

Doppler parameters in the ductus venosus during the third trimester of pregnancy in goats

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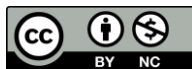
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SUMMARY

The aim of the study was to assess the haemodynamics in the ductus venosus in the third trimester of pregnancy in goats. Blood flow parameters in the ductus venosus were measured using colour Doppler combined with the pulsed-wave Doppler technique. The wave spectrum of blood flow in the ductus venosus during the study period had a specific pulsating character with two visible acceleration phases. The study showed an increase in peak systolic velocity, end-diastolic velocity, resistance index, and pulsatility index in the last period of the third trimester of pregnancy. All Doppler parameters in the ductus venosus were correlated with the day of gestation. Blood flow parameters and the Doppler spectrum were shown to change during the third trimester of pregnancy in goats. The results may be useful for future study of the ductus venosus in foetal goats.

KEY WORDS: ductus venosus, ultrasonography, Doppler, pregnancy, goat



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INTRODUCTION

In recent years, the possibilities for ultrasound imaging of vascular haemodynamics have increased enormously. One of the uses of Doppler ultrasonography is to monitor embryo-foetal development (Kumar *et al.*, 2015). The uteroplacental arteries (Ramírez-González *et al.*, 2023), umbilical vessels (Serin *et al.*, 2010; Kumar *et al.*, 2015; Wojtasiak *et al.*, 2023), and foetal vessels, such as the aorta (Fasulkov *et al.*, 2021) and foetal renal vessels (Stankiewicz *et al.*, 2023), are examined using this non-invasive technique. It also provides information about the condition of the foetus and helps in the diagnosis of any abnormalities that may affect the survival of the foetus and newborn (Da Silva *et al.*, 2018).

Ultrasonography of the liver is of great importance in these studies. The liver is one of the most important organs with active roles in various metabolic functions, such as the metabolism of proteins, lipids, carbohydrates, and vitamins A and B; synthesis of fibrinogen, globulins, clotting factors, and albumins; bile secretion; glycogen and fat storage; and excretion of urea and uric acid. It is also involved in other functions, such as detoxification of various metabolic waste products and drugs (Mahadeep *et al.*, 2013). The foetal liver is the main haematopoietic organ during foetal development, with an important role supporting haematopoietic homeostasis (Lewis *et al.*, 2021). It also occupies a privileged position in foetal circulation, as the first organ to which blood flows directly from the placenta (Sørensen *et al.*, 2011). Oxygenated blood enters the goat foetal liver from the portal vein and umbilical veins, which form the intra-abdominal umbilical vein inside the foetus (Bejdić *et al.*, 2021). The left lobe of the liver is supplied with nutrient-rich blood from the intra-abdominal umbilical vein, while half of the blood for the right lobe of the liver comes from the intra-abdominal umbilical vein and the other half from the nutrient-poor blood of the portal vein (Haugen *et al.*, 2004; Sørensen *et al.*, 2011). This division of blood flow between the portal vein and the intra-abdominal umbilical vein accounts for a functional dichotomy that can be modified by haemodynamic influences (Kiserud, 2003; Haugen *et al.*, 2004). The foetal liver with its venous system are the main areas of interest in foetal circulation – particularly the blood flow through the ductus venosus and its connection with the intra-abdominal umbilical vein. The ductus venosus in postnatal life is known as the left branch of the portal vein, while in foetal development it forms the transverse sinus and originates in the intra-abdominal section of the umbilical vein (Mavrides *et al.*, 2001; Bejdić *et al.*, 2021). The ductus venosus of a ruminant foetus is a curved, trumpet-shaped vessel located in the central part of the liver, above the porta hepatis (Bejdić *et al.*, 2021). It plays a key role in the distribution of highly oxygenated umbilical venous blood, some of which bypasses the liver parenchyma passing through the ductus venosus, caudal vena cava, foramen ovale, and left atrium and finally reaches the heart and brain (Seravalli *et al.*, 2016). The waveform of the Doppler spectrum in the ductus venosus is associated with changes in pressure and volume in the atria and is therefore important in monitoring any foetal condition that may affect future cardiac function (Seravalli *et al.*, 2016). Doppler examination of foetal venous circulation provides valuable diagnostic information. It is also of great importance for arterial circulation. Quantitative assessment of venous flow provides information on foetal physiology, in terms of both the umbilical circulation and details of distribution in the liver and heart (Kiserud, 2003).

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Doppler ultrasonography is increasingly used to assess blood flow through the ductus venosus when growth retardation, oedema, or congenital heart defects are suspected in the foetus (Seravalli *et al.*, 2016). Some studies have shown an association between foetal chromosomal/cardiac abnormalities and abnormal ductus venosus blood flow during the first trimester of pregnancy (Marvides *et al.*, 2001). With these considerations in mind, data from ultrasound examination of the ductus venosus during the third trimester of pregnancy in goats can be regarded as important. The main objective of the study was to evaluate Doppler parameters in the ductus venosus in the third trimester of pregnancy in goats. It was hypothesized that the blood flow in the ductus venosus may change during the third trimester of pregnancy in goats.

MATERIALS AND METHOD

Experimental animals and management

The study was carried out on 14 Boer goats kept on a farm at the Experimental Department of the National Research Institute of Animal Production in Kołbacz (Poland: latitude 53°30'N). The goats were kept in an indoor system with pasture. Feeding was in accordance with the standards adopted for this species, based on green pasture and other roughage and concentrate, depending on the season. The goats had constant access to water and salt licks. The goats were healthy, multiparous, 5 to 6 years old, with similar body weight (75–80 kg). All goats were mated in September with the same buck. Gestation length was determined based on the day of mating. The effectiveness of mating was determined by transectal ultrasound. After delivery, the date of conception was confirmed retrospectively, assuming that the pregnancy lasted 148 days (Stankiewicz *et al.*, 2020; Wojtasiak *et al.*, 2023). All goats were pregnant with twins. Pregnancy and delivery were uneventful, and all kids were born healthy.

Ultrasound examination

The haemodynamics in the ductus venosus were assessed in pregnant goats that had not previously been sedated (Stankiewicz *et al.*, 2020; Wojtasiak *et al.*, 2023). The examination was conducted in the third trimester of pregnancy, divided into three periods: 1 (100–110 days), 2 (120–130 days) and 3 (140–148 days). The examination was always performed by the same experienced and trained operator, in a quiet and dimly lit room. Transabdominal ultrasound examination was performed using an ultrasound scanner (EDAN U50 USG scanner) equipped with a sector probe with a frequency up to 5 MHz (model C352UB) and a linear probe with a frequency up to 9.4 MHz (model V742UB). Prior to the examination, the inguinal and caudal abdominal regions areas were shaved, the skin was cleaned with soap and water, and a sufficient amount of transmission gel was applied. The goats were kept in a standing position during the examination. After visualization of the foetus in B-Mode, vascularity was assessed using colour and pulsed Doppler. The ductus venosus was visualized in a sagittal or oblique transection of the foetal abdomen and examined at the isthmus, near its origin in the umbilical vein. This vessel was located in the central part of the liver and ran cephalad with increasing inclination in the same sagittal plane as the original direction of the umbilical vein. The following Doppler parameters were determined: peak systolic velocity (PSV), end diastolic velocity (EDV), PSV/EDV ratio, resistive Index [RI = (PSV – EDV) / PSV],

and pulsatility index [PI = (PSV –EDV) / mean velocity]. The flow angle during the test was kept as close as possible to a < 20 degrees, making appropriate adjustments to the angle when necessary. This procedure was performed twice, and the average for each vessel was calculated. Measurements were not recorded during maternal and foetal movements. In the case of signs of anxiety or changes in the maternal respiration rate, the examination was postponed until the body was seen to be in a stable position.

Statistical analysis

Statistical analysis of the results was performed. The results are presented as means ± SEM. The Shapiro–Wilk test was used to assess the normality of the data distribution. One-way repeated measures ANOVA was performed, where the grouping variable was gestational days, and the dependent variable was the Doppler parameter. Differences between the means for individual groups were analysed using a post hoc test. The Tukey test was used to verify the significance of differences at $P < 0.05$. The correlations between parameters and the day of pregnancy were calculated with the Pearson rank correlation coefficient (r). Statistical analyses were conducted using STATISTICA version 13.3, Stat Soft, Poland.

The results were analysed according to the following statistical model:

$$Y_{ijk} = \mu + \tau_i + \pi_j + \varepsilon_{ijk}$$

where:

Y_{ijk} – analysed trait

μ – overall mean

τ_i – fixed effect of i^{th} period of the third trimester of pregnancy ($i = 1, \dots, 3$)

π_j – fixed effect of j^{th} Doppler parameter ($j = 1, 2, \dots, 5$)

ε_{ijk} – error associated with each record (all error terms were assumed to be random, normally distributed and independent, with expectation equal to zero).

RESULTS

The waveform of the Doppler spectrum in the ductus venosus was pulsating. Two phases of acceleration (first and second peak) were visible in the Doppler spectrum. A representative image of blood flow in the ductus venosus is shown in Figure 1.

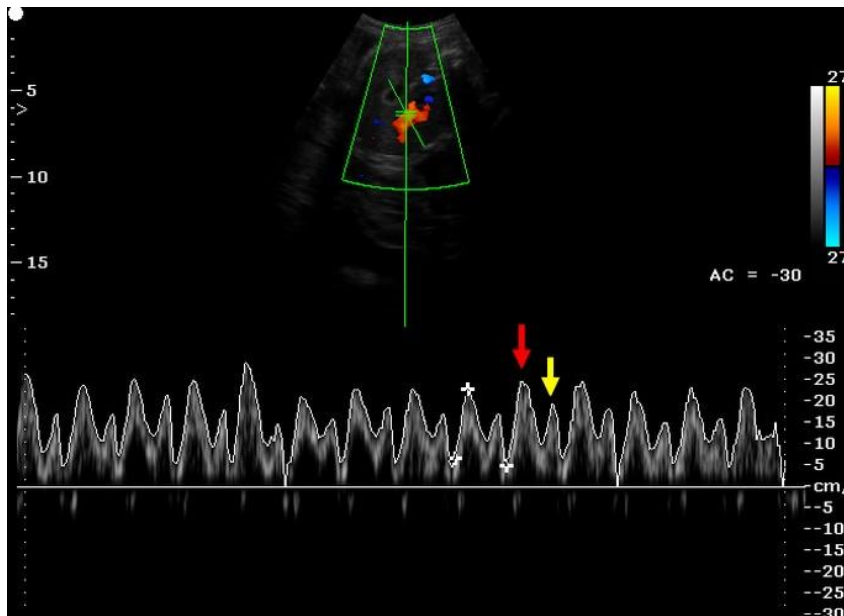


Figure 1. Ultrasound images showing Doppler blood flow velocity patterns from the ductus venosus in goats at 130 days of gestation. Red arrow – first peak systolic velocity; yellow arrow – second peak systolic velocity.

Table 1 shows the mean values of Doppler parameters in the ductus venosus in the third trimester of pregnancy in goats. Peak systolic velocities, PSV/EDV, and the resistive and pulsatility indexes were significantly higher in the final days of pregnancy than in earlier periods. However, the EDV value at the end of pregnancy was lower. All Doppler parameters examined in the ductus venosus were significantly correlated with the day of gestation.

Table 1.

Mean (\pm SEM) value of Doppler parameters in the ductus venosus in goat foetuses during the third trimester of pregnancy in goats (n = 14)

Parameters	Days of gestation		
	100-110	120-130	140-148
PSV I (cm/s)	22.42 \pm 1.79 ^a	29.96 \pm 1.34 ^b	38.43 \pm 1.48 ^c
PSV II (cm/s)	16.06 \pm 1.79 ^a	19.43 \pm 1.55 ^a	24.35 \pm 0.85 ^b
EDV (cm/s)	9.92 \pm 1.25 ^a	11.73 \pm 0.82 ^a	7.83 \pm 0.94 ^b
PSV/EDV	2.97 \pm 0.29 ^a	2.83 \pm 0.27 ^a	4.99 \pm 0.62 ^b
RI	0.62 \pm 0.05 ^a	0.60 \pm 0.04 ^a	0.75 \pm 0.04 ^b
PI	0.83 \pm 0.08 ^a	0.85 \pm 0.06 ^a	1.11 \pm 0.08 ^b

PSV I – first peak systolic velocity; PSV II – second peak systolic velocity; EDV – end-diastolic velocity; RI – resistive index; PI – pulsatility index

Values with different letters in a row are significantly different (P < 0.05).

The values of the correlation coefficients are presented in Table 2.

Table 2.

Pearson correlation coefficients (r) between the day of gestation and Doppler parameters in the ductus venosus in the third trimester of pregnancy in goats (n = 14)

	Parameters	Correlation coefficients	Significance level
Ductus venosus	PSV I	0.52	P < 0.05
	PSV II	0.75	P < 0.01
	EDV	-0.91	P < 0.01
	PSV/EDV	0.96	P < 0.01
	RI	0.92	P < 0.01
	PI	0.93	P < 0.01

PSV I – first peak systolic velocity; PSV II – second peak systolic velocity; EDV – end-diastolic velocity; RI – resistive index; PI – pulsatility index

DISCUSSION

The examination showed that the parameters of blood flow and the Doppler spectrum change during the third trimester. To our knowledge, this is the first study to describe haemodynamic changes in the liver venous system of foetuses in goats that have not previously been sedated. The ductus venosus, which originates in the umbilical vein, is the only venous vessel that regulates the nutrient supply via the blood from the umbilical veins between the liver and the heart. Blood flowing into the ductus venosus is

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significantly accelerated towards the foramen ovale. This separates the bloodstream from the other venous stream entering the heart and allows nutrient-rich blood to reach the left ventricle instead of flowing through the tricuspid valve into the right ventricle (Seravalli *et al.*, 2016). In the present study, the waveform of the Doppler spectrum in the ductus venosus was pulsating with two visible phases of acceleration. The available scientific literature contains no data on the waveform of the Doppler spectrum in the ductus venosus in goats. However, the results are in line with those obtained by Saemundsson *et al.* (2011) in sheep. They also showed that during the onset of tachycardia in sheep foetuses, the Doppler spectrum of the ductus venosus shows three repetitive reversals of flow velocity during atrial contraction (Seravalli *et al.*, 2016). The course and waveform of the Doppler spectrum in the ductus venosus may explain the changes in atrial pressure and volume in the systolic and diastolic phases of the heart cycle (Saemundsson *et al.*, 2011; Seravalli *et al.*, 2016). Abnormal waveforms of the Doppler spectrum in the ductus venosus cause increased cardiac preload, abnormal cardiac function or structure, or increased cardiac afterload (Saemundsson *et al.*, 2011; Seravalli *et al.*, 2016). Therefore, an abnormal waveform requires careful examination of all potential cardiovascular factors. The scientific literature currently provides no data pertaining to values of Doppler indices in the ductus venosus of goats under physiological conditions. Most research describes the results of studies carried out in human foetuses (Nakagawa *et al.*, 2012) and sheep foetuses (Mäkikallio *et al.*, 2010). In the present study, peak systolic velocities increased significantly in the final days of the third trimester, while EDV values decreased significantly. Similar observations have been reported in human foetuses (Nakagawa *et al.*, 2012).

In this study, for the first time, second peak systolic values were determined for the diastolic peak when the atrioventricular valves open during early passive diastolic ventricular filling. The results of human studies show that in the second phase of acceleration, blood flow velocity values increase during blood flow through the atria (Seravalli *et al.*, 2016). In the present study, the mean PI values in the ductus venosus increased with gestational age. Similar observations were reported in studies conducted in sheep (Mäkikallio *et al.*, 2010), whereas in humans, the average PI values during pregnancy are similar for most of the time, decreasing slightly at the end of pregnancy (Hofer, 2000; Nakagawa *et al.*, 2012). In those studies, PI values were also found to be associated with gestational age (Hofer, 2000; Nakagawa *et al.*, 2012). In the present study as well, significant correlations were found between these indices and gestational age. The results of the present study show that the mean RI values in the ductus venosus at the end of the third trimester, as in the case of the PI, were significantly higher than at the beginning of the third trimester of gestation in goats. Human studies have shown that for umbilical cord blood to enter the left atrium, it requires kinetic energy and high pressure to overcome the resistance of the ductus venosus and enter the foramen ovale (Kiserud and Kessler, 2023). This may explain the high values of Doppler parameters such as flow velocity, pulsatility index, and resistance index.

CONCLUSIONS

Summing up, the results presented in this paper may be useful in determining the reference values of haemodynamic ultrasound parameters of the ductus venosus in goats during pregnancy. The Doppler indices obtained indicate that haemodynamics in the ductus venosus change during the third trimester of pregnancy in goats, so these factors should be taken into account in assessment of hepatic venous system flow and heart function in goat foetuses.

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