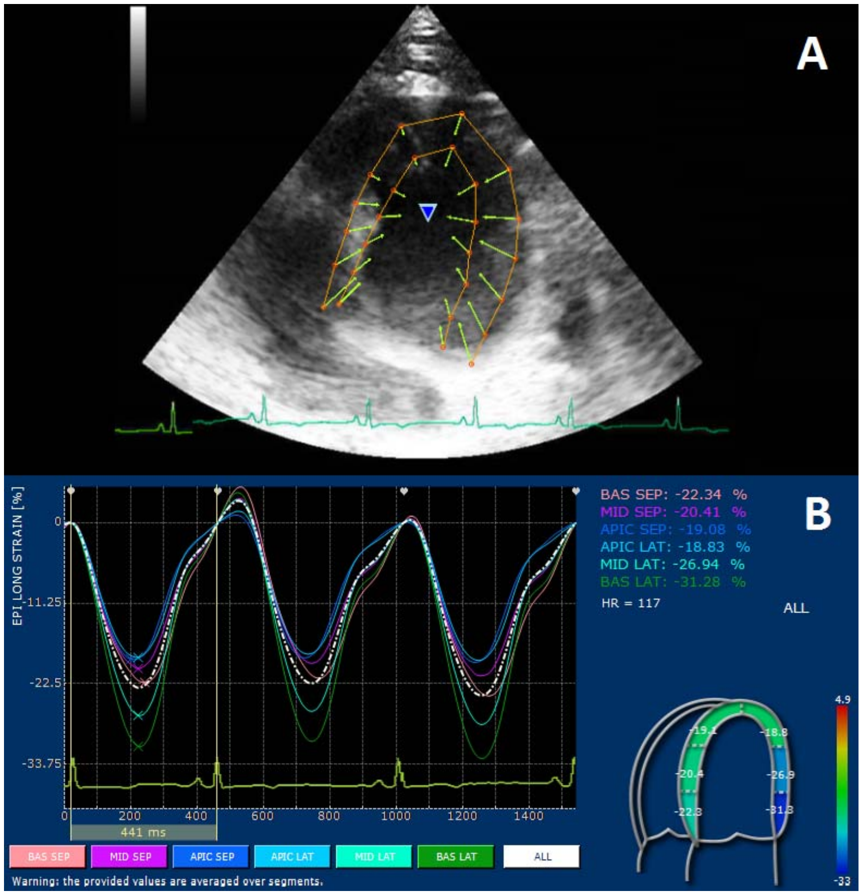

Fig 1. Figures illustrating myocardial tracking in a cat. (**A**) 2D Apical Four chamber view in a non-sedated healthy cat, demonstrating myocardial tracking process and velocity vectors by STE; (**B**) 2D-STE analysis of left ventricular epicardial longitudinal strain in a healthy cat. The myocardium is automatically divided into 6 segments: Basal (Bas Sept), Middle (Mid Sept) and Apical (Apic Sept) segments for the interventricular septum and Basal (Bas Lat), Middle (Mid Lat) and Apical (Apic Lat) lateral segments for the left ventricular posterior wall.

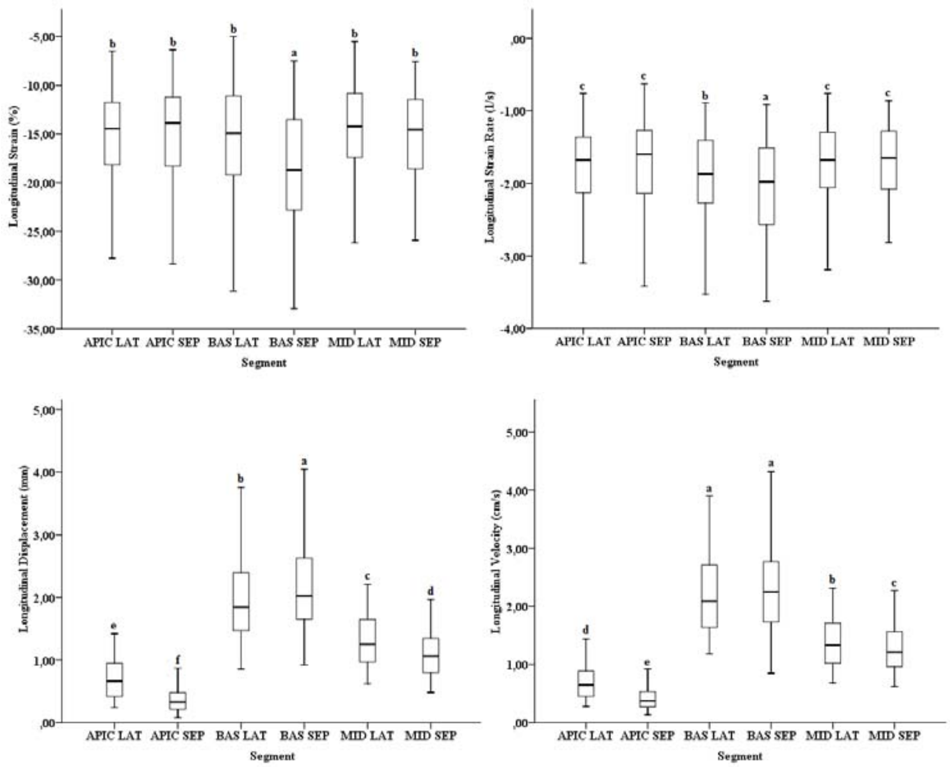

Fig 2. Graphical illustration of segmental differences of 2D STE measurements of LV longitudinal function in non-sedated healthy cats (n=30). The line near the middle of the box indicates the middle half of the observations, the top and the bottom of the box indicates the upper and lower quartile, and the whiskers corresponds to the range of observations (smallest and largest observations, respectively). Boxes marked with different letters are significantly different from each other to Mann-Whitney test (P<0.05).

Table 1. Demographic data (age, weight, heart rate, gender and breed) and systolic blood pressure in non-sedated healthy cats (n = 30).

Variables		Mean ± Standard deviation (SD)
Age (months)		36.00 ± 33.43
Weight (kg)		4.11 ± 0.94
Heart rate (beats/min)		161.20 ± 39.55
Gender		
	Male	n = 20 (66.67%)
	Female	n = 10 (33.33%)
Breeds		Mixed breed cats (n = 22 – 73.34%)
		Persa (n = 7 – 23.33%)
		Siamês (n = 1 – 3.33%)
Systolic pressure (mmHg)		129.50 ± 15.03

Table 2. Data of main conventional echocardiographic variables in non-sedated healthy cats (n = 30).

Variables	Mean ± Standard deviation (SD)
Left atrium (mm) – LA	7.25 ± 0.96
Aorta (mm) – Ao	7.04 ± 0.85
Ratio LA/Ao	1.03 ± 0.11
Pulmonary artery (m/s)	0.88 ± 0.16
RVDd (mm)	2.75 ± 0.98
IVSd (mm)	4.10 ± 1.08
LVDd (mm)	11.07 ± 2.06
PWd (mm)	4.39 ± 0.97
IVSs (mm)	5.77 ± 0.94
LVDs (mm)	6.07 ± 1.26
PWs (mm)	6.45 ± 1.07
FS (%)	44.86 ± 7.82
E mitral (m/s)	0.90 ± 0.14
A mitral (m/s)	0.65 ± 0.15
Tric flow (m/s)	0.76 ± 0.11
Aortic flow (m/s)	0.92 ± 0.16
Aortic root (mm)	6.41 ± 0.69

RVDd: right ventricular diastolic diameter; IVSd: interventricular septum at diastole; LVDd: left ventricle diastolic diameter; PWd: posterior wall at diastole; IVSs: interventricular septum at systole; LVDs: left ventricle systolic diameter; FS: fractional shortening; E mitral: transmitral peak early diastolic velocity; A mitral: transmitral peak late diastolic velocity; Tric flow: peak of tricuspid flow velocity.

Table 3. Values of global, endocardial and epicardial regions of longitudinal strain, strain rate, displacement and velocity, displayed as mean ± standard deviation of healthy cats (n=30).

Variables	Endocardium	Epicardium	Average	P value
LSt (%)	-15.15 ± 5.25 a	-16.12 ± 5.61 b	-15.65 ± 5.46	0.0020*
LStR (1/s)	-1.79 ± 0.56 a	-1.82 ± 0.62 a	-1.80 ± 0.59	0.6720
Ldisp (mm)	1.22 ± 0.67 a	1.32 ± 0.91 a	1.27 ± 0.80	0.6440
Lvel (cm/s)	1.36 ± 0.74 a	1.46 ± 0.98 a	1.41 ± 0.87	0.6280

LSt: Longitudinal Strain (%); LStR: Longitudinal Strain Rate (1/s); Ldisp: Longitudinal displacement (mm); Lvel: Longitudinal Velocity (cm/s).

*Means followed by different letters in the line differ by the Mann-Whitney test (P<0.05).

Table 4. Values of segmental and averaged longitudinal strain, strain rate, displacement and velocity, displayed as mean ± standard deviation of healthy cats (n=30).

Variable	Segment	N	Mean ± Standard deviation*
Longitudinal Strain (%)	APIC LAT	278	-15.15 ± 4.81 b
	MID LAT	279	-14.57 ± 4.92 b
	BAS LAT	270	-15.57 ± 6.18 b
	APIC SEP	289	-14.91 ± 5.14 b
	MID SEP	282	-15.23 ± 4.54 b
	BAS SEP	265	-18.63 ± 6.10 a
	Global mean	1663	-15.65 ± 5.46
Longitudinal Strain Rate (1/s)	APIC LAT	299	-1.74 ± 0.54 c
	MID LAT	291	-1.73 ± 0.56 c
	BAS LAT	281	-1.91 ± 0.61 b
	APIC SEP	313	-1.73 ± 0.63 c
	MID SEP	298	-1.69 ± 0.50 c
	BAS SEP	279	-2.04 ± 0.64 a
	Global mean	1761	-1.80 ± 0.59
Longitudinal Displacement (mm)	APIC LAT	260	0.70 ± 0.32 e
	MID LAT	260	1.30 ± 042 c
	BAS LAT	260	1.96 ± 0.67 b
	APIC SEP	260	0.37 ± 0.20 f
	MID SEP	260	1.09 ± 0.37 d
	BAS SEP	289	2.14 ± 0.68 a
	Global mean	1589	1.27 ± 0.80
Longitudinal Velocity (cm/s)	APIC LAT	260	0.69 ± 0.27 d
	MID LAT	263	1.38 ± 0.42 b
	BAS LAT	274	2.20 ± 0.67 a
	APIC SEP	260	0.41 ± 0.20 e
	MID SEP	259	1.28 ± 0.41 c
	BAS SEP	310	2.31 ± 0.75 a
	Global mean	1626	1.41 ± 0.87

*Means followed by different letters in the column differ by the Mann-Whitney test (P<0.05).

Table 5. Table displays the value of between-day intra-observer variability (%).

	Variable	Endocardium	Epicardium	Average
Between-Day	LSt	12.2	10.8	11.7
Intra-observer	LStR	10.8	11.3	11.5
Variability	Ldisp	7.2	1.3	6.0
(CV in %)	Lvel	5.3	2.8	5.8

LSt: Longitudinal Strain (%); LStR: Longitudinal Strain Rate (1/s); Ldisp: Longitudinal displacement (mm); Lvel: Longitudinal Velocity (cm/s).

ANEXO

Certificado fornecido pela Comissão de Ética no Uso de Animais da UFLA.

UNIVERSIDADE FEDERAL DE LAVRAS
PRÓ-REITORIA DE PESQUISA
COMISSÃO DE ÉTICA NO USO DE ANIMAIS
Cx.P.3037 - Lavras – MG – 37200-000 – (35) 3829-5182 cba@nintec.ufla.br

CERTIFICADO

Certificamos que o **Protocolo nº 052/11**, relativo ao projeto intitulado **"Avaliação Ecocardiográfica da Função Miocárdica em Felinos Domésticos"**, que tem como responsável **Ruthnéa Aparecida Lázaro Muzzi**, está de acordo com os Princípios Éticos da Experimentação Animal, adotados pela **Comissão de Ética no Uso de Animais (Comissões Permanentes/PRP-Ufla)**, tendo sido aprovado na reunião de 29/09/2011.

CERTIFICATE

We hereby certify that the **Protocol nº 052/11**, related to the project entitled **"Echocardiographic Evaluation of Myocardial Function in Domestic Cats"**, under the supervision of **Ruthnéa Aparecida Lázaro Muzzi**, is in agreement with the Ethics Principles in Animal Experimentation, adopted by the **Bioethic Committee in Utilization of Animals (Comissões Permanentes/PRP-Ufla)**, and was approved in **September 29, 2011**.

Lavras, 29 de setembro de 2011.

Profª. Gabriela Rodrigues Sampaio
Presidente em exercício da Comissão de Ética no Uso de Animais CEUA

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