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RESEARCH ARTICLE

Early Pregnancy Diagnosis and Fetometry Using B-Mode Real-Time Ultrasonography in Damascus Goats in Sudan

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Abstract

This study evaluated the accuracy of real-time B-mode ultrasonography for early pregnancy diagnosis and established gestational age prediction equations in Damascus (Shami) goats under Sudanese conditions. Twenty-four non-pregnant Damascus does (12–55 months; 40–65 kg) were synchronized with $PGF_2\alpha$ and naturally mated. Transrectal ultrasonography (3.5–7.5 MHz) was performed from day 18–25 post-mating for pregnancy diagnosis, followed by weekly transabdominal scanning (2.5–5.5 MHz) from day 35–102 for fetal biometry. Crown-rump length (CRL), biparietal diameter (BPD), placentome diameter (PD), and umbilical cord diameter (UCD) were measured. Pregnancy diagnosis accuracy was 100% (24/24), confirmed at parturition. Singleton and twin pregnancies were identified with 75% and 25% accuracy, respectively. Fetal heartbeat was first detected on day 22. All biometric parameters showed highly significant linear correlations with gestational age ($p < 0.0001$). The derived regression equations were: $GA = 3.874 \times CRL + 28.836$ ($R^2 = 0.96$); $GA = 18.104 \times BPD + 23.989$ ($R^2 = 0.96$); $GA = 17.460 \times PD + 22.669$ ($R^2 = 0.94$); $GA = 77.039 \times UCD + 16.879$ ($R^2 = 0.95$). Mean CRL ranged from 1.60 cm (day 35) to 14.00 cm (day 84); BPD from 1.12 cm (day 44) to 3.82 cm (day 93); PD from 0.83 cm (day 37) to 3.64 cm (day 86); and UCD from 0.56 cm (day 60) to 1.11 cm (day 102). No fetal abnormalities or abortions were observed. Real-time B-mode ultrasonography is a reliable, non-invasive tool for early pregnancy diagnosis and accurate gestational age estimation in Damascus goats using the proposed equations.

Keywords: Damascus Goat, Early Pregnancy Diagnosis, Real-Time Ultrasonography, Fetometry, Crown-Rump Length, Gestational Age.

1. Introduction

Goats play a vital role in the agricultural economy of Sudan, contributing significantly to meat, milk, and hide production. According to FAO (1992), Sudan's goat population exceeds 40.5 million head, comprising mainly indigenous breeds (Nubian, Nilotic, Dwarf, and Tegri) as well as imported breeds and their crosses (Ibrahim, 2000). Among the imported breeds, the Damascus (Shami) goat—native to the Middle East—has gained popularity due to its high milk yield, large body size (65–75 kg adult weight), and prolificacy averaging 1.80 kids per kidding (Abdullah et al., 2012).

Efficient reproductive management is crucial for maximizing productivity in goat herds. Early and accurate pregnancy diagnosis allows farmers to identify non-pregnant animals promptly, reduce inter-kidding intervals, optimize feed allocation, and implement appropriate health management protocols (Ishwar, 1995; Goel and Agrawal, 1992). Traditional methods of pregnancy diagnosis include non-return to estrus, abdominal ballottement, progesterone assay,

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radiography, and ultrasonography (Noakes et al., 2001). However, each method has inherent limitations in terms of accuracy, timing, cost, or practicality under field conditions.

Real-time B-mode ultrasonography has revolutionized reproductive management in small ruminants. It offers a rapid, non-invasive, safe, and highly accurate means of pregnancy diagnosis, fetal counting, viability assessment, and gestational age estimation (Buckrell, 1988; Griffin and Ginther, 1992; Russel and Goddard, 1995). Transrectal ultrasonography using high-frequency linear probes (5–7.5 MHz) enables detection of the gestational sac as early as 18–20 days post-mating in goats (Martinez et al., 1998; Padilla-Rivas et al., 2005), while transabdominal scanning with lower-frequency convex probes (3.5–5 MHz) is more suitable for fetal biometry from mid-gestation onward (Gonzalez-Bulnes et al., 1998).

Fetal biometric parameters commonly used to estimate gestational age include crown-rump length (CRL), biparietal diameter (BPD), placentome diameter (PD), and umbilical cord diameter (UCD). Several studies have established regression equations for these parameters in various goat breeds, including Saanen (Abdelghafar et al., 2011), Egyptian Balady (Karen et al., 2009), Anglo-Nubian (Martinez et al., 1998), Korean Black (Lee et al., 2005), and Red Sokoto (Nwaogu et al., 2010). However, breed-specific fetometric standards for Damascus goats under Sudanese environmental and management conditions remain unavailable. Therefore, the objectives of this study were to evaluate the accuracy of transrectal real-time B-mode ultrasonography for early pregnancy diagnosis (day 18–25) in Damascus goats, as well as determine fetal number and viability using combined transrectal and transabdominal approaches and establish linear regression equations for predicting gestational age based on CRL, BPD, PD, and UCD measurements obtained by transabdominal ultrasonography.

2. Materials and Methods

2.1 Ethical Approval

This study was approved by the Institutional Animal Care and Use Committee (IACUC) of the Faculty of Veterinary Medicine, Al-Butana University (Approval No. ABU/VET/2014/03). All procedures were conducted in accordance with the ethical guidelines for animal experimentation of the Sudanese Ministry of Animal Resources and Fisheries.

2.2 Study Location and Duration

The study was conducted at Al-Nawader Farm, Hilat Kuku, Khartoum North, Sudan, from February to July 2014.

2.3 Experimental Animals

Does were housed in a semi-open shaded pen with concrete flooring *(Fig. 1)*. They were fed fresh alfalfa (*Medicago sativa*) twice daily and supplemented with a concentrate ration (0.5 kg/doe/day) consisting of groundnut cake, wheat bran, sorghum, and molasses. Clean drinking water and mineral blocks were available *ad libitum*.

Figure 1. *Experimental animals (Damascus goats).*

2.4 Estrus Synchronization and Mating

Estrus was synchronized by a single intramuscular injection of 1 mL prostaglandin $F_2\alpha$ ($PGF_2\alpha$, Cloprostenol sodium equivalent). Estrus detection was performed twice daily (morning and evening) using a vasectomized teaser buck. Does exhibiting standing heat were naturally mated twice—on the day of detected estrus (designated as day 0 of gestation) and the following day—using a fertile Damascus buck of proven fertility.

2.5 Ultrasound Equipment

Ultrasonographic examinations were performed using two B-mode real-time scanners:

Scanner A: Digital ultrasonic diagnostic imaging system (BPL US 9601 vet, India) equipped with a 3.5–7.5 MHz linear-array transducer for transrectal (TR) scanning *(Fig. 2A).*

Figure 2A. *Ultrasound scanner.*

Scanner B: ECM full digital ultrasound scanner (France) equipped with a 2.5–5.5 MHz convex-array transducer for transabdominal (TA) scanning *(Fig. 2B).*

Figure 2B. *Ultrasound scanner.*

2.6 Animal Preparation for Ultrasound Scanning

For transrectal (TR) scanning *(Fig. 3),* no special preparation was required other than gentle evacuation of fecal material from the rectum. For transabdominal (TA) scanning *(Fig. 4),* does were fasted for 12 hours to reduce gastrointestinal gas accumulation. The ventral abdominal area (approximately 15–20 cm cranial to the udder) was clipped and shaved, and acoustic coupling gel (Aquasonic®, Parker Laboratories, USA) was liberally applied to ensure adequate skin-transducer contact.

Figure 3. *Transrectal methods.*

Figure 4. *Transabdominal methods.*

2.7 Transrectal Ultrasonography (Days 18–25)

Does were restrained in a standing position. The lubricated TR probe was gently inserted into the rectum and advanced approximately 15 cm until the urinary bladder was visualized. The probe was then slowly rotated and moved cranially to scan the uterine horns. Pregnancy was confirmed by visualization of a fluid-filled anechoic gestational sac, embryo proper, or embryonic heartbeat.

2.8 Transabdominal Ultrasonography (Days 35–102)

From day 35 onward, does were examined in dorsal recumbency using the TA probe. The transducer was placed on the shaved ventral abdomen and moved systematically in a "W" pattern to locate the gravid uterus. Fetal structures were identified, and biometric measurements were recorded.

2.9 Fetal Biometric Measurements

All measurements were taken in centimeters (cm) using the built-in electronic calipers of the ultrasound machine. Each parameter was measured 2–3 times per session, and the mean value was recorded.

2.9.1 Crown-Rump Length (CRL)

CRL was measured as the longest distance from the crown (top of the skull) to the rump (sacral region) in a fully extended fetus *(Fig. 5).* Measurements were taken weekly from day 35 to day 84 of gestation (days 35, 42, 49, 56, 63, 70, 77, and 84).

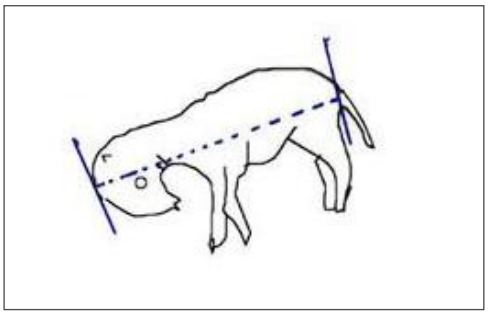

Figure 5. *CRL criteria.*

2.9.2 Biparietal Diameter (BPD)

BPD was measured on a transverse axial plane of the fetal head, visualizing the falx cerebri midline dividing the brain into symmetrical hemispheres, with the lateral ventricles visible on both sides. Measurements were taken from the outer margin of the proximal calvarium to the inner margin of the distal calvarium. Weekly measurements were performed from day 44 to day 93 (days 44, 51, 58, 65, 72, 79, 86, and 93).

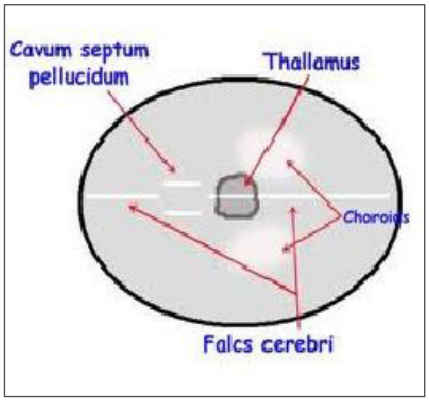

Figure 6. *BPD Criteria.*

2.9.3 Placentome Diameter (PD)

Placentomes were identified as hyperechoic C-shaped or O-shaped structures protruding into the anechoic allantoic fluid. The largest diameter of clearly visualized placentomes was measured weekly from day 37 to day 86 (days 37, 44, 51, 58, 65, 72, 79, and 86).

2.9.4 Umbilical Cord Diameter (UCD)

UCD was measured in a longitudinal section of a straight segment of the umbilical cord, from its placental insertion to its entry into the fetal abdomen. Measurements were taken weekly from day 60 to day 102 (days 60, 67, 74, 81, 88, 95, and 102).

2.10 Confirmation of Pregnancy and Fetal Number

Pregnancy status and fetal number were confirmed at parturition. Gestational length was recorded for each doe.

2.11 Statistical Analysis

Data were entered into Microsoft Excel 2010 and analyzed using SPSS for Windows version 15.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics (mean ± standard deviation) were calculated for each parameter at each gestational age. Simple linear regression analysis was performed to derive equations predicting gestational age (dependent variable, y) from each biometric parameter (independent variable, x):

$$y=a+bx$$

where y= gestational age in days, x= biometric measurement in cm, a= intercept, and b= slope. The coefficient of determination (R^2) was calculated to assess the strength of the linear relationship. Statistical significance was set at $P < 0.05$.

3. Results

3.1 Early Pregnancy Diagnosis

Transrectal ultrasonography successfully detected pregnancy in all 24 does. The gestational sac was first visualized as an anechoic, elongated structure cranial to the urinary bladder on day 18 of gestation *(Fig. 7)*. The embryo proper was identifiable from day 22–25 *(Fig. 8–10)*. Fetal heartbeat was first detected on day 22 of gestation, with a mean rate of 195 ± 15 beats per minute on day 44 *(Fig. 11)*. The overall accuracy of ultrasonographic pregnancy diagnosis was 100% (24/24), confirmed at parturition.

Of the 24 pregnant does, 18 (75%) gave birth to singletons and 6 (25%) gave birth to twins *(Table 1)*. The earliest differentiation of single vs. twin fetuses was possible on day 30 of gestation. All kids were born alive and morphologically normal; no abortions or fetal abnormalities were observed throughout the study. The mean gestational length was 148 ± 2 days.

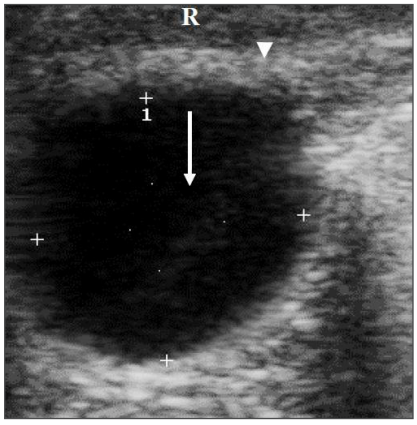

Figure 7. *Ultrasound image of gestational sac (arrow) on day 18 of gestation using transrectal probe. Fluid (F), rectal wall (R), and sac wall (arrowhead) are visible.*

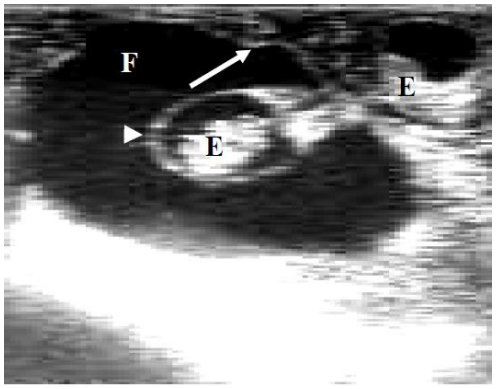

Figure 8. *Ultrasound Image of gestation twins. E=Embryo, F= fluid, uterine wall (arrow) and amnion membrane (arrow head) were detected on day 22 of gestation (early stage) using transrectal probe.*

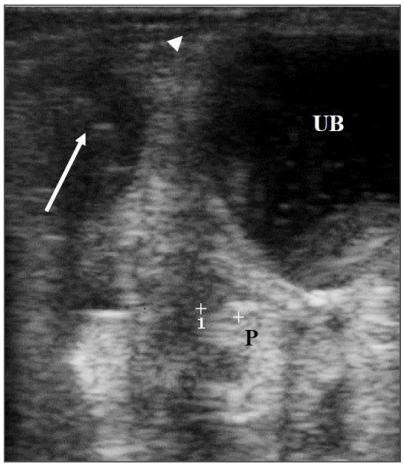

Figure 9. *Ultrasound image of gestational sac (arrow) with urinary bladder (UB) on day 35 of gestation using transrectal probe. P = placentome.*

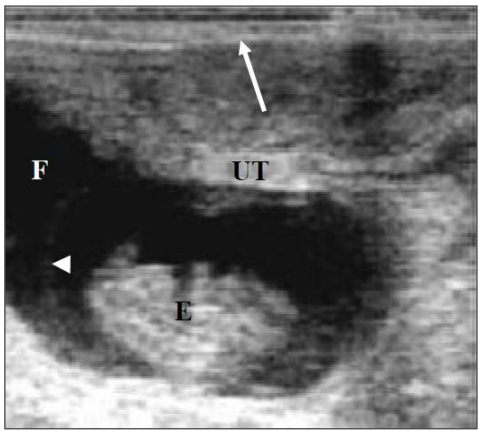

Figure 10. *Ultrasound image of single embryo (E) on day 35 of gestation measuring 1.51 cm CRL using transrectal probe. F = fluid, UT = uterus, using transrectal probe.*

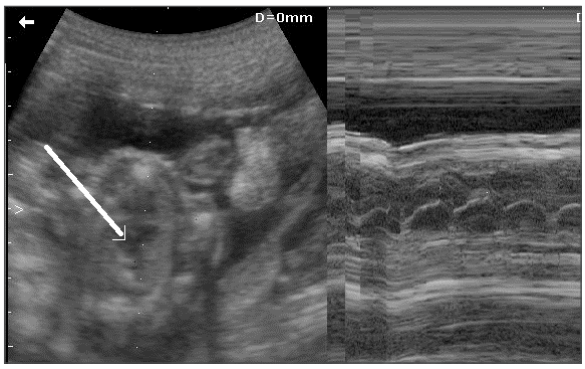

Figure 11. *Ultrasound image of fetal heartbeat (arrow) on day 44 of gestation using transabdominal probe with M-mode. Heart rate: 195 ± 15 beats/min.*

Table 1. *Comparison of fetal number determined by ultrasonography and confirmed at parturition in Damascus goats (n = 24).*

Parameter	Ultrasound Diagnosis	Parturition Outcome
Singleton (S)	18 (75%)	18 (75%)
Twins (T)	6 (25%)	6 (25%)
Triplets or more	0 (0%)	0 (0%)
Total	24 (100%)	24 (100%)

3.2 Crown-Rump Length (CRL)

CRL was measurable from day 35 to day 84 of gestation. The mean CRL increased progressively from 1.60 ± 0.10 cm at day 35 to 14.00 ± 0.30 cm at day 84 *(Table 2)*. Linear regression analysis revealed a highly significant positive correlation between CRL and gestational age ($R^2 = 0.96$, $P < 0.0001$). The derived equation was:

$$\mathbf{GA\ (days) = 3.874 \times CRL\ (cm) + 28.836}$$

Table 2. *Mean (± SD) crown-rump length (CRL) at different gestational ages in Damascus goats.*

Gestational Age (days)	N	CRL (cm) Mean ± SD
35	24	1.60 ± 0.10
42	24	3.40 ± 0.20
49	24	5.40 ± 0.20
56	24	7.20 ± 0.20
63	24	8.85 ± 0.10
70	24	10.70 ± 0.20
77	24	12.45 ± 0.20
84	24	14.00 ± 0.30

3.3 Biparietal Diameter (BPD)

BPD was measurable from day 44 to day 93 of gestation. The mean BPD increased from 1.12 ± 0.20 cm at day 44 to 3.82 ± 0.20 cm at day 93 *(Table 3; Fig. 12 A&B)*. A highly significant linear correlation was found between BPD and gestational age (R^2 = 0.96, $P < 0.0001$). The derived equation was:

GA (days) = 18.104 × BPD (cm) + 23.989

Table 3. *Mean (± SD) biparietal diameter (BPD) at different gestational ages in Damascus goats.*

Gestational Age (days)	N	BPD (cm) Mean ± SD
44	24	1.12 ± 0.20
51	24	1.50 ± 0.20
58	24	1.90 ± 0.10
65	24	2.28 ± 0.10
72	24	2.66 ± 0.20
79	24	3.05 ± 0.30
86	24	3.45 ± 0.20
93	24	3.82 ± 0.20

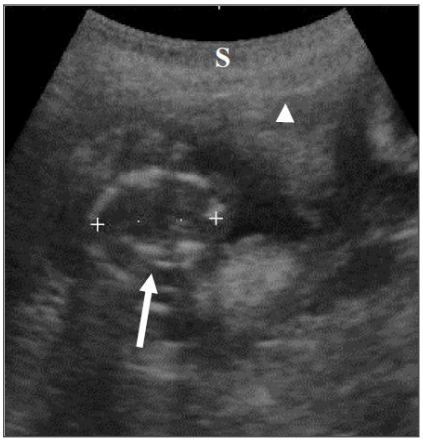

Figure 12A. *Ultrasound image of biparietal diameter (BPD) (arrow), skin (S) and body wall (arrow head) were detected on day 44 of gestation. BPD measuring 1.18 cm (early stage) using transabdominal probe.*

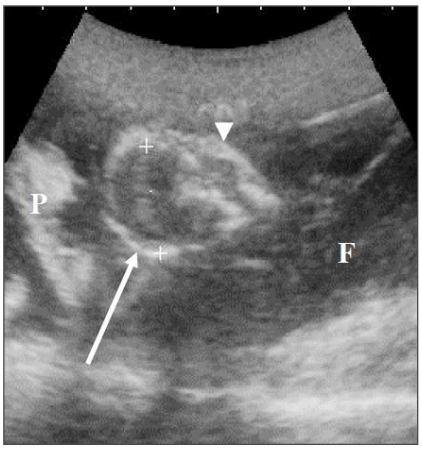

Figure 12B. *Ultrasound image of biparietal diameter (BPD) on day 48 of gestation measuring 1.27 cm using transabdominal probe. Nasal bone (arrowhead) visible.*

3.4 Placentome Diameter (PD)

Placentomes were first detectable on day 28–30 of gestation as small hyperechoic nodules on the endometrial surface. Their diameter increased progressively from 0.83 ± 0.10 cm at day 37 to 3.64 ± 0.10 cm at day 86 *(Table 4; Fig. 13 A&B).* A highly significant linear correlation was observed between PD and gestational age ($R^2 = 0.94$, $p < 0.0001$) *(Fig. 14 A&B).* The derived equation was:

GA (days) = 17.460 × PD (cm) + 22.669

Table 4. *Mean (± SD) placentome diameter (PD) at different gestational ages in Damascus goats.*

Gestational Age (days)	N	PD (cm) Mean ± SD
37	24	0.83 ± 0.10
44	24	1.24 ± 0.10
51	24	1.65 ± 0.20
58	24	2.05 ± 0.20
65	24	2.45 ± 0.30
72	24	2.83 ± 0.20
79	24	3.24 ± 0.10
86	24	3.64 ± 0.10

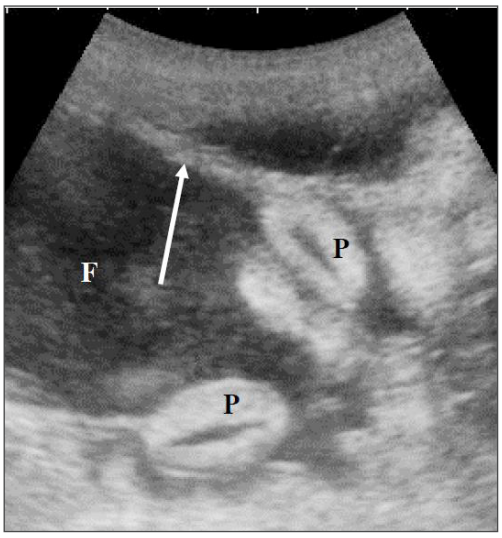

Figure 13A. *Ultrasound image of placentomes (P), F=fluid, and uterine wall (arrow) were detected on day 50 of gestation. PD measuring 1.4cm (mid stage) using transabdominal probe.*

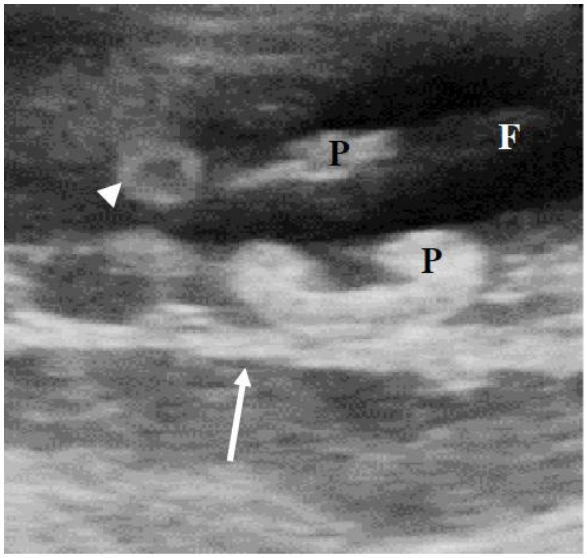

Figure 13B. *Ultrasound image of placentomes (P), F=fluid, and uterine wall (arrow) cross section of placentome (arrow head) were detected on day 52 of gestation. PD measuring 1.6 cm (mid stage) using transrectal probe.*

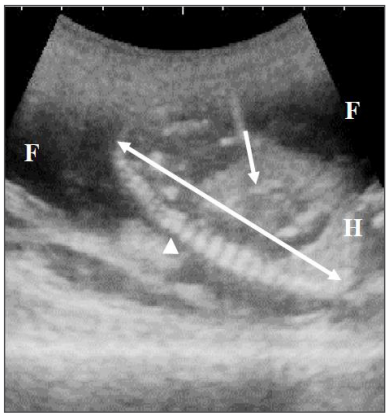

Figure 14A. *Ultrasound image of fetus: F=fluid, H=head, abdomen (arrow) and spinal column (arrow head) were detected on day 52 of gestation. CRL measuring 7.2 cm (mid stage) using transabdominal probe.*

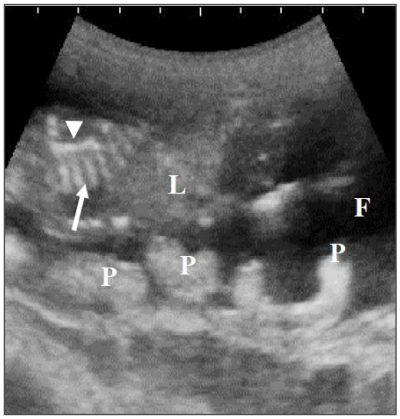

Figure 14B. *Ultrasound image of fetus: F=fluid, P=placentome, L=liver, Ribs (arrow) andhummers (arrow head)were detected on day 60 of gestation (mid stage), using transabdominal probe.*

3.5 Umbilical Cord Diameter (UCD)

UCD was measurable from day 60 to day 102 of gestation. The mean UCD increased from 0.56 ± 0.10 cm at day 60 to 1.11 ± 0.20 cm at day 102 *(Table 5; Fig. 15 A-C)*. A highly significant linear correlation was found between UCD and gestational age (R^2 = 0.95, $P < 0.0001$). The derived equation was:

GA (days) = 77.039 × UCD (cm) + 16.879

Table 5. *Mean (± SD) umbilical cord diameter (UCD) at different gestational ages in Damascus goats.*

Gestational Age (days)	N	UCD (cm) Mean ± SD
60	24	0.56 ± 0.10
67	24	0.66 ± 0.10
74	24	0.75 ± 0.20
81	24	0.84 ± 0.10
88	24	0.93 ± 0.20
95	24	1.02 ± 0.20
102	24	1.11 ± 0.20

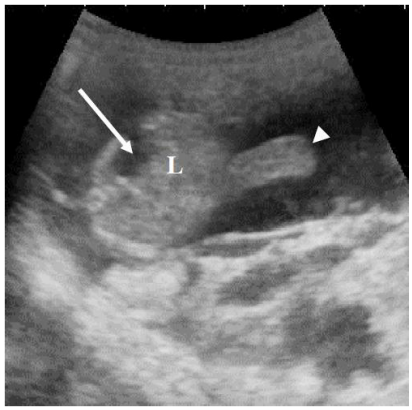

Figure 15A. *Ultrasound image of umbilical cord entering the liver: Umbilical cord (head arrow), L= liver and gall bladder (arrow) were detected on day 67 of gestation. UCD measuring 0.67 cm (mid stage), using transabdominal probe.*

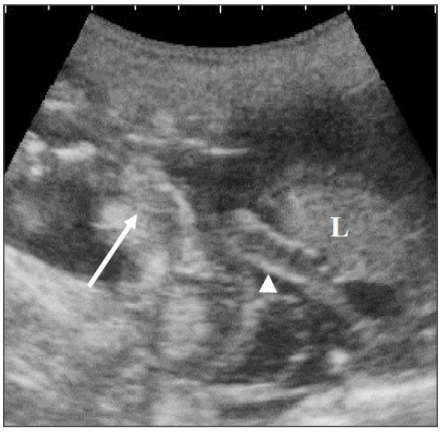

Figure 15B. *Ultrasound image of umbilical cord entering the liver: L=liver, umbilical cord (head arrow) and placentome (arrow) were detected on day 74 of gestation. UCD measuring 0.75 cm (mid stage), using transabdominal probe.*

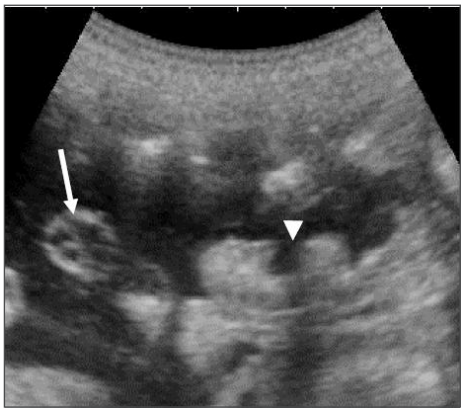

Figure 15C. *Ultrasound image of cross section of umbilical cord: Two arteries and two veins (arrow) and placentome (head arrow) were detected on day 81 of gestation.UCD measuring 0.81 cm using transabdominal probes.*

3.6 Summary of Regression Equations

Table 6 summarizes the regression equations, R^2 values, and measurement ranges for all four biometric parameters.

Table 6. *Summary of gestational age prediction equations for Damascus goats.*

Parameter	Measurement Range (days)	Regression Equation	R^2	p-value
CRL (cm)	35–84	GA = 3.874 × CRL + 28.836	0.96	< 0.0001
BPD (cm)	44–93	GA = 18.104 × BPD + 23.989	0.96	< 0.0001
PD (cm)	37–86	GA = 17.460 × PD + 22.669	0.94	< 0.0001
UCD (cm)	60–102	GA = 77.039 × UCD + 16.879	0.95	< 0.0001

4. Discussion

4.1 Early Pregnancy Detection

The present study demonstrated that transrectal real-time B-mode ultrasonography using a 3.5–7.5 MHz linear probe achieves 100% accuracy in diagnosing pregnancy in Damascus goats as early as day 18 post-mating. This finding is consistent with previous reports in goats. Medan et al. (2004) reported 100% accuracy in Shiba goats using transrectal scanning on day 21, while Gonzalez et al. (2004) achieved 98.7% accuracy in mixed-breed goats. The high accuracy in our study may be attributed to the use of a high-resolution probe and the experience of the operator.

Detection of the gestational sac on day 18 in our study is earlier than the day 20–21 reported by Martinez et al. (1998) in Anglo-Nubian goats and Padilla-Rivas et al. (2005) in Boer goats. This discrepancy may be due to breed differences, probe frequency, or operator skill. The ability to diagnose pregnancy at such an early stage has significant economic implications, allowing early rebreeding or culling of non-pregnant does.

4.2 Fetal Number Determination

The accuracy of fetal number determination in our study was 100% for both singletons (75%) and twins (25%), confirmed at parturition. This contrasts with some studies reporting difficulty in differentiating twins from triplets or quadruplets (Goel and Agrawal, 1992). Karen et al. (2001) noted that accuracy in detecting ewes carrying two or more fetuses was

disappointing. The high accuracy in our study may be explained by the use of a 3.5 MHz transducer, which provides greater penetration depth compared to the 5 MHz transducer used in many earlier studies (Buckrell, 1988).

4.3 Fetal Heartbeat Detection

Fetal heartbeat was first detected on day 22 of gestation, with a mean rate of 195 ± 15 bpm on day 44. This aligns with Martinez et al. (1998), who detected heartbeat on day 21, and Suguna et al. (2008), who reported detection on day 23. Detection of fetal heartbeat is the most reliable indicator of fetal viability and is crucial for confirming pregnancy in doubtful cases.

4.4 Safety of Ultrasonography

Repeated exposure of fetuses to ultrasound waves (3.5 and 6 MHz) throughout gestation did not result in any fetal deaths, abortions, or morphological abnormalities. All kids were born alive and healthy, corroborating the safety profile of diagnostic ultrasound reported by Haibel (1990) and Padilla-Rivas et al. (2005).

4.5 Crown-Rump Length (CRL)

CRL showed a strong linear relationship with gestational age ($R^2 = 0.96$), consistent with findings in other goat breeds. Abdelghafar et al. (2011) reported $R^2 = 0.90$ for CRL in Saanen goats, while Karen et al. (2009) found $R^2 = 0.94$ in Egyptian Balady goats. Martinez et al. (1998) reported $R^2 = 0.89$ in Anglo-Nubian goats. The slight variation in R^2 values may be attributed to breed differences, sample size, and measurement intervals. CRL is most reliable during the first half of gestation (up to day 84), after which fetal curling makes accurate measurement difficult.

4.6 Biparietal Diameter (BPD)

BPD also demonstrated a high correlation with gestational age ($R^2 = 0.96$), similar to reports by Haibel (1989) in Toggenburg, Nubian, and Angora goats ($R^2 = 0.975–0.995$) and Reichle (1991) in Pygmy goats ($R^2 = 0.97$). However, Lee et al. (2005) reported a lower correlation ($R^2 = 0.81$) in Korean Black goats, possibly due to longer intervals between measurements or breed-specific skull morphology. In our study, BPD was reliably measurable from day 44 onward, consistent with Haibel's (1989) recommendation that BPD measurement should commence around day 40 for optimal accuracy.

4.7 Placentome Diameter (PD)

PD showed a strong correlation with gestational age ($R^2 = 0.94$), comparable to Suguna et al. (2008) who reported $R^2 = 0.99$ in Indian goats. However, Roukbi (2013) found a lower correlation ($R^2 = 0.83$) in Damascus goats, possibly due to a wider measurement window (days 44–120) compared to our narrower range (days 37–86). Nwaogu et al. (2010) reported an even lower correlation ($R^2 = 0.45$) in Red Sokoto goats, likely due to breed differences and longer measurement intervals (10–15 days vs. 7 days in our study).

4.8 Umbilical Cord Diameter (UCD)

UCD exhibited a high correlation with gestational age ($R^2 = 0.95$), similar to Karen et al. (2009) in Egyptian Balady goats ($R^2 = 0.93$) and Abdelghafar et al. (2011) in Saanen goats ($R^2 = 0.87$). Lower correlations were reported by Gonzalez-Bulnes et al. (1998) in Manchega sheep ($R^2 = 0.77$) and Lee et al. (2005) in Korean Black goats ($R^2 = 0.71$). These differences may be attributed to species, breed, measurement intervals, and operator variability.

4.9 Study Limitations

Despite the promising results, this study has several limitations:

Sample Size: The study included only 24 does. Larger sample sizes would improve the generalizability of the equations.

Single Breed: Only Damascus goats were studied. The equations may not be directly applicable to other goat breeds without validation.

Limited Gestational Window: CRL was measured only up to day 84, BPD up to day 93, PD up to day 86, and UCD up to day 102. Equations for late gestation (day 103–150) were not developed.

Single Operator: All measurements were performed by one operator, introducing potential observer bias.

No Cross-Validation: The derived equations were not validated on an independent group of goats.

Future studies should address these limitations by including larger sample sizes, multiple breeds, extended gestational windows, and cross-validation on independent populations.

5. Conclusion

This study confirms that real-time B-mode ultrasonography is a highly accurate, non-invasive, and safe tool for early pregnancy diagnosis and gestational age estimation in Damascus goats. The key conclusions are: 1) Transrectal ultrasonography achieves 100% accuracy in diagnosing pregnancy from day 18 post-mating. 2) Fetal number (singleton

vs. twins) can be reliably determined with 100% accuracy. 3) Fetal viability can be confirmed by detecting fetal heartbeat from day 22 onward. 4) CRL, BPD, PD, and UCD all exhibit strong linear correlations with gestational age ($R^2 \geq 0.94$). 5) The derived regression equations provide a practical, breed-specific tool for estimating gestational age in Damascus goats under Sudanese conditions.

Future Research Directions

- Validate the derived equations on larger, independent populations of Damascus goats.
- Develop gestational age equations for additional parameters, including gestational sac diameter (first trimester), abdominal circumference, fetal heart rate, and estimated fetal weight.
- Extend the measurement range to cover the entire gestational period (days 105–150).
- Compare the accuracy of different ultrasound modes (B-mode vs. M-mode) for fetal heart rate assessment.
- Evaluate the feasibility of integrating ultrasonography with other reproductive biotechnologies (e.g., artificial insemination, embryo transfer) in farm management programs.

Ethical Statement

This study was approved by the Institutional Animal Care and Use Committee of the Faculty of Veterinary Medicine, Al-Butana University (Approval No. ABU/VET/2014/03). All animal procedures complied with the Sudanese Animal Welfare Act and international guidelines for the care and use of agricultural animals in research.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Author Contributions

Omer Adam Ibrahim Salih: Conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft. **Ayman Ahmed Elzain Elnahas:** methodology. **Hosameldeen Mohamed Husien:** writing – review and editing. **Elsir Abdelhai Babiker Abdelhai:** Supervision, conceptualization, methodology, resources, writing – review and editing. **Ashwag Elnour Ahmed:** Supervision, conceptualization, methodology, resources, writing – review and editing.

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