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Review article

Ultrasound examination of pregnancy in the domestic goat (*Capra hircus*) - a review

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Ultrasonography (USG) for embryo-foetal foetometry is widely used in the management of goat breeding. Tissues and organs of the embryo/foetus are measured and evaluated to assess gestational age. Transrectal, transabdominal and transvaginal probes are used to perform the ultrasound examination. Technological advances, especially with regard to ultrasound image resolution, enable precise visualization of embryo-foetal structures in goats. The article reviews the foetometric measurements used in ultrasound examination of pregnancy in goats. Performing this examination during specific periods of gestation enables effective monitoring of embryonic and foetal growth and development. In addition to measurements of embryo-foetal structures, measurements of foetal-maternal structures such as the placentomes and umbilical cord are important as well. The role of ultrasound in monitoring goat pregnancy, both normal and pathological, was also emphasized.

KEY WORDS: ultrasound examination, embryo-foetal foetometry, pregnancy, goat

In recent years, ultrasonography has become one of the most important imaging techniques used to manage breeding of small ruminants. It is the preferred diagnostic tool because it is a relatively simple and non-invasive technique (Erdogan, 2012). The main practical applications of ultrasound in breeding of small ruminants are to confirm that mating has successfully resulted in pregnancy and to carry out precise biometric measurements, referred to as embryo-foetal foetometry (Santos et al., 2007; Karen et

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al., 2009; Samir et al., 2016). Available reports describe this diagnostic imaging as one of the most important elements of monitoring pregnancy in goats (Padilla-Rivas et al., 2005; Raja-Khalif et al., 2014). It is a valuable and practical method for monitoring embryonic and foetal development in most mammals, including goats. This paper presents a review of currently used ultrasound measurements of embryonic and foetal structures and their potential practical uses in monitoring the course of pregnancy in goats.

Pregnancy ultrasonography in goats - the most important parameters of embryo-foetal biometry

Ultrasound examination can be used to determine gestational age (GA) based on foetal development and thus to determine the date of parturition (Karen et al., 2009; Raja-Ili Airina et al., 2011). In goats, ultrasound imaging for the purpose of performing foetal biometric measurements is primarily used to assess gestational age (Padilla-Rivas et al., 2005; Raja-Ili Airina et al., 2011; Yazici et al., 2018). Ultrasound foetometry involves measurement of selected anatomical structures of the uterus and embryo/foetus, as well as assessment of foetal growth in successive stages of gestation.

Foetometric measurements include the following parameters:
– uterine lumen diameter – ULD (Karadaev et al., 2016)
– crown-rump length – CRL (Kumar et al., 2015b; Rasheed, 2017)
– trunk diameter – TD (Kumar et al., 2015b)
– biparietal diameter – BPD (Roukbi, 2013)
– foetal orbit diameter – OD (Kandiel et al., 2015)
– heart longitudial (long) axis – HLA (Karadaev et al., 2016)
– heart transverse (short) axis) – HTA (Lee et al., 2005; Karadaev et al., 2016)
– foetal heart rate – FHR (Karen et al., 2009; Karadaev et al., 2016)
– chest diameter – CD (Kandiel et al., 2015)
– femur length – FemL (Kandiel et al., 2015, Zongo et al., 2018)
– tibia length – TL (Kandiel et al., 2015, Zongo et al., 2018)
– humerus length – HL (Abdelghafar et al., 2012)
– length of six thoracic vertebrae – L6TV (Kandiel et al., 2015)
– length of six lumbar vertebrae – L6LV (Kandiel et al., 2015)
– occipitonasal length – ONL) (Kandiel et al., 2015)
– inner placentome diameter – IPD (Karadaev et al., 2016)
– outer placentome diameter – OPD (Roukbi, 2013)
– umbilical cord diameter (UCD) and diameter of umbilical vessels (Lee et al., 2005)
– aortic diameter – AD (Karadaev et al., 2018)

Preparation of the female goat and ultrasound examination techniques

Early detection of pregnancy in goats is performed using brightness mode (B-Mode) ultrasonography in real time. The presence of a fertilized egg with an embryo and amnio-

tic fluid together with observation of the embryonic heartbeat clearly confirm pregnancy in ultrasound imaging during this period (Raja-Ili Airina et al., 2011; Samir et al., 2016; Anya et al., 2017). B-mode ultrasonography presents echogenicity specific to individual embryo-foetal structures in the form of images with darker or lighter areas (Kharche and Kouamo, 2015). Linear high-frequency probes used in early pregnancy diagnosis allow for precise imaging of individual foetometric parameters in transrectal examination (Kumar et al., 2015a). In goats, ultrasound foetometry can be performed using transrectal probes generating ultrasonic waves with a frequency of 5 to 10 MHz (Kumar et al., 2015a). Transabdominal probes with frequencies from 3.5 to 5 MHz (Raja-Ili Airina et al., 2011; Samir et al., 2016) and transvaginal probes with frequencies from 5 to 7.5 MHz may be used as well (Koker et al., 2012, Philip et al., 2017). During the ultrasound examination, pregnant females may stand (Koker et al., 2012), sit, or lie on their backs (Vinoles-Gil et al., 2010). For examination with a transrectal probe, first the faeces are removed from the rectum, and then a gel-coated ultrasound probe is inserted. The head of the probe is placed against the abdomen and its position is adjusted until the bladder becomes visible. At that time the uterine horns appear in the ultrasound image in the cranial position. Then, by moving the probe backward and forward and rotating it 90° to the right and left, the other elements of the reproductive system can be examined (Raja--Khalif et al., 2014; Samir et al., 2016).

For transabdominal ultrasound examination, the hair of the goat should be cut short on an area of 100-200 cm^2 on the right side just above the lower abdomen. The examination is then performed by guiding the probe head placed on this region of the skin (Suguna et al., 2008).

Transvaginal ultrasound in goats is usually performed in a standing position. The probe is coated with ultrasound gel and gently inserted into the vagina. First, the head of the probe is positioned dorsally at a 45° angle, and then moved forward cranially. By further rotating the head 90°, the reproductive system of the goat is visualized. To optimize the ultrasound image, the abdominal wall may be gently raised (Koker et al., 2012; Philip et al., 2017).

Ultrasound biometric features of the embryo and foetus in goats

Gestational age is estimated on the basis of measurements of embryonic and foetal structures obtained from ultrasound images. Determining gestational age by ultrasound foetometry has become a useful method in management of goat breeding, especially when the exact date of mating is unknown (Kandiel et al., 2015; Samir et al., 2016; Jones and Reed, 2017). Depending on the stage of pregnancy, different foetometric parameters can be visualized and measured.

In goats, pregnancy lasts about 150 days and can be divided into three trimesters. The first trimester lasts up to the 49th day of pregnancy, the second lasts from days 50 to 100, and the third begins on the 101st day of pregnancy (Karadaev et al., 2018). In the ultrasound image, pregnancy is confirmed by the presence in the uterus of anechoic amniotic

fluid in the fertilized egg and a hyperechogenic embryo (Suguna et al., 2008; Raja-Ili Airina et al., 2011; Raja-Khalif et al., 2014).

Sometimes it is also possible to visualize the embryonic heartbeat and to perform biometric measurements of the heart (Raja-Ili Airina et al., 2011; Mali et al., 2019). In goats, this type of examination can be performed from the 21st day of gestation (Suguna et al., 2008), and according to some authors as early as the 15th day of gestation (Yazici et al., 2018).

Uterine lumen diameter

The uterine lumen diameter is one of the first foetometric measurements taken during obstetric examination of goats. It can be measured from the 21st day of gestation until the end of the first trimester (Karadaev et al., 2016). The examination is performed by determining the maximum transverse diameter of the uterus on the ultrasound image (Martinez et al., 1998). In the later stages of pregnancy, uterine lumen diameter is measured in the embryonic region (Karadaev et al., 2016; Karadaev et al., 2018).

Crown-rump length

In the early stages of pregnancy, the structures of the embryo are not yet differentiated. In this case, crown-rump length is defined as the length of the entire embryo/foetus (Karadaev et al., 2018). In the later stages of gestation, CRL is measured from the top of the foetal skull to the end of the sacrum (Abdelghafar et al., 2007; Roukbi, 2013; Pati et al., 2016). When the foetus is in a curved position, crown-rump length is measured first from the head to the heart, and then from the heart to the end of the sacrum (Abdelghafar et al., 2011; Karadaev et al., 2018). CRL in goats can be measured from the 21st to the 49th day of gestation (Karadaev et al., 2018). Some authors, however, have shown that this parameter can be measured in the goat foetus as early as day 19 of gestation, and in the later stages of foetal development up to day 75 (Kuru et al., 2018). Table 1 presents CRL measurements in goats taken at various times during pregnancy.

Biparietal diameter, foetal orbit diameter, and occipitonasal length

During ultrasound examination in the first trimester of pregnancy in goats, it is also possible to determine the biparietal diameter of the foetal head. The cross-section of this structure should be visualized in the ultrasound image, because image of the foetal head in this projection must be symmetrical to enable an accurate and reliable measurement (Lee et al., 2005). BPD measurement is performed on the visualized closed contour of the skull and both well visualized eye orbits (Lee et al., 2005). Next, BPD length is measured from the outer to the inner surface of the upper part of the skull (Amer, 2008; Karadaev et al., 2018). In the ultrasound image of the foetal head, in addition to the biparietal diameter, it is also possible to measure the foetal orbit diameter and occipitonasal length. Accurate measurement of the foetal orbit diameter requires lateral visualization of the head so that the orbit is visible on the ultrasound image in

Table 1

Crown-rump length determined by ultrasound in the first and second trimester of pregnancy in goats of different breeds

Day of gestation	Crown-rump length (mm)	Breed	Author
19	5.3	Anglo-Nubian	Martinez et al., 1998
21	4.8	Bulgarian	Karadaev et al., 2018
	5,2	Bulgarian	Karadaev et al., 2016
	7	Shiba	Kandiel et al., 2015
25	12	Damascus	Karenet al., 2009
30	16	Gürcü	Kuru et al., 2018
	17	Abaza	
35	23	Saanen	Abdelghafar et al., 2011
	27.82	Osmanabadi	Pati et al., 2016
37	33	Jamnapari	Abubakar et al., 2016
40	35.9	Damascus	Amer, 2008
46	34.4	Saanen	Abdelghafar et al., 2007
60	65	Abaza	Kuru et al., 2018
	72	Gürcü	
75	92	Abaza	Kuru et al., 2018
	99	Gürcü	

the form of a spherical structure with a pronounced closed hyperechogenic contour (Lee et al., 2005; Nwaogu et al., 2010; Karadaev et al., 2018). Occipitonasal length is defined as the distance between the top of the head and the tip of the nose (Yazici et al., 2018). BPD (Table 2) in goats can be determined from the 30th day of gestation (Karen et al., 2009], and ONL from the 37th day (Yazici et al., 2018). Foetal orbit diameter in goat foetuses can usually be determined at about the 49th day of gestation (Karadaev et al., 2016), although some authors suggest that earlier imaging is possible (Kandiel et al., 2015; Yazici et al., 2018). Variation in the time when OD measurements can be made may be due to differences in the characteristics of specific breeds (Table 2).

Table 2

Biparietal diameter, occipitonasal length and orbit diameter of the foetus determined by ultrasound in the first and second trimester of pregnancy in goats of different breeds

Foetal biometric parameter	Day of gestation	Measurement (mm)	Breed	Author
BPD	37	7	Saanen	Yazici et al., 2018
	40	11.9	Damascus	Amer, 2008
	42	9.4	Bulgarian	Karadaev et al., 2016
		9.9	Bulgarian	Karadaev et al., 2018
	46	11.6	Saanen	Abdelghafar et al., 2007
	57	20	Sokoto	Nwaogu et al., 2010
OD	42	3	Shiba	Kandiel et al., 2015
	44	4	Saanen	Yazici et al., 2018
	49	6.5	Bulgarian	Karadaev et al., 2016
		6.4	Bulgarian	Karadaev et al., 2018
	57	6	Sokoto	Nwaogu et al., 2010
	60	9,5	Korean Black	Lee et al., 2005
ONL	37	10	Saanen	Yazici et al., 2018
	42	13.37	Shiba	Kandiel et al., 2015
	57	5	Sokoto	Nwaogu et al., 2010

BPD – biparietal diameter; OD – orbit diameter; ONL – occipitonasal length

Foetal trunk diameter and chest diameter

The foetal trunk is also analysed during ultrasound examination of pregnancy in goats (Table 3). Its diameter (TD) is determined in lateral imaging as the maximum length measured from the spine through the abomasum to the abdominal wall (Karadaev et al., 2016; Karadaev et al., 2018). Kandiel et al. (2015) define the trunk diameter as the diameter measured at the height of the stomach and liver or the entry of the umbilical cord to the

foetus. In the ultrasound image, TD measurements in goats are performed in the transverse or sagittal plane (Gosselin et al., 2018). The first TD measurement can be made from the 28th day of gestation (Karadaev et al., 2016).

The chest is another element of the ultrasound examination of the foetus in goats. Its diameter (CD) is defined as the distance between the ventral and dorsal border of the thoracic cavity, at the height of the centre of the heart (Kandiel et al., 2015). CD measurement can be performed from the 37th day of gestation (Yazici et al., 2018).

Table 3
Diameter of the trunk and chest determined by ultrasound in the first trimester of pregnancy in goats of different breeds

Foetal biometric parameter	Day of gestation	Measurement (mm)	Breed	Author
TD	28	6.8	Bulgarian	Karadaev et al., 2016
		7.1	Bulgarian	Karadaev et al., 2018
	40	12	Damascus	Karen et al., 2009
	42	16.32	Shiba	Kandiel et al., 2015
CD	37	10	Saanen	Yazici et al., 2018
	4	10.93	Shiba	Kandiel et al., 2015

TD – trunk diameter; CD – chest diameter

Foetal heart rate and the heart transverse (short) and longitudinal (long) axis

As the pregnancy develops, changes are observed in the echogenicity of the embryonic/foetal heart. These changes can be seen in the varied greyscale typical of B-mode ultrasound imaging of the structures forming the heart of the embryo/foetus (Raja-Ili Airina et al., 2011). Until the 30th day of gestation, the foetal heart is highly echogenic, which is seen in the ultrasound image as a distinct white colour. Between weeks 4 and 8, the echogenicity of this organ decreases, as seen in the whitish-grey colours of the ultrasound images. Between 8 and 12 weeks of gestation in goats, the foetal heart is seen as a clearly outlined grey shape. From weeks 12 to 16 it is greyish-black, and around the 21st week it appears black in ultrasound images (Raja-Ili Airina et al., 2011). According to Anya et al. (2017), imaging of the embryonic heartbeat in goats is first possible from the 23rd day of gestation, and its frequency can be measured from the 25th day of gestation (Karen et al., 2009). In

this case, simultaneous recording in M-mode (motion mode) is used. In this technique, the onset or more often the peak of the contraction serves as an indirect timestamp of the corresponding electrical event (Dancea et al., 2000). Therefore, FHR is measured as the distance between systolic waves and then calculated automatically by the software of the ultrasound apparatus (Karadaev et al., 2016).

The longitudinal (long) and transverse (short) axes of the foetal heart (Table 4) should be measured in the diastolic phase while the foetus is not making any movements of its own. The measurement is performed in cross-section and in a four-chamber view of the heart (Lee et al., 2005). The longitudinal and transverse axes of the foetal heart can be measured from the 42nd day of gestation (Karen et al., 2009).

Table 4
Longitudinal and transverse axis of the heart determined by ultrasound in the first and second trimester of pregnancy in goats

Foetal biometric parameter	Day of gestation	Measurement (mm)	Breed	Author
HTA	42	3	Shiba	Kandiel et al., 2015
	44	3	Saanen	Yazici et al., 2018
	49	4.4	Bulgarian	Karadaev et al., 2016
	60	7.4	Korean Black	Lee et al., 2005
HLA	42	5	Shiba	Kandiel et al., 2015
	49	6.1	Bulgarian	Karadaev et al., 2016
	60	10.4	Korean Black	Lee et al., 2005

HTA – Transverse axis of heart; HLA – Longitudinal axis of heart

Femur, tibia, and humerus length

In the second trimester of pregnancy in goats, more foetal anatomical structures are subjected to ultrasound examination. The length of the femur and tibia can be measured at this time. In the ultrasound image, the foetal limbs should be visible in a longitudinal cross--section, so they can be measured from one end of the femoral and tibial shaft to the other (Kandiel et al., 2015). In measuring the length of the humerus, imaging of the foetal heart

and scapula is helpful. The humerus is then measured according to zones of intense calcification (Abdelghafar et al., 2012). The first FemL, TL and HL measurements in goat foetuses can be made from the 56th day of gestation (Abdelghafar et al., 2012; Kandiel et al., 2015).

Also from the 8th week of gestation in goats, ultrasound foetometry can be used to measure the length of six thoracic vertebrae and six lumbar vertebrae (Kandiel et al., 2015).

Umbilical cord diameter and foetal aortic diameter

Ultrasound foetometry also includes measurements of the diameter of the umbilical cord (Table 5) and umbilical vessels (Lee et al., 2005). In goats, umbilical vessels are represented by two arteries and two veins (Kumar et al., 2015c; Elmetwally and Meinecke-Tillmann, 2018). UCD measurement is performed when the umbilical cord and the foetus are visible in the ultrasound image at the same time. Umbilical cord diameter can be measured in two places: at the entry to the foetus and at a distance of one centimetre from the entry (Lee et al., 2005; Yazici et al., 2018). Umbilical vessels should be measured in a perpendicular projection (at maximum magnification) and where

Table 5
Diameter of the umbilical cord and aorta determined by ultrasound in the first and second trimester of pregnancy in goats of different breeds

Foetal biometric parameter	Day of gestation	Measurement (mm)	Breed	Author
UCD	30	2.5	Damascus	Karen et al., 2009
	42	3.18	Shiba	Kandiel et al., 2015
	51	3.8	Saanen	Yazici et al., 2018
	56	6	Saanen	Abdelghafar et al., 2011
	57	4	Red Sokoto	Nwaogu et al., 2010
	60	3.4	Korean Black	Lee et al., 2005
AD	60	2.2	Korean Black	Lee et al., 2005
	77	3.2	Bulgarian	Karadaev et al., 2018

UCD – umbilical cord diameter; AD – aortic diameter

the umbilical cord is closest to the foetus. In this way, differences in diameter occurring along the length of the umbilical cord are taken into account (Lee et al., 2005; Kandiel et al., 2015). The first measurements of the umbilical cord can be made from the 30th day of gestation (Karen et al., 2009).

In goats between 60 and 135 days of gestation, the aortic diameter of the foetus can be measured (Table 5). The measurement is taken in a cross-section of the foetal aorta, along the longitudinal axis of the left ventricle, when the foetus is not making any movements on its own (Lee et al., 2005; Karadaev et al., 2018).

In ultrasound examination of pregnancy development, in addition to determining the biometric features of embryos and foetuses, it is also very important to make precise measurements of extra-foetal structures. The placenta is the organ that should be analysed to assess the course of the pregnancy.

In pregnant goats, the placenta is perceived as a concave structure with a round shape. In the ultrasound image, it appears as a grey image in the shape of the letter C or O, depending on the imaging plane (Rasheed, 2016). This is a characteristic image ascribed to placentomes, whose size in ultrasound imagine is determined by measuring two diameters. The first is the outer placentome diameter, between its two most distal parts

Table 6
Diameter of the placentomes determined by ultrasound in the first and second trimester of pregnancy in goats of different breeds

Foetal biometric parameter	Day of gestation	Measurement (mm)	Breed	Author
OPD	27	3	Damascus	Roukbi, 2013
	30	4	Saanen	Yazici et al., 2018
	35	7.5	Saanen	Rasheed, 2016
	42	9.3	Bulgarian	Karadaev et al., 2016
	57	14	Sokoto	Nwaogu et al., 2010
	60	14.7	Korean Black	Lee et al., 2005
IPD	42	3.8	Bulgarian	Karadaev et al., 2016
		3.5	Bulgarian	Karadaev et al., 2018

OPD – outer placentome diameter; IPD – inner placentome diameter

(Nwaogu et al., 2010; Karadaev et al., 2016), while the inner diameter is located in the anechoic part of the placentome (Karadaev et al., 2016). To obtain accurate measurements, it is necessary to measure the placentomes located near the foetus and to use the arithmetic mean of the measurements (Lee et al., 2005; Karadaev et al., 2018). In goats, the placentome diameters can first be measured from about the 30th day of gestation (Roukbi, 2013; Rasheed, 2016; Yazici et al., 2018) – Table 6.

Conclusions

The information presented here indicates that ultrasonography is a helpful diagnostic tool in management of reproduction in goats. The use of linear high-frequency ultrasound probes can confirm pregnancy at an early stage of its development. The most foetal biometric measurements can be made in the early and middle periods of gestation.

Implementation of this technique in practice allows tests to be performed in cyclic repetitions in the same embryos/foetuses. This is crucial for monitoring the growth and development of embryo-foetal and extra-foetal structures at every stage of pregnancy, both normal and pathological. The data presented in this study show that ultrasound provides an accurate and non-invasive way to monitor pregnancy in goats. Moreover, technological advances in the field of ultrasonography continue to improve mainly image resolution, which allows more accurate imaging of more details of the goat embryo and foetus, especially those of very small size.

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