ACTA VETERINARIA INDONESIANA
P-ISSN 2337-3202, E-ISSN 2337-4373

Penelitian

Vol. 12, No. 3: 249–256, November 2024

Nilai Normal Ekokardiografi Transthorakalis pada Hewan Model Babi (*Sus scrofa domestica*)

(Normal Value of Transthoracic Echocardiography in Swine Model Animals (Sus scrofa domestica)

Bintang Nurul Iman[1*], Fitria Senja Murtiningrum[1], Dwi Utari Rahmiati[1,3], Nindya Dwi Utami[3], Arni Diana Fitri[2,3], Gunanti[1], Deni Noviana[1]

[1]Division of Surgery and Radiology, School of Veterinary Medicine and Biomedical Science, IPB University
[2]Veterinary Teaching Hospital, School of Veterinary Medicine and Biomedical Science, IPB University
[3]Graduate School, Animal Biomedical Science, School of Veterinary Medicine and Biomedical Science, IPB University
*Penulis untuk korespondensi: bintangnuruliman@gmail.com
Diterima: 10 Agustus 2023, Disetujui: 21 Oktober 2024

ABSTRAK

Penelitian gangguan sistem kardiovaskular semakin berkembang dilakukan pada hewan model. Babi merupakan hewan model yang umum digunakan dalam penelitian biomedis. Penelitian ini dilakukan untuk mengetahui nilai normal ekokardiografi jantung babi (Sus scrofa domestica) jantan dan betina. Babi yang digunakan dalam penelitian ini berjumlah 12 ekor babi yang digunakan dalam penelitian ini dengan usia 3 sampai 4 bulan dengan rata-rata berat badan 55 Kg (52 sampai 69 Kg). Pemeriksaan ekokardiografi transtorakalis dengan posisi right parasternal (RPS) long-axis (LAx) dan short-axis (SAx) menggunakan transduser phase-array probe dengan frekuensi 2.5-6.0 MHz yang dilakukan pada babi dalam kondisi teranestesi. Posisi RPS-SAx bertujuan menilai bentuk dan struktur dari ventrikel kiri jantung babi, sedangkan RPS-LAx bertujuan membandingkan dimensi antara ventrikel serta melihat pergerakan katup mitral jantung. Hasil pemeriksaan ekokardiografi menunjukkan bahwa struktur dari ventrikel kiri babi yang dapat terlihat adalah interventricular septum (IVS), left ventricle (LV), left ventricle wall (LVW), pericardium (P), papillary muscle (PM), dan right ventricle (RV). Hasil penelitian menunjukkan bahwa nilai pada parameter frekuensi jantung (HR), left ventricular internal dimension at end-diastole (LVIDd), dan stroke volume (SV) menunjukkan hasil yang berbeda secara signifikan, sedangkan parameter lainnya memiliki hasil yang tidak signifikan antara jantan dan betina. Nilai ekokardiografi normal pada babi ini dapat digunakan sebagai acuan dalam penelitian kardiovaskular lanjut yang menggunakan babi sebagai hewan model.
Kata kunci: Babi, Transtorakalis Ekokardiografi, Hewan Model, Jantung

ABSTRACT

Research on cardiovascular system disorders is increasingly being carried out in animal models. Swine is an animal model that is commonly used in biomedical research. This study was conducted to determine the normal value of the heart echocardiography of male and female swine (Sus scrofa domestica). There were 12 swine used in this study with an age of 3 to 4 months with an average body weight of 55 kg (52 to 69 kg).Transthoracic echocardiography examination with right parasternal (RPS) long-axis (LAx) and short-axis (SAx) positions using a 2.5-6.0 MHz phase-array probe transducer was performed on anesthetized swine. The RPS-SAx position aims to assess the shape and structure of the left ventricle of the swine heart, while the RPS-LAx aims to compare the dimensions between the ventricles and observe the movement of the mitral valve of the heart. The results of echocardiography examination showed that the structures of the left ventricle of swine that could be seen were the interventricular septum (IVS), left ventricle (LV), left ventricle wall (LVW), pericardium (P), papillary muscle (PM), and right ventricle (RV). The results showed that the values for the parameters of heart frequency (HR), left ventricular internal dimension at end-diastole (LVIDd), and stroke volume (SV) showed significant different results, while other parameters had non-significant results between males and females. Normal echocardiographic values in swine can be used as a reference in further cardiovascular research using swine as animal models.
Keywords*:* Swine, Transthoracic Echocardiography, Animal Model, Heart

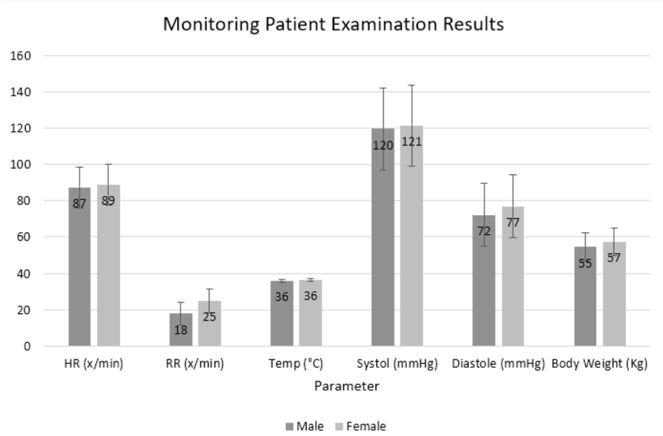

Figure 1 Results of examination of patient monitoring data in swine (*Sus scrofa domestica*); HR: heart rate, RR: respiratory rate, Temp: temperature, Systol, Diastole, Body Weight.

M-mode. M-mode echocardiography examination used the Cube Test and Teichholz methods to determine the wall thickness and dimensions of the left ventricular lumen of the heart (Egemnazarov et al. 2015). The EF value is the percentage of the difference between EDV and ESV divided by EDV, with the normal value in swine according to Paslawska (2014) is 58 ± 5%. FS is the percentage of the difference between end-diastolic and end-diastolic diameter divided by end-diastolic end-diastolic, with a normal value in swine of 32 ± 4% (Paslawska 2014; Corda et al. 2019). Assessment of changes in EF and FS from echocardiographic results can be used to assess the function and structure of the left ventricle of the heart, so that it can be an indicator of heart failure (Cikes and Solomon 2016; He et al. 2009).

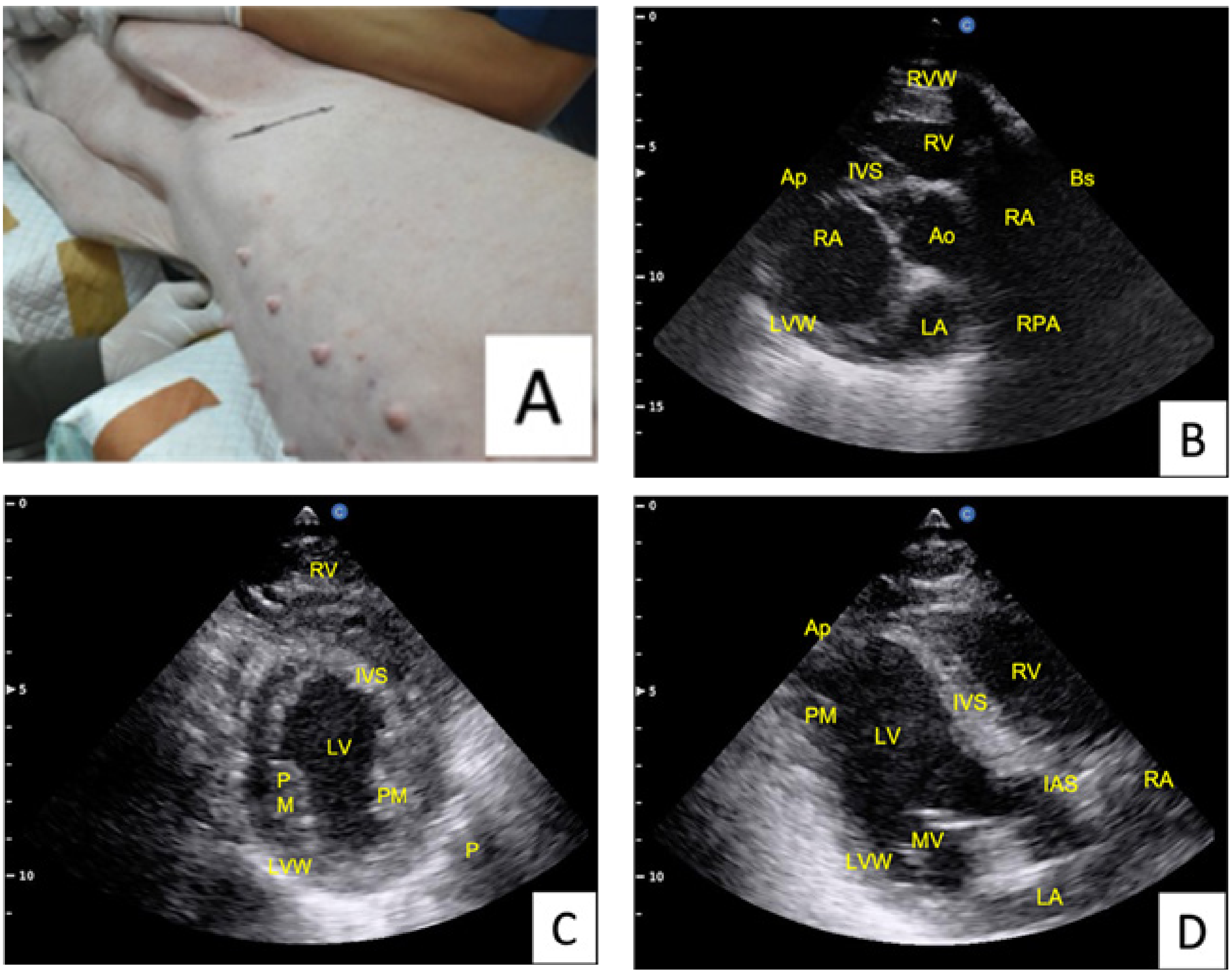

Figure 2 Position of right parasternal echocardiography (RPS) examination in swine with right lateral recumbency (A) position. The results of echocardiography examination of the heart of B-mode swine with the right parasternal (RPS) short axis (B and C) position. B-mode echocardiography examination with right parasternal (RPS) long axis (D) position. Ao: aorta, Ap: apex, Bs: base, IVS: interventricular septum, LA: left atrium, LV: left ventricle, LVW: left ventricle wall, P: pericardium, PM: papillary muscle, RA: right atrium, RPA: right main pulmonary artery, RV: right ventricle, RVW : right ventricle wall.

INTRODUCTION

Disorders of the cardiovascular system are one of the leading causes of death in the world. Around 64.3 million people live with heart failure worldwide. The incidence of heart failure in developed countries is generally estimated to be 1% to 2% of the general adult population (Groenewegen 2020). Based on research conducted by Artha et al. (2017) myocardial infarction is still the main cause of mortality in Indonesia with the number increasing by 10.5% from 5.9 million people in 2006 to 6.52 million people in 2016 with an estimated incidence of 200 incidents per 100,000 population each year. Treatment for disorders of the cardiovascular system is increasingly being carried out in animal models. Swine are one of the large animal species that are commonly used as model animals in biomedical research. This is because swine have many anatomical similarities to humans (Gunanti et al. 2020) such as organ weight, organ physiological processes and disease development (Bassols et al. 2014; Hafizsha et al. 2021). Swine are genetically and physiologically similar when compared to humans (Yan et al. 2018). Swine are the most suitable animal models for research on the cardiovascular system, this is because the shape of the heart, especially the swine coronary arteries, is the same as the human heart (Lelovas et al. 2014).

Monitoring the physiological value of the heart in animal models is generally carried out invasively and continuously using cardiac catheterization. A cardiac catheter can be inserted through the femoral vein to measure arterial and venous blood pressure (Mendler et al. 2018; Gunanti et al. 2020). Radiographic imaging of the functioning of the cardiovascular system of swine as animal models is still challenging. Examinations using magnetic resonance imaging (MRI) and computed tomography (CT) are still not widely available and performed, while examinations using invasive catheterization can affect animal models. Therefore, among non-invasive tests for cardiac function analysis, transthoracic echocardiography can be a suitable method for obtaining cardiac echocardiography values because of its combination of accuracy, practicality, high availability, and low cost (Schwarz 2019; Egemnazarov et al. 2015; Romano et al. 2012). Transthoracic echocardiography examination technique is a non-invasive diagnostic method using ultrasound. Echocardiographic examination can assess and measure the internal structure of the heart, which consists of the cardiac muscle wall and its proportions, cardiac blood vessels, and cardiac systole and diastole (Chetboul et al. 2012; Noviana et al. 2013). Information on normal values for echocardiographic examination of swine is useful for the selection of animal models used in biomedical studies of cardiovascular diseases in humans using swine. This study was conducted to obtain normal values for echocardiography of the swine heart (Sus scrofa domestica).

MATERIALS AND METHODS

This study used a sample of swine (Sus scrofa domestica) with a total of 12 swine consisting of 6 male swine and 6 female swine aged 3 to 4 months with an average body weight 55 kg (52 to 69 kg). The determination of the number of swine model animals in this study was carried out based on the recommended number in the Guide for the Care and Use of Laboratory Animals Eighth Edition book (National Research Council 2010). The research was conducted at the Laboratory Animal Care Unit of the School of Veterinary Medicine and Biomedical Science (UPHL SKHB) IPB University and the Veterinary Teaching Hospital (RSHP) SVMBS IPB. This research has been approved by the VTH SVMBS IPB Animal Ethics Commission with certificate number 158/KEH/SKE/XII/2019.

Swine heart echocardiography examination and interpretation of echocardiography results were carried out at the Cardiology Service Center, VTH SVMBS IPB. Six swine were acclimatized for 14 days. Acclimatization with anthelmintic albendazole 1 bolus every 300 kg body weight for 6 days orally mixed with feed, the antibiotic marbofloxacin 1 ml/50 kg body weight intramuscularly (IM) for 3 consecutive days, the antiparasitic ivermectin 0.3 mg/Kg body weight given once subcutaneously (SC) on the first day of acclimatization, as well as growth promoters and muscle strengthening (5 ml/head/day) given IM for 5 days. Feeding and drinking swine ad-libitum during the acclimatization process, then feed was given 2 times a day during the study.

Swine to be examined for cardiac echocardiography were previously fasted from eating first for 8-12 hours. Then the swine were anesthetized using a combination of ketamine (20 mg/kg BW) and xylazine (2 mg/kg BW) intramuscularly to the muscles in the neck followed by atropine sulfate (0.04 mg/kg BW) (Fitri et al. 2020). Swine that have been anesthetized by the Mindray® MEC-1000 patient monitoring device are then used to obtain the physiological values of the swine such as heart rate, respiratory rate, body temperature and blood pressure. Echocardiographic examination of the heart using an ultrasound Chison® type Ebit-60.

Echocardiography in swine begins with determining the transthoracic orientation point, namely at the third and fourth intercostals, then shaving the area around the orientation point. Swine were examined by echocardiography in the right lateral-recumbency position for the right parasternal (RPS) long-axis (LAx) and short-axis view (SAx) examination (Figure 2). The RPS-LAx scanning technique is performed by placing the transducer in the intercostal area parallel to the longitudinal axis of the heart, while the RPS-SAx technique is performed by positioning the transducer in a transverse direction to the longitudinal axis of the heart (Noviana et al. 2018). The transducer (probe) used is a phase-array-probe with a frequency of 2.5-6.0 MHz which has previously been added with ultrasound gel.

The type of echocardiographic imaging used in this study is Brightness mode (B-mode) followed by Motion mode (M-mode) with Cube and Teichholz methods to interpret intracardiac dimensions, heart wall thickness, lumen dimensions, and cardiac muscle contractility (Fitri et al. 2020; Penninck and d'Anjou 2015). Echocardiographic calculations were performed 3 times for each swine and then the average value was taken so that the total data obtained were 18 males and 18 females. Echocardiography parameters will be compared between male and female swine and with normal values of cardiac echocardiography in swine from other studies. The data obtained will be analyzed using ANOVA data analysis method and Mann-Whittney follow-up test to see the significance difference ($P < 0.05$) between echocardiography of male and female swine.

RESULT

Based on the results of observations on monitoring patients (Table 1), it can be seen that the average heart rate of male swine is 87.33 ± 15.42 per minute and female swine are 89 ± 8.05 per minute, the average respiratory rate of male swine is 17.83 ± 3.76 per minute and sows 24.83 ± 6.91 per minute. Then the average temperature of male swine examined was 36.07 ± 0.82 °C and sows were 36.45 ± 0.7 °C. The average value of systolic and diastolic blood pressure in male swine was 119.56 ± 9.39 mmHg and 72.11 ± 7.76 mmHg, while the systolic and diastolic blood pressure of female swine wes 121.33 ± 31.92 mmHg and 77 ± 24.18 mmHg, respectively.

Figure 1 shows a comparison chart of the results of the physiological examination of male and female swine using patient monitoring. Differences in respiratory rate and temperature in this study can be caused by several factors such as high ambient temperature, restraint process and animal transfer. The results of the B-Mode echocardiography examination in swine can be seen in Figures 2B and 2C with the RPS-Short Axis taking position to assess the shape and structure of the left ventricle of the swine's heart. Figure 2D is the result of echocardiography with the RPS-Long Axis taking position which aims to compare the dimensions between the left and right ventricles and see the movement of the heart's mitral valve.

The echocardiographic examination in Figure 3 shows the results of echocardiographic imaging of the heart of swine using the B and M-mode methods which aim to determine the normal echocardiographic values in swine. Figure 3 was performed using the Cube and Teichholz method to determine the dimensions of the cardiac chamber (LVID) and to measure the thickness of the heart muscle in systole and diastole conditions.

Based on the results of the analysis using the Mann-Whitney statistical test, it shows that only the parameters of heart frequency (HR), left ventricular internal dimension at end-diastole (LVIDd), and stroke volume (SV) have a P-Value < 0.05, so it can be said that these parameters have different and significant values between male and female swine. Whereas in other parameters, male and female swine the difference between values is not significant. The results of the examination in Table 2 show the HR value in male swine of 84.96 ± 5.75 times per minute and female swine of 98.72 ± 12.7 times per minute. The LVIDd value in male swine was 56.11 ± 20.58 mm and in female swine 41.4 ± 14.14 mm. The value of end diastolic volume (EDV) and end systolic volume (ESV) in the results of echocardiography of male swine showed values of 158.62 ± 73.52 and 59.79 ± 46.78, while in female swine 106.62 ± 47.09 and 37.51 ± 21.98. EDV and ESV values are used as a reference in measuring cardiac systolic function based on the value of ejection fraction (EF) and fractional shortening (FS). The EF and FS values in male and female swine obtained through M-mode transthoracic echocardiography were within the normal range (Table 2).

Table 2 shows the SV value in male swine 98.84 ± 31.99 ml and female swine 70.23 ± 33.92 ml. A high SV value in male swine indicates that the more blood the heart pumps.

DISCUSSION

The results of observations on patient monitoring status include heart rate, respiration, temperature, systolic and diastolic blood pressure (Checketts et al. 2016). Physiological examination of the animal's body is an animal's response to changes in internal and external factors. The values of heart, breath, and body temperature of swine are 60-100 times per minute, 8-18 times per minute, and 38-40 °C, respectively (Reed et al. 2018; Zhang et al. 2019; Karlsson et al. 2021).

Table 1 Results of examination of patient monitoring data in swine (*Sus scrofa domestica*)

Parameter	Male	Female	Mean
Heart rate (times/minute)	87.33 ± 15.42	89 ± 8.05	88.17 ± 11.76
Breathing Frequency (times/minute)	17.83 ± 3.76	24.83 ± 6.91	21.33 ± 6.44
Temperature (°C)	36.07 ± 0.82	36.45 ± 0.7	36.26 ± 0.75
Systolic Blood Pressure (mmHg)	119.56 ± 9.39	121.33 ± 31.92	120.44 ± 22.45
Diastolic Blood Pressure (mmHg)	72.11 ± 7.76	77 ± 24.18	74.56 ± 17.31
Body Weight (Kg)	54.5 ± 3.83	57.33 ± 10.5	55.92 ± 7.68

Table 2 Results of the M-mode echocardiography of swine (*Sus scrofa domestica*)

Parameter	Male (n=18)	Female (n=18)	P-value	Normal healthy swine (Paslawska 2014)
HR (times/minute)	84.96 ± 5.75	98.72 ± 12.7	0	71
IVSd (mm)	14.01 ± 4.5	12.46 ± 3.2	0.254	0.84 ± 0.03
LVIDd (mm)	56.11 ± 20.58	41.4 ± 14.14	0.038	4.88 ± 0.31
LVPWd (mm)	11.42 ± 2.7	14.52 ± 4.94	0.082	0.92 ± 0.09
IVSs (mm)	16.8 ± 4.7	15.5 ± 3.82	0.393	1.16 ± 0.11
LVIDs (mm)	41.71 ± 16.6	29.42 ± 10.77	0.062	3.42 ± 0.44
LVPWs (mm)	16.15 ± 2.16	18.11 ± 3.7	0.117	1.47 ± 0.14
EDV (ml)	158.62 ± 73.52	106.62 ± 47.09	0.076	-
ESV (ml)	59.79 ± 46.78	37.51 ± 21.98	0.129	-
SV (ml)	98.84 ± 31.99	70.23 ± 33.92	0.046	-
CO (L/minutes)	8.42 ± 2.82	6.79 ± 3.2	0.117	-
EF (%)	66.48 ± 13.62	67.06 ± 17.1	0.681	58 ± 5
FS (%)	31.83 ± 9.92	32.82 ± 13.11	0.924	32 ± 4
LAAs (mm)	20.17 ± 7.65	20.57 ± 3.22	0.669	-
AoDd (mm)	20.82 ± 4.87	21.46 ± 2.56	0.537	-
LA/Ao	1.08 ± 0.27	0.96 ± 0.12	0.187	1.58 ± 0.14

Description: normal value in swine (Sus scrofa domestica) with an average body weight of 55 Kg. M-mode: Motion mode, LVIDd: left ventricular internal dimension at end-diastole, LVIDs : left ventricular internal dimension at end-systole, LVPWd : left ventricular posterior wall thickness at end-diastole, LVPWs : left ventricular posterior wall thickness at end-systole, EDV : end diastolic volume, ESV : end systolic volume, SV : stroke volume, EF : ejection fraction, FS : fraction shortening, LAAs: left atrial appendage-sistole, AoDd : aortic diameter-diastole, LA/Ao : comparison between LAAs and AoDd.

Transthoracic echocardiography examination of the swine heart is a useful method for imaging the structure of the swine heart. The process of echocardiographic examination was carried out under anesthetized swine conditions (Chang et al. 2016; Rahmiati et al. 2021). Echocardiography with the RPS-Long Axis can determine the changes in the heart due to congenital heart disease (Vezzosi et al. 2021; Noviana et al. 2018). Figure 2 using the B-mode method in swine echocardiography shows that the structures of the swine left ventricle that can be seen are the interventricular septum (IVS), left ventricle (LV), left ventricle wall (LVW), pericardium (P), papillary muscle (PM), and the right ventricle (RV). Changes in the heart that can be observed using B-mode and M-mode imaging types such as heart valve abnormalities, abnormalities in intracardiac dimensions, heart wall thickness, lumen dimensions, and cardiac muscle contractility.

According to Penninck and d'Anjou (2015), cardiac ultrasound examination methods that can be used in echocardiographic examination are B-mode and

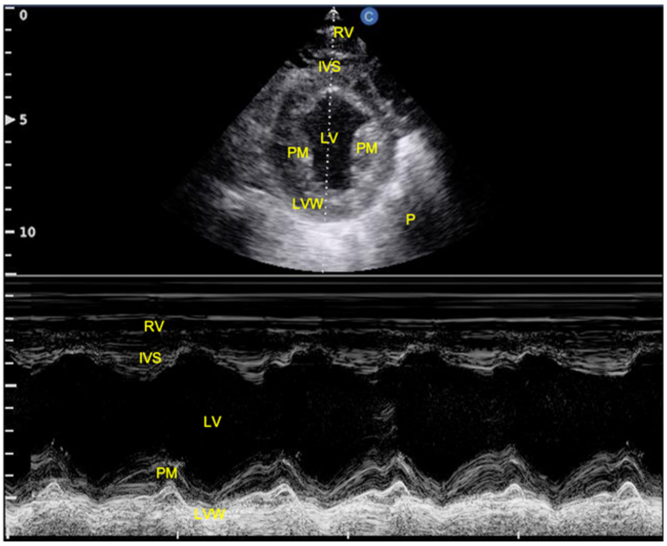

Figure 3 Motion mode (M-mode) porcine heart echocardiography technique with the right parasternal short axis position. IVS: interventricular septum, LV: left ventricle, LVW: left ventricle wall, P: pericardium, PM: papillary muscle, RV: right ventricle.

Stroke volume (SV) is the volume of blood pumped by the ventricles of the heart each time it contracts. SV value is needed to measure and determine the value of cardiac output. Cardiac output (CO) is the volume of blood pumped by the ventricles per minute which is obtained by multiplying the heart rate (HR) by SV (Seckerdieck et al. 2015; Penninck and d'Anjou 2015).

Calculating SV and CO values indicates how much blood is pumped into the body in one minute by the left ventricle so it can be used as a way to assess heart function and predisposition to heart disease (Monditzki et al. 2021). Differences in male and female echocardiographic values can be caused by several factors, namely physiological sex hormones estradiol and testosterone, enzyme and protein expression in male and female animals (Parois et al. 2015; Tadros et al. 2014; Thompson et al. 2020).

Based on the results of this study, we present normal values for transctoracal echocardiography of male and female swine hearts (Sus scroba domestica). The results of echocardiography showed that the values for the parameters of heart frequency (HR), left ventricular internal dimension at end-diastole (LVIDd), and stroke volume (SV) showed significant different results, while other parameters had non-significant results between males and females. Data from this study strengthens the advantages of using swine as animal models for human cardiovascular disease research. The echocardiographic data from this study reinforce the advantages of using swine as an animal model for research on cardiovascular disease in humans. This is because swine have genetic, anatomical, and physiological similarities with humans rather than small animals/laboratory animals. Another reason for using swine as animal models is that they have physiological and anatomical similarities with human organs such as the heart (Yan et al. 2018).

ACKNOWLEDGEMENT

The author would like to thank the Ministry of Education, Culture, Research and Technology for funding research on the Higher Education Excellence Research grant program with contract number 1/E1/KP.PTNBH/2021. The author also expresses his gratitude to the Division of Surgery and Radiology, Laboratory Animal Care Unit, Veterinary Teaching Hospital School of Veterinary Medicine and Biomedical Science IPB University for assisting the research, so that the research can be carried out properly.

REFERENCES

Alkhusari A, Handayani M, Saputra MAS, Rhomadhon M. 2020. Analisis Kejadian Penyakit Jantung Koroner di Poliklinik Jantung. J. 'Aisyiyah Medika. 5(2).

Artha IMJR, Dwipayana IMP, Saputra BMI, Juzar DA, Soerianata S. 2017. Clinical Characteristics, Medical Management and Outcomes of Patients with ST-Elevation Myocardial Infarction in Sanglah General Hospital, Denpasar, Bali, Indonesia. Biomel and Pharmacol J. 10(3): 1197-1206.

Bassols A, Costa C, Eckersall PD, Osada J, Sabria J, Tibau J. 2014. The swine as an animal model for human pathologies: A proteomics perspective. Proteomics Clin. Appl. 8:715-731.

Chang MY, Huang TT, Chen CH, Cheng B, Hwang SM, Hsieh PC. 2016. Injection of human cord blood cells with hyaluronan improves postinfarction cardiac repair in swine. Stem Cells Transl. Med. 5(1): 56-66.

Checketts MR, Alladi R, Ferguson K, Gemmell L, Handy JM, Klein AA, Rodney GE. 2016. Recommendations for standards of monitoring during anaesthesia and recovery 2015: Association of Anaesthetists of Great Britain and Ireland. Anaesthesia. 71(1): 85-93.

Chetboul V, Petit A, Gouni V, Trehiou-Sechi E, Misbach C, Balouka D, Sampedrano CC, Pouchelon JL, Tissier R, Abitbol M. 2012. Prospective echocardiographic and tissue doppler screening of a large sphynx cat population: reference ranges, heart disease prevalence and genetic aspects. J Vet Cardiol. 14(4): 497-509.

Cikes M, Solomon SD. 2016. Beyond ejection fraction: an integrative approach for assessment of cardiac structure and function in heart failure. European heart journal. 37(21): 1642-1650.

Corda A, Parpaglia MLP, Sotgiu G, Zobba R, Ochoa PG, Rames JP, French A. 2019. Use of 2-dimensional speckle-tracking echocardiography to access left ventricular systolic function in dogs with systemic inflammatory response syndrome. J Vet Intern Med. 33(2): 423-431.

Egemnazarov B, Schmidt A, Crnkovic S, Sydykov A, Nagy BM, Kovacs G, Weissmann N, Olschewski H, Olschewski A, Kwapiszewska G, Marsh LM. 2015. Pressure overload creates right ventricular diastolic dysfunction in a mouse model: Assessment by echocardiography. J Am Soc Echocardiogr. 28: 828-843.

Fitri A, Noviana D, Suprayogi A. 2020. Penilaian Fungsi dan Dinamika Kerja Jantung melalui Ekokardiografi terhadap Pengaruh Kombinasi Anestesia Umum pada Babi Domestik (Sus domesticus). Acta Vet. Indones. 8(3): 22-30.

Groenewegen, A., Rutten, F. H., Mosterd, A., & Hoes, A. W. 2020. Epidemiology of heart failure. EJHF. 22(8): 1342-1356.

Gunanti, Pudjiadi AH, Purba MS, Kusumanto GS. 2020. Gambaran kelistrikan jantung anak babi pada kondisi renjatan dengan resusitasi hipervolemik menggunakan cairan kristaloid natrium chlorida 0, 9%. Jurnal Veteriner. 21(1):38-43.

Gunanti, Putra MA. Fitria NA, Kusuma TR, Purba MS, Boediono A, Noviana D. 2020. The effect of heart infarction on electrocardiogram value of porcine (Sus scrofa) as a model for human. Vet Pract. 21(2): 220-221.

Hafizsha NL, Gunanti G, Noviana D, Widhyari SD. 2021. Konsentrasi IL-6 Serum terhadap Penyembuhan Luka Pasca Pemasangan Implan Paduan Logam pada Babi (Sus scrofa). Acta Vet. Indones. 9(1): 21-29.

He KL, Burkhoff D, Leng WX, Liang ZR., Fan L, Wang J, Maurer MS. 2009. Comparison of ventricular structure and function in Chinese patients with heart failure and ejection fractions >55 % versus 40 % to 55 % versus <40 %. The American journal of cardiology. 103(6): 845-851.

Karlsson J, Lönnqvist PA, Wallin M, Hallbäck M. 2021. A continuous noninvasive method to assess mixed venous oxygen saturation: a proof-of-concept study in swine. Anesthesia & Analgesia. 132(6):1768-1776.

Kerut EK, Valina CM, Luka T, Pinkernell K, Delafontaine P. 2004. Technique and imaging for transthoracic echocardiography of the laboratory swine. Echocardiography. 21: 439-42.

Lelovas PP, Kostomitdopoulod NG, Xanthis TT. 2014. A comparative anatomic and physiologic overview of the porcine heart. J. Am. Assoc. Lab. Anim. Sci. 53(5): 432-438.

Mendler MR, Schwarz S, Hechenrieder L, Kurth S, Weber B, Höfler S. 2018. Successful resuscitation in a model of asphyxia and hemorrhage to test different volume resuscitation strategies. A study in newborn swinelets after transition. Front Pediatr. 6:192.

Mondritzki T, Mai TA, Vogel J, Pook E, Wasnaire P, Schmeck C, Huser J, Dinh W, Truebell H, Kolkhof P. 2021. Cardiac output improvement by pecavaptan: a novel dual-acting vasopressin V1a/V2 receptor antagonist in experimental heart failure. European journal of heart failure. 23:743-750.

National Research Council. 2010. Guide for the Care and Use of Laboratory Animals 8th Edition. Washington DC (US): The National Academies Press.

Noviana D, Aliambar SH, Ulum MF, Siswandi R, Widyananta BJ, Gunanti, Soehartono RH, Soesatyoratih Rr, Zaenab S. 2018. Diagnosis Ultrasonografi pada Hewan Kecil Edisi Kedua. Bogor (ID): PT Penerbit IPB Press.

Noviana D, Wulandari R, Wulansari R. 2013. 1 Ekokardiografi endokardiosis penyakit katup mitral jantung anjing. J Vet. 14(1): 1-14.

Parois SP, Prunier A, Mercat MJ, Merlot E, Larzul C. 2015. Genetic relationships between measures of sexual development, boar taint, health, and aggressiveness in swine. J Anim Sci. 93(8): 3749-3758.

Paslawska U, Noszczyk-Nowak A, Paslawski R, Janiszewski A, Kiczak L, Zysko D, Ponikowski P. 2014. Normal electrocardiographic and echocardiographic (M-mode and two-dimensional) values in Polish Landrace pigs. Acta Veterinaria Scandinavica. 56(1): 1-13.

Rahmiati DU, Gunanti G. 2021. Ultrasound imaging of the spleen, stomach, liver, kidneys, bladder, and prostate in swinelets (sus scrofa domestica). Indonesian Journal of Veterinary Sciences. 15(4): 123-131.

Reed R, Barletta M, Grimes J, Mumaw J, Park HJ, Giguère S, Azain M, Fang X, Quandt J. 2018. Accuracy of an oscillometric blood pressure monitor in anesthetized swine. Laboratory Animals. 52(5):490-496.

Romano MM, Pazin-Filho A, O'Connel JL, Simoes MV, Schmidt A, Campos EC, Rossi M, Maciel BC. 2012. Early detection of doxorubicin myocardial injury by ultrasonic tissue characterization in an experimental animal model. Cardiovascular Ultrasound. 10:40.

Schwarz S, Kalbitz M, Hummler HD, Mendler MR. 2019. Transthoracic Echocardiography of the Neonatal Laboratory Swinelet. Front Pediatr. 7: 318.

Seckerdieck M, Holler P, Smets P, Wess G. 2015. Simpson's method of discs in Salukis and Whippets: echocardiographic reference intervals for end-diastolic and endsystolic left ventricular volumes. J Vet Cardiol. 17(81): 271.

Tadros R, Ton AT, Fiset C, Nattel S. 2014. Sex differences in cardiac electrophysiology and clinical arrhythmias: epidemiology, therapeutics, and mechanisms. Canadian Journal of Cardiology. 30(7): 783-792.

Thompson LP, Turan S, Aberdeen GW. 2020. Sex differences and the effects of intrauterine hypoxia on growth and in vivo heart function of fetal guinea swine. Am J Physiol Regul Integr Comp Physiol. 319(3): R243-R254.

Yan S, Tu Z, Liu Z, Fan N, Yang H, Yang S, Yang W, Zhao Y, Ouyang Z, Lai C. 2018. A hunting knocking swine model recapitulates features of selective neurodegeneration in huntington's disease. Cell. 173:1-14.

Zhang Z, Zhang H, Liu T. 2019. Study on body temperature detection of swine based on infrared technology: A review. Artificial intelligence in agriculture. 1:14-26.