



Sonographic Assessment of Foetal Growth Indices and Haemodynamics at Different Stages of Gestation in Goats: A Review

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ABSTRACT

Ultrasonography is a useful non-invasive technique to measure the foetal growth, age and viability in goats. The maternal and foetal parameters such as uterine lumen diameter, placentome size, crown rump length, biparietal diameter, foetal orbit length, trunk diameter, occipito-snout diameter, thoracic diameter, long and short axis of heart, diameter of aorta, umbilical cord diameter, humerus, femoral and tibial length were studied in different breeds of goats to assess the foetal development. Doppler ultrasonic technique has been used to monitor the uterine and umbilical arterial blood flow in pregnant animals. However, there is a scarcity of data on the haemodynamic indices and blood flow velocity of the uterine artery during pregnancy to determine the normal physiological or pathological states. These parameters could serve as valuable determinants for the normal intrauterine foetal development and thus differentiates from gestational pathologies in goats. This review highlights the pivotal role of ultrasonography and Doppler techniques in advancing our understanding of foetal growth and maternal hemodynamics in goats.

Key words: Doppler sonography, Foetometric measurements, Haemodynamics, Pregnant goats.

Goat farming is a thriving agricultural business in India, which opens huge employment opportunities and livelihood for rural communities. Breeding and reproduction play pivotal role in goat enterprise, in which early pregnancy diagnosis and assessment of foetal development is crucial in deciding the management practice. The diagnosis of non-pregnant does early in the breeding season is the first stage in the reproductive herd health program. Pregnant and non-pregnant animals can be distinguished to reduce reproductive and productive losses. Ultrasonography is a commonly practiced and widely accepted non-invasive technique to detect pregnancy and foetal viability (Karen *et al.*, 2009 and Amer, 2010). During gestation, Doppler ultrasound offers a pattern of blood flow in the organ of interest, such as velocity, circulation and blood type, which has critical clinico-gynecological significance in animal species. Compared to companion animals and other species, the Doppler technique has not been widely used in goat obstetrics and only a few studies have investigated Doppler predictors in aberrant gestation.

Doppler ultrasonography measures velocity indices and blood flow volume to assess vascular perfusion. The haemodynamic changes of umbilical cord vascular system provide blood flow to the developing placenta and fetus and poor uterine perfusion has been identified as the leading cause of prenatal growth restriction. However, despite progress in ultrasonographic methodologies, there exists a notable deficiency in the thorough documentation and standardization of hemodynamic indices and blood flow parameters, especially concerning the uterine and umbilical arteries in goats across various breeds and

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gestational periods. Research examining the relationship between these indices and the early identification of gestational disorders is scarce, creating a significant gap in understanding how these parameters can be utilized for clinical diagnostics and treatment in caprine species. This review emphasizes the crucial contribution of ultrasonography and Doppler techniques in enhancing our comprehension of fetal development and maternal hemodynamics in goats. By synthesizing current knowledge and pinpointing research deficiencies, the article highlights the necessity for ongoing exploration in this field, which could greatly improve reproductive management strategies, enhance neonatal health outcomes and enable the early detection of gestational abnormalities in goats.

Maternal and foetal echobiometry of caprine pregnancy

B-mode real-time ultrasonography is a reliable, quick and easy imaging approach for detecting pregnancy in goats with approximately 100 per cent accuracy (Buckrell, 1988 and Dhillon *et al.*, 2020). To achieve high-quality images, it is essential to select the appropriate probe type (linear, sector, or convex) and frequency (3.5, 5, or 7.5 MHz), particularly as transrectal palpation is infrequently employed in small ruminants, making this choice even more critical. B-mode ultrasonography is generally used for biometric and foetal morphological examinations.

An effective method for determining the stage of pregnancy is ultrasound foetal biometry. In Saanen goats (Abdelghafar *et al.*, 2011), Japanese miniature Shiba goats (Kandiel *et al.*, 2015) and Jamnapari goats (Abubakar *et al.*, 2016), the crown to rump length, biparietal, femur and trunk were correlated with the gestational age. Ultrasonography examinations can be performed in all the stages of pregnancy. Small ruminant gestation can be divided into three stages for the foetometric measurements. The first stage lasts for 50 days, the second stage lasts for 50-100 days and the third stage accounts for more than 100 days till parturition (Erdogan, 2012).

Uterine lumen diameter

The uterine lumen diameter is measured during early pregnancy in goats. It can be measured from the 21st day of gestation until the end of the first stage (Karadaev *et al.*, 2016). According to Padilla-Rivas *et al.* (2005), a tiny, fluid-filled, non-echogenic vesicle measuring about 1 cm in diameter was observed in the uterine lumen of Boer goats by day 21. Amer (2010) verified that the transverse diameter of the embryonic vesicle was around 10 mm when it was initially observed in dairy goats at gestational day 19.5 ± 0.30 . According to Karadaev *et al.*, (2018), the first metric measured (10.15 ± 2.39 mm) in Bulgarian goats on the 21st day of gestation was the increased uterine lumen filled with anechoic amniotic fluid.

Crown rump length (CRL)

Crown rump length is defined as the length of the entire foetus, measured from the top of the foetal skull to the end of the sacrum. When the foetus is in a curved position, CRL is measured first from the head to the heart and then from the heart to the end of the sacrum (Abdelghafar *et al.*, 2011 and Karadaev *et al.*, 2018). Madhusudhan (2017) reported that the average foetal CRL measurements in Malabari does were 2.33 ± 0.009 to 15.18 ± 0.064 cm on days 30, 44, 59, 74 and 89 of gestation. The equation formulated for gestational age calculation was $y = 24.226 + 4.529x$, where x is the foetal CRL ($R^2 = 0.968$). CRL in goats can be measured from the 21st to 49th day of gestation (Karadaev *et al.*, 2018). The average CRL of the foetus on days 30, 45 and 60 of gestation was 1.38 ± 0.11 , 3.74 ± 0.26 and 7.7 ± 0.24 cm in singleton pregnancies and 1.32 ± 0.08 , 3.90 ± 0.20 and 7.6 ± 0.18 cm in multiple foetal pregnancies,

according to Vinayak (2015). He concluded that the CRL not significant difference between singleton and multiple pregnancies.

According to Saeedipanah *et al.* (2022), the straight CRL in Baluchi sheep was demarcated as the longest straight length of the foetal mass between the occipital bone and the rump. The CRL was measured transrectally from days 19 to 55 and transabdominally from days 81 to 83. The formula for calculating gestational age in Baluchi sheep is $Y_{\text{days}} = 21.537 + 0.3722 \text{ CRL}^{\text{mm}}$.

Bi-parietal diameter (BPD)

In goats, the BPD of the foetal skull is measured from the first stage of pregnancy itself. The cerebral falx midline should divide the hemispheres into two equidistant sections when taking the BPD and the measurement is taken from the outer surface of the proximal calvarium to the inner surface of the distal calvarium (Amer, 2008). Kandiel *et al.* (2015) found that the braincase diameter of Miniature Shiba goat fetuses increased dramatically from 10.50 ± 0.17 mm to 64.00 ± 0.91 mm at the first to fourth month and that it has strong positive correlation ($R^2 = 0.98$) with gestational age. Biparietal diameter as shown to be the most reliable variable for identifying gestational age in sheep ($R^2 = 95.0$) compared to goats ($R^2 = 96.5$) (Ejaz-ul-Haq *et al.*, 2020), where it was measurable from 34 to 125 days with $R^2 = 83.0$. Gouda *et al.* (2021) reported that the mean biparietal diameter could be accurately measured between 6th to 16th gestational weeks 20.00 ± 0.05 and 64.00 ± 0.00 to estimate the gestational age in Baladi goats. Due to its extended application time and strong correlation ($R^2 = 0.96$) with gestational duration, BPD is a better option for small ruminants than CRL.

Occipito nasal length (ONL)/Occipito-snout diameter (OSD)

According to Yazici *et al.* (2018), Occipito Nasal Length (ONL) in Turkish Sannen goats can be measured as early as day 37 of pregnancy. The ONL and gestational age showed strong correlations ($r = 0.99$), consistent with previous studies on sheep (Gonzalez de Bulnes *et al.*, 1998; Gurler and Kaymaz, 2011) and goats (Kandiel *et al.*, 2015). The ONL's linear regression equation was $y = -30 + 1.07x$, with little difference between singleton and twins pregnancies in Turkish Saanen goats. Santos *et al.* (2018), who could measure ONL from sixth week of pregnancy in Santa Ines sheep. A positive correlation was obtained between gestational age and ONL ($r = 0.9873$) and regression equations generated as $y = 9.471x + 25.66$ respectively. It concluded that ONL was precise over BPD in predicting parturition dates in Nellore Brown ewes. According to Saeedipanah *et al.* (2022), the OSD was indicated as the best parameter for predicting gestational age between days 36 and 109 in Baluchi sheep due to the lowest residuals, highest correlation coefficient. The regression equation $y = 24.79 + (0.8271 \times \text{OSD}^{\text{mm}})$ had a high correlation coefficient ($R^2 = 0.981$) in Baluchi sheep.

Thoracic diameter

Suguna *et al.* (2008) used B- mode ultrasonography to evaluate the thoracic diameter in crossbred does during pregnancy and concluded that the thoracic diameter significantly increased as the gestational stage progressed. There was a high correlation between gestational age and thoracic diameter ($r = 0.99$). The formula derived for thoracic diameter regression was $y = 26.0 (x^{cm}) - 4.8$. Silva *et al.* (2021) used a linear regression model to determine the gestational age of Saanen goats having a coefficient (R^2) of more than 90 per cent using parameters. Abdominal diameter and Thoracic diameter had strong predictive power for gestational age ($R^2=93.4$ and $R^2=92.0$). So, both parameters can be used as reliable estimators of the Saanen goat's gestational stage. The conjugated equation for determining gestational age in Saanen goats was $GA = 22.2152 + 0.892503 \times BPD^{mm} + 0.936015 \times TCD^{mm}$ ($R^2=95.05$).

In Baluchi sheep, the thoracic diameter was measured at two levels by Saeedipannah *et al.* (2022), one at the central (TDC) and other at final rib junction (TDR) on days 36-109 and 36-138, respectively. Foetal age and TDC ($R^2 = 0.958$) and TDR ($R^2 = 0.975$) showed a positive significant connection in Baluchi sheep. The regression equations obtained were $Y^{days} = 24.933 + (2.1279 \times TDC^{mm})$ and $Y^{days} = 31.961 + (1.2103 \times TDR^{mm})$, respectively. According to Muhammad and Aziz (2022), the foetus's chest diameter in Shami goats increased drastically from 11.52 ± 0.84 mm on days 51–60 of pregnancy to 56.35 ± 0.93 mm on days 101–110. They observed a high positive correlation between gestational age and chest diameter in this breed ($r=0.935$) and the regression line of equation was $Y^{days}=1.4470 X^{mm}+37.565$.

Foetal trunk diameter

The foetal trunk diameter (FTD), one of the greatest diameters of the foetal body was measured from the ventral aspect of the spinal column to the ventral aspect of the abdomen. The formula derived for FTD in Korean goats was $Y=13.2648 X (cm) + 33.7059$ (Lee *et al.*, 2005). In one study, Kandiel *et al.* (2015) measured the FTD during pregnancy and found that it was increased significantly as the pregnancy progressed, from 16.32 ± 1.61 mm to 61.25 ± 3.27 mm at first to fourth month, with a correlation coefficient of $R^2 = 0.8969$. While Karadaev *et al.* (2016) reported that the TD in Bulgarian local goats was 6.8 ± 0.9 mm on day 28 of gestation and 18.8 ± 1.1 mm at the end of the first trimester of pregnancy using transrectal ultrasonography with a linear transducer (5.0-12.0 MHz). Madhusudhan (2017) assessed the mean FTD (cm) in Malabari goats between days 44 and 114 days of gestation and reported a consistent increase as 1.48 ± 0.007 to 5.99 ± 0.014 , respectively. The regression formula derived; $GA=24.63+14.93 TD$ could be used to predict the gestational age of Malabari goat fetuses with high ($R^2=0.998$) correlation coefficient.

Eye orbit diameter

The eye orbit diameter (EOD) is used to estimate the gestational age of goat fetuses between 57 and 124 days of gestation. Once the eye orbit is identified in ultrasonography in a rounded shape at its greatest size, the diameter of the circle created is measured (Erdogan, 2012). Nwaogu *et al.* (2010) found the orbital, biparietal and occipitonasal diameters all exhibited a positive correlation ($R = 0.97$, 0.98 and 0.92) and high significance ($P<0.001$) with gestational age. The growth equations that were derived were $GA = 22.881 + 6.668 ONL$, $GA = 26.938 + 14.30 BPD$ and $GA = 17.326 + 43.534 OD$.

According to Kandiel *et al.* (2015), the foetal orbit diameter increased from 12.24 ± 0.93 mm in the first month of gestation to 69.62 ± 6.29 mm in the fourth month, indicating a strong correlation ($R^2=0.9239$) between the two variables in Shiba goats. The linear regression equation $Y^{days} = 1.6628 x^{cm} - 5.2055$. By using ultrasound examination on the 49th day of pregnancy, Karadaev *et al.* (2016) discovered that the average foetal orbit diameter in Bulgarian local goats was 6.5 ± 0.5 mm. In Murciano-Granadina goat breed gestation was assessed between 75-125 days of post-breeding using the regression model, $Y^{days} = 60.9832 x^{cm} + 10.4719$ and the mean measurement of eye orbit diameter was $1.21 \pm 0.03 - 2.00 \pm 0.03$ cm between 75-125 days of gestation (Ramírez-González *et al.*, 2023).

Placentomes diameter

As the pregnancy continues, the concave round shape of the small ruminant placentomes produces C-shaped or O-shaped gray pictures against the black uterine fluid, depending on the plane of section. The placentome diameters (PD) were measured from the 18th to 20th day of pregnancy in Baluchi sheep and at least five large placentomes were required for the precise assessment. However, it had the lowest correlation coefficient with gestational age among the parameters tested as several placentomes appeared in the same picture in ultrasonography and the size of each placentome varied with gestational age (Saeedipannah *et al.*, 2022).

Meanwhile Suguna (2008) reported a strong correlation ($r = 0.99$) between placentome diameter and gestational age in crossbred does, having placentome diameter increased dramatically from day 42 to day 130 of gestation (0.97 ± 0.1 cm to 3.07 ± 0.2 cm). Yaseen Mahmood (2016), observed a significant difference in PD between single and twin pregnancies of Iraq local goat breeds. The average PD size in single and twin-pregnant does were 7.5 ± 0.41 mm and 9.2 ± 0.74 mm, respectively between days 35 to 45 of gestation. The maximal size of placentome was 39.2 ± 2.50 mm in singleton-bearing does during 116-125 days and 41.0 ± 2.19 mm in twin bearing does during 126-135 days of gestation. However, determination of gestation age based on placentome measurement beyond day 90 was not trustworthy.

Kuru *et al.* (2018) also observed a significant correlation ($P < 0.001$) between placentome diameter and gestational age in Abaza and Gurcu goats. This study were similar findings to those of Karen *et al.* (2009) ($R^2 = 0.905$) and Kandiel *et al.* (2015) ($R^2 = 0.899$) and higher than those of Lee *et al.* (2005) ($r = 0.574$) and Nwaogu *et al.* (2010) ($r = 0.45$).

Vinayak (2015) compared the PD between single and multiple pregnancies during 45 to 135 of gestation in Malabari goats. The mean value of PD in singleton ranged from 1.14 ± 0.02 to 3.28 ± 0.02 and in multiple pregnancies were 1.13 ± 0.01 to 3.25 ± 0.01 cm, respectively. The regression equation for estimation of gestational age in Malabari goats was $Y = -4.757 + 41.564 \times \text{cm}$ ($R^2 = 0.959$). He concluded that, there was no significant between single and multiple pregnancies but significant difference was observed between the days ($p < 0.05$).

According to Saeedipanah *et al.* (2022), there was a substantial, nonlinear correlation between placental development and gestational age in Baluchi sheep. There was a strong correlation ($p < 0.001$) between foetal age and BPD (between 36 -96 days) ($R^2 = 0.961$), CRL ($R^2 = 0.935$), FL ($R^2 = 0.950$), OSD ($R^2 = 0.981$) and TD ($R^2 = 0.975$). BPD and Placental diameter were used to measure significant non-linear correlation with age.

Measurements of foetal heart rate

Foetal heart rate was measured following the methods of Curran and Ginther (1995) and Karen *et al.* (2009). Serin *et al.* (2010) state that although the Foetal Heart Rate (FHR) was decreased during pregnancy, this was not evident until the final two weeks of the pregnancy. Specifically, between 130 and 145 days of pregnancy, the average FHR value dropped to 140 ± 6.4 bpm ($P < 0.05$). The FHR values for multiple pregnancies and singleton pregnancies did not change ($P > 0.05$). Erdogan *et al.* (2012) used B-mode doppler ultrasonography to measure the foetal heart rate (FHR) in Karya ewes. For multiple pregnancies, the average FHR during late gestation was 140.5 ± 3.4 bpm, while for singleton conceptions, it was 141.70 ± 5.4 bpm. In healthy pregnancies, the FHR values were above 220 bpm in the first trimester and below 190 bpm in the third. Jyothi *et al.* (2021), all fetuses showed cardiac movements in the chest area for the first time on days 36 and 43 in Nellore ewes. However, heartbeats were found earlier than this study (19-24 days) by Padilla-Rivas *et al.* (2005), Karen *et al.* (2009) and Kumar *et al.* (2015).

Measurement of heart axis length

According to Lee *et al.* (2005), the imaging of the foetal heart atria and ventricles in transverse axial projection during diastole and no movement of the foetus, the longitudinal (long) and transverse (short) heart axes were measured. The longitudinal and transverse heart axis had the greatest significant correlation to gestational age in Korean black goats. A study by Airina *et al.* (2011) examined the measurements of the foetal heart size in goats of mixed breeds of does at 7th to 21st week of gestation during both

singleton and multiple pregnancies. The heart size for the single and twin pregnancy was 0.36 ± 0.07 to 7.90 ± 1.22 (cm^2) and 0.41 ± 0.01 to 14.09 ± 1.24 in cross bred does. The coefficient of determination of R^2 in polynomial regression in Jermasia ($R^2 = 0.931$) was found to be slightly higher than those in linear regression ($R^2 = 0.910$), which may be due to the polynomial growth pattern of the foetus's foetal heart during pregnancy.

Kandiel *et al.* (2015), the longitudinal (long) and transverse (short) axis of the foetal heart in Shiba goats during pregnancy days increased from first months were 6.43 ± 0.17 mm and 4.83 ± 0.41 mm to 35.71 ± 1.13 mm and 25.68 ± 0.70 mm in fourth months, respectively. A linear regression line equated with $y = 3.1536x - 14.748$ and $y = 2.0632x - 8.2609$, which were highly correlated with gestation $R^2 = 0.9382$ and 0.9589 , respectively. According to Karadaev *et al.* (2021), the foetal heart short axis had values greater than those of the external one ($R^2 = 0.95, 0.97, 0.97$), while the long axis of foetal heart had the following values for $R^2 = 0.94, 0.96, 0.96$ and for SEE = 7.0, 5.5, 5.5 days for the linear, quadratic and exponential correlations, respectively.

Measurements of humerus and femur length

Usually, humerus is identified following the location of foetal heart and scapula and the femur is confirmed by identifying the foetus urinary bladder. For measuring the foetal development, Kahn (2004) measured the humerus and femur length in Saanen goats on weekly basis starting from week 8 till the parturition and the lengths of the bones were measured according to the zones of intensive calcification which appeared echo-rich. In Saanen goats, measurements of the humerus and femur were reported to be useful for predicting gestational age in the second and third trimesters (Abdelgafar *et al.*, 2012).

According to Kahn (2004) the femur length and gestational age had higher correlations and coefficients of determination and femur length was a good predictor of foetal age in Kari sheep. The 6th and 18th weeks had the smallest and largest femur lengths of 17 and 45 mm, respectively. Also, in Yankasa ewes, femur length and gestational age had a significant connection ($R^2 = 0.9871$) from days 60 to 103 of pregnancy which can be reliably during the second and third trimesters (James *et al.* (2015).

Yadav (2021) measured the length of the foetus' femur to estimate the gestational age of 21 pregnant Bangladeshi goats. Femur length (FL) was 37.2 mm and their real gestational age was 80 days. There was a significant difference between the estimated and actual gestational ages regarding FL ($P \leq 0.05$). The following formulas were created to predict the gestational age of Bangladeshi goats: $GA = 1.27 + 0.98CRL$, $GA = 22.99 + 1.94BPD$, $GA = 34.67 + 1.35FL$ and $GA = 4.43PD - 37.41$, with coefficients of determination ($R^2 = 98, 96, 91$ and 63) accordingly. Based on the current study, it can be said that the CRL and BPD were very reliable for estimating GA in the first and second trimesters, whereas FL is advised in the third.

Doppler ultrasonography of umbilical artery, uterine artery and foetal aorta

The study on the pulsatility of umbilical artery by Surat and Adamson (1996) implied a correlation between the vascular walls and vascular resistance of placenta. As the fetal size increases, the arteries develop greater vascular musculature that decreases their radius and results in a progressive decrease in pulsatility index (PI). In other studies (Serin *et al.*, 2010 and Martínez-Díaz *et al.*, 2022) the resistance index (RI) values decreased progressively and significantly throughout the pregnancy corresponding to the increased requirements of foetus due to its rapid growth. As a result, low resistance of the umbilical arteries favored increased blood flow to the umbilical cord. Beltrame (2017) used a trans-rectal transducer to locate the uterine artery by lateralizing the transducer and using the external iliac artery as a reference point cranio-lateral to the bladder.

Measurements of umbilical artery

Doppler ultrasonography can be successfully utilized to assess the umbilical blood flow in fetuses of pregnant sheep and goats. The increase in umbilical PI and RI values after 19th week of gestation may be indicative of decrease foetal growth rate and decreased blood flow and oxygen tension in foetal blood. The size of the fetoplacental vascular bed and the Systolic/Diastolic ratio was related to umbilical blood flow and this link facilitated the detection of anomalies in size or function in foeto-placental vascularization, in addition to changes in the umbilical cord (Ramírez-González, 2023).

Serin *et al.* (2010), compared the blood flow of umbilical artery (UA) between singleton and multiple pregnancies of healthy pregnant Saanen goats and found no significant variations in umbilical artery with respect to pulsatility, or resistance in foetus. The RI values were more stable than the PI values. The 85th and 130th days of pregnancy showed two notable drops in the mean RI value, which was limited to 0.97 during pregnancy. A threshold stage for indices in the caprine pregnancy pattern was found to be the middle of the second trimester.

Doppler sonography was used by Kumar *et al.* (2015) to assess the hemodynamic features of the foetal umbilicus in Beetal goats from days 20 to 120 of gestation. Peak systolic velocity (PSV) increases significantly between days 39 and 67 and then again between days 98 and 120 of gestation ($p < 0.05$); however, there was no discernible rise or fall in end-diastolic velocity (EDV). The characteristics of umbilical blood flow (UM) were examined by Elmetwally and Meinecke-Tillmann (2018) using 18 pregnant ewes and 20 pregnant goats. According to a qualitative assessment of UM blood flow, BFV, TAMV and TAMEAN levels in sheep and goat fetuses increased ($P < 0.001$) until week 19, after which they dropped ($P < 0.001$) until parturition. In both species, between weeks 4 and 12 of pregnancy, there was no end diastolic velocity (EDV) of umbilical artery blood flow.

According to Silva *et al.* (2022) the umbilical artery (UMB) in Saanen goats during physiological pregnancy was

monitored using Doppler throughout the 21st to 143rd day of gestation. RIUMB demonstrated a low negative association with the number of fetuses per pregnancy and both PIUMB and RIUMB correlated with gestational age ($p < 0.001$). The mean values decreased during pregnancy and the spectral trace's flow pattern changed, although PSVUMB and EDVUMB values did not correlate with gestational age.

Measurements of uterine artery

According to Elmetwally *et al.* (2016), doppler sonography is a helpful technique for evaluating how maternal anxiety affects intrauterine foetal growth in pregnant goats and sheep. They also compared the groups that were more reactive (MR) and less reactive (LR). At weeks six, ten and twelve of pregnancy, UtA-PI was substantially greater in MR ewes than in LR ewes ($P > 0.01$) and a tendency was noted at week fourteen ($P = 0.054$). He concluded that ewes and goats have higher UtA-PI and UtA-RI in MR than in LR animals.

Beltrame *et al.* (2017), reported Santa Ines sheep's doppler indices for uterine artery resistance, or the impedance of blood flow, decreased during the first, middle and late stages of gestation (PI: 1.15, 1.04, 31 0.97; RI: 0.61, 0.59, 0.57, respectively) ($p < 0.05$). The hemodynamic indices for single and multiple pregnancies did not differ from one another, nor did the means of the variables in relation to the right and left uterine arteries. Sudha *et al.* (2019) evaluated the efficiency of Doppler indices for diagnosis of uterine torsion in Malabari does. The PI and RI values of arteries ipsilateral and contralateral to the side of uterine torsion measured the resistive index were 0.77 ± 0.03 and 0.56 ± 0.03 and the values were observed to be higher in ipsilateral uterine arteries of torsion than in contralateral and normal kidding does; the value was lowest (0.47 ± 0.02) in normal does.

Silva *et al.* (2022) assess the doppler sonography of pregnant Saanen goats' uterine arteries blood flow. PSVUT, EDVUT, PIUT and RIUT, the mean values of the uterine artery doppler velocimetric variables, did not correlate with gestational age. The mean velocity of the uterine artery MVUT and PSVUT were negatively correlated with the number of fetuses per pregnancy. This suggests that the values of these variables will be lower when the pregnancy is multiple.

Akkus *et al.* (2023) assessed Awassi ewes to ascertain the alterations in uterine artery blood flow following the second half of pregnancy. Using Doppler ultrasound, measurements were made of the blood flow in the uterine arteries. The PSV value was found to be substantially greater on day 135 of pregnancy than it was on days 90, 105 and 120 ($P < 0.001$). At day 135 of pregnancy, the EDV and TAP values were considerably greater than those days ($P < 0.01$). On day 135, the RI value was considerably lower ($P < 0.001$) and the PI and S/D values were significantly lower ($P < 0.01$). They concluded that measuring changes in Doppler ultrasonography parameters will help to increase hemodynamic information because the most foetal development takes place in the second half of pregnancy.

Measurements of foetal aorta

Lee *et al.* (2005), the measurement of foetal aorta on 60, 75, 90, 105, 120 and 135 (cm) days of gestation is 0.22 ± 0.001 to 0.57 ± 0.07 in Korean Black goats. The regression equation for estimating gestational age by foetal aorta is $y = 151.1366x + 37.4774$. The diameter of long and short axis of heart and foetal aorta were significantly increased with the gestational age ($P < 0.05$).

According to Karadaev *et al.* (2018), the mean values of foetal aortic diameter was measured in Bulgarian local goats from 77, 91, 105, 119 and 133 days of gestation were 3.2 ± 0.3 to 7.6 ± 0.7 , respectively. The results showed the high correlation between gestational age and the foetal aortic diameter, which could be measured between gestation days 63 and 133 ($R^2 = 0.91$). The regression equation of linear, quadratic and exponential associated between gestational age and foetal aorta in Bulgarian local goats were $Y = 10.97x + 47.161$, $Y = -0.3996x^2 + 15.218x + 37.158$ and $Y = 44.977x^{0.5481}$, respectively.

CONCLUSION

The ultrasonographic examination is performed using different techniques and it is an accurate diagnostic method for determining foetal number and estimating gestational age in small ruminants. Various foetal biometric factors are being effectively utilized to determine the stage of pregnancy. The foetal parameters, BPD, CRL, OSD, FTD, TD, Heart axis, FA, FL and KL are highly correlated with gestational age in small ruminants. During pregnancy, the uterine and umbilical blood flows rise continually to satisfy the increased nutritional demands of the growing foetus and placenta. Doppler indices UA, UMA and foetal aorta can be successfully evaluating the potential foetal risk during pregnancy and its prognosis.

Future prospects

It is high time to evaluate the breed specific echobiometric indices which has high correlation with gestational age in small ruminants. Doppler ultrasonography being a non-invasive method can safely be used to track changes in umbilical and uterine blood flow in normal and abnormal pregnancies. The application of 3D ultrasonography can improve the diagnostic confidence in veterinary practice by adopting standardized procedures.

Conflict of interest

The authors have no conflict of interest.

REFERENCES

- Abdelgafar, R.M., Ahmed, B.H., Abdelrahim, M.S. and Ibrahim, M.T. (2012). The accuracy of gestational age predicted from femur and humerus length in Saanen goats using ultrasonography. *Acta Veterinaria Brno*. **81**: 295-299.
- Abdelghafar, R.M., Ahmed, B.H., Ibrahim, M.T. and Mantis P. (2011). Prediction of gestational age by transabdominal real-time ultrasonographic measurements in Saanen goats (*Capra hircus*). *Global Veterinaria*. **6**: 346-351.
- Abubakar, F., Kari, A., Ismail, Z., Baba, A.R. and Usman, T.H. (2016). Accuracy of transrectal ultrasonography: In estimating the gestational age of Jamnapari goats. *Malaysian Applied Biology*. **45**: 49-54.
- Airina, R.K.R.I., Nizam, A.R.M., Abdullah, R.B. and Khadijah, W.E.W. (2011). Using fetal-heart size measured from ultrasound scanner images to estimate age of gestation in goat. *Journal of Animal Veterinary Advances*. **10**: 2528-2540.
- Akkus, T., Emre, B. and Yaprakci, O. (2023). Doppler ultrasonography assessment of uterine artery blood flow throughout late pregnancy in awassi ewes. *Animal Health Production Hygiene*. **12**(2): 42-49.
- Amer, H.A. (2008). Determination of first pregnancy and foetal measurements in Egyptian Baladi goats (*Capra hircus*). *Veterinaria Italiana*. **44**: 429-437.
- Amer, H.A. (2010). Ultrasonographic assessment of early pregnancy diagnosis, foetometry and sex determination in goats. *Animal Reproduction Science*. **117**: 226-231.
- Beltrame, R.T., Covre, C., Littig, L.B., de Barros Martins, A., Quirino, C.R., Junior, A.B. and da Costa, R.L.D. (2017). Transrectal doppler sonography of uterine blood flow in ewes during pregnancy. *Theriogenology*. 1-18. doi: 10.1016/j.theriogenology. 2016.12.026.
- Buckrell, B.C. (1988). Application of ultrasonography in reproduction in sheep and goats. *Theriogenology*. **29**: 71-83.
- Curran, S. and Ginther, O.J. (1995). M-mode ultrasonic assessment of equine fetal heart rate. *Theriogenology*. **44**: 609-617. [https://doi.org/10.1016/0093-691X\(95\)00241-Y](https://doi.org/10.1016/0093-691X(95)00241-Y).
- Dhillon S. Navjot, Cheema S. Ranjna, Singhal S. (2020). Proteins and heparin binding proteins of spermatozoa and seminal Plasma in beetal bucks: Purification, characterization and role in *in vivo* Fertility. *Indian Journal of Animal Research*. **55**(4): 394-400. doi: 10.18805/ijar.B-3974.
- Ejaz-ul-Haq, M., Hameed, N., Khan, M.I.R., Abbas, Q., Sohail, T. and Rehman, A. (2020). Temporal changes in physical signs of Oestrous and validation of foetal parameters for estimation of gestational stage through b-mode ultrasonography in Beetal goats. *Pakistan Veterinary Journal*. **40**: 425-30.
- Elmetwally, M.A., Rohn, K. and Meinecke-Tillmann, S. (2016). Noninvasive colour Doppler sonography of uterine blood flow throughout pregnancy in sheep and goats. *Theriogenology*. **85**: 1070-1079.
- Elmetwally, M.H. and Meinecke-Tillmann, S. (2018). Simultaneous umbilical blood flow during normal pregnancy in sheep and goat fetuses using non-invasive colour Doppler ultrasound. *Animal Reproduction*. **15**: 148-155.
- Erdogan, G. (2012). Ultrasonic Assessment During Pregnancy in Goats. *Reproduction Domestic Animal*. **47**: 157-163. 10.1111/j.1439-0531.2011.01873.x ISSN 0936-6768.
- Gonzalez De Bulnes, A., Moreno, J.S. and Sebastian, A.L. (1998). Estimation of foetal development in Manchega dairy ewes by transrectal ultrasonographic measurements. *Small Ruminant Research*. **27**: 243-50.
- Gouda, A.H., Agag, M.A. and Kandiel, M.M.M. (2021). Ultrasound guided fetometry in Egyptian sheep and goats. *Benha Veterinary Medical Journal*. **40**: 114-118.
- Gurler, H. and Kaymaz, M. (2011). Determination of embryonic and fetal age by transrectal and transabdominal ultrasonographic examination in Akkaraman ewes. *Veterinary Journal of Ankara Iversity*. **58**: 99-104.

- James, A.A., Chom, N.D., Fadason, S.T. and Emmanuel, E.G. (2015). Ultrasonographic determination of gestational age in yankasa ewes. *Journal of Veterinary Advances*. **5**: 1169-1175.
- Jyothi, K., Sudha, G., Krishna, K.M., Sahadev, A., Narayana Swamy, M., Rao, S. and Appaiah Kshama, M. (2021). Gestational age estimation and validation using ultrasonic measurements of fetal biparietal diameter and occipito nasal length in nellore brown ewes. *Journal of Animal Research*. **11**: 325-331. doi:10.30954/2277-940X.02.2021.14
- Kahn, W. (2004). Veterinary reproductive ultrasonography. Schlutersche Verlagsgesellschaft, mbH and CO. KG, Hans-Bockler-Allee 7, 30173 Hannover, Germany.
- Kandiel, M.M., Watanabe, G. and Taya, K. (2015). Ultrasonographic assessment of foetal growth in miniature Shiba" goats (*Capra hircus*). *Animal Reproduction Science*. **162**: 1-10.
- Karadaev, M., Fasulkov, I., Stanimir, Y., Atanasova, S. and Vasilev, N. (2018). Determination of gestational age through ultrasound measurements of some uterine and foetal parameters in Bulgarian local goats. *Reprod. Domes. Anim*. **53**: 1456-1465.
- Karadaev, M., Fasulkov, I., Vasilev, N. and Atanasova, S. (2021). The use of ultrasonographic measurement of the heart size and fetal heart rate variation for gestational age determination in local Bulgarian goats. *Veterinary Medicine and Science*. **7(5)**: 1736-1742.
- Karadaev, M., Fasulkov, I., Vassilev, N., Petrova, Y., Tumbev, A. and Petelov. (2016). Ultrasound monitoring of the first trimester of pregnancy in local goats through visualization and measurements of some biometric parameters. *Bulgarian Journal of Veterinay Medicine*. **19**: 209-217. ISSN 1311-1477; doi: 10.15547/bjvm.909.
- Karen, A.M., Fattouh, E.M. and Abu-Zeid, S.S. (2009). Estimation of gestational age in Egyptian native goats by ultrasound foetometry. *Animal Reproduction Science*. **114**: 167-174.
- Kumar, K., Chandolia, R.K., Kumar, S., Jangir, T., Luthra, R.A., Kumari, S. and Kumar, S. (2015). Doppler sonography for evaluation of hemodynamic characteristics of fetal umbilicus in Beetal goats. *Veterinary World*. **8**: 412-416.
- Kuru, M., Oral, H. and Kulaksiz R. (2018). Determination of gestational age by measuring defined embryonic and foetal indices with ultrasonography in Abaza and Gurcu goats. *Acta Veterinaria Brno*. **87**: 357-362.
- Lee, Y., Lee, O., Jongki, C.H.O., Hyunguk, S., Yoonsuk, C., Yonghee, S., Wonil, C., Heejae, S., Doosoo, L., Gwansun, L. and Hanmi. (2005). Ultrasonic measurement of fetal parameters for estimation of gestational age in Korean black goats. *Journal of Veterinary Medical Science*. **67**: 497-502.
- Madhusudhan (2017). Ultrasonographic assessment of embryonic and foetal development in Malabari goats. *M.V.Sc. Thesis*, Kerala Veterinary and Animal Science University, Pookode, Kerala. 75p.
- Martínez-Díaz, S., García-Vázquez, F.A., Luongo, C. and Ruiz, S. (2022). Assessment of arterial flow of the umbilical cord in goat foetuses of the Murciano-granadina race using spectral doppler ultrasonography. *The veterinary Journal*. **36**: 513-941.
- Muhammad, R.S. and Aziz, D.M. (2022). Estimation of gestational age in Shami goats based on transabdominal ultrasonographic measurements of fetal parameters. *Iraqi J. Vet. Sci*. **36**: 839-846.
- Nwaogu, I.C., Anya, K.O., Agada, P.C. (2010). Estimation of foetal age using ultrasonic measurements of different foetal parameters in Red Sokoto goats (*Capra hircus*). *Veterinarski Arhiv*. **80**: 225-233.
- Padilla-Rivas, G.R., Sohnrey, B. and Holtz, W. (2005). Early pregnancy detection by real time ultrasonography in Boer goats. *Small Ruminant Research*. **58**: 87-92.
- Ramírez-González, D., Poto, A., Peinado, B., Almela, L., Navarro-Serna, S. and Ruiz, S. (2023). Ultrasonography of pregnancy in murciano-granadina goat breed. foetal growth indices and umbilical artery doppler parameters. *Animals*. **13**: 618.
- Saeedipannah, A.M., Khoramian Toosi, B., Azzizadeh, M. and Rajabioun, M. (2022). Estimation of gestational age using ultrasonography in Baluchi sheep. *Veterinary Research Forum*. **13**: 257-263.
- Santos, V.J.C., Rodriguez, M.G.K., Da Silva, P.D.A., Mariano, R.S.G., Taira, A.R., De Almeida, V.T. and Vicente, W.R.R. (2018). B-mode ultrasonography and ecobiometric parameters for assessment of embryonic and fetal development in sheep. *Animal Reproduction Science*. **197**: 193-202.
- Serin, G., Gokdal, O., Tarimcilar, T. and Atay, O. (2010). Umbilical artery doppler sonography in Saanen goat foetuses during singleton and multiple pregnancies. *Theriogenology*. **74**: 1082-1087.
- Silva, P., dos Santos, F.C., dos Santos, V.J.C., Uscategui, R.A.R., Padilha Nakaghi, L.C., Mariano, R.S.G., Rodriguez, M.G.K., Amoroso, L., Vicente, W.R.R. and Feliciano, M.A.R. (2022). Doppler sonography of the umbilical and uterine arteries blood flow of pregnant Saanen goats. *Animal Reproduction*. **19(3)**: e20220014.
- Silva, P.D., Santos, F.C.D., Santos, V.J.C., Simoes, A.P.R., Uscategui, R.A.R., Vicente, W.R.R. and Feliciano, M.A.R. (2021). B-mode ultrasound and ecobiometric parameters to assess embryonic and fetal development and estimate gestational age in goats. *Theriogenology*. **175**: 123-133.
- Sudha, C.M., Unnikrishnan, M.P., Kurien, M.O., Abhilash, R.S. and Thirupathy, V. (2019). Doppler ultrasonographic evaluation of uterine torsion in does. *Journal of Veterinary Animal Sciences*. **50(2)**: 125-128.
- Suguna, K.S., Mehrotra, S. K., Agarwal, M., Hoque, S., Singh, K., Shanker, U. and Sarath, T. (2008). Early pregnancy diagnosis and embryonic and fetal development using real time B mode ultrasound in goats. *Small Ruminant Research*. **80**: 80-86.
- Surat, D.R. and Adamson, S.L. (1996). Downstream determinants of pulsatility of the mean velocity waveform in the umbilical artery as predicted by a computer model. *Ultrasound Medical Biology*. **22**: 707-717.
- Vinayak, B. (2015). Uterine artery haemodynamics in singleton and multiple foetal gestation in Malabari goats. *M.V.Sc. Thesis*. Kerala Veterinary and Animal Science University, Pookode, Kerala.
- Yadav, U. (2021). Estimation of gestational age by ultrasonographic measurement of different foetal parameters in goats. *M.V.Sc Thesis*. Chattogram Veterinary and Animal Sciences University, Chattogram, Bangladesh. 50p.
- Yaseen Mahmood, R. (2016). Ultrasonic estimation of gestation age in goats via placentomes diameter. *Iraqi Journal of Veterinary Medicine*. **40**: 100-106.
- Yazici, E., Ozenc, E., Celik, H.A. and Ucar, M. (2018). Ultrasonographic foetometry and maternal serum progesterone concentrations during pregnancy in Turkish Saanen goats. *Animal Reproduction Science*. **197**: 93-105.