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Doppler indices of umbilical and uterine arteries in singleton and multiple pregnancies of Malabari goats

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Abstract

The present study evaluated the Doppler indices of the umbilical (UMA) and uterine arteries (UTA) in singleton and multiple pregnancies of Malabari goats. Sixty-eight pregnant goats were categorised into singleton (Group I, n = 32) and multiple pregnancies (Group II, n = 36) based on gestational sac and foetal counts by ultrasonography on day 21, 30, 45 and 60 of gestation. Pulsatility index (PI) and resistance index (RI) of UMA and bilateral UTA were assessed on day 45, 90 and 120 of gestation. In singleton pregnancies, the PI of UMA significantly decreased from 1.91 ± 0.04 to 1.24 ± 0.01, while in multiples it declined from 1.51 ± 0.03 to 1.17 ± 0.02 (P < 0.05). The RI of UMA reduced from 0.81 ± 0.01 to 0.66 ± 0.01 in singletons and from 0.80 ± 0.01 to 0.66 ± 0.01 in multiples (P < 0.05). The significantly higher PI of UMA in singleton pregnancies indicated the influence of foetal number on foeto-placental resistance during the pregnancy in this breed. The PI of left UTA decreased 1.69 ± 0.08 to 1.23 ± 0.01 in singletons and 1.69 ± 0.07 to 1.24 ± 0.01 in multiples. The PI of right UTA reduced from 1.77 ± 0.07 to 1.24 ± 0.02 and 1.78 ± 0.07 to 1.25 ± 0.02 in singleton and multiple pregnancies, respectively. The RI of bilateral UTA also showed a declining trend (P < 0.05) without intergroup differences. All Doppler indices declined with gestational progression, reflecting adaptive haemodynamic changes in Malabari goats.

Keywords: *Umbilical artery, uterine artery, singleton, multiple pregnancy, doppler indices*

Doppler ultrasonography has become a pivotal, non-invasive modality for assessing the maternal and foetal haemodynamics during gestation in small ruminants. It facilitates real-time evaluation of blood flow dynamics, with emphasis on pulsatility index (PI) and resistance index (RI), which serve as reliable indicators of vascular resistance and placental function. Heppelmann *et al*. (2013) emphasised the diagnostic importance of Doppler indices in detecting periparturient complications such as uterine torsion, placental retention and dystocia. Santos *et al*. (2015) reinforced the prognostic value of Doppler ultrasonography in assessing the severity of reproductive disorders and the health status of the dam and foetus. Serin *et al*. (2010) demonstrated the clinical significance of umbilical artery Doppler indices in goats, highlighting the role in monitoring foetal perfusion and viability, especially in multiple pregnancies where compensatory

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mechanisms are critical for foetal survival. Similarly, Elmetwally and Meinecke-Tillmann (2012) reported that umbilical artery Doppler parameters effectively reflected changes in foetoplacental haemodynamics in both normal and high-risk pregnancies in sheep. Nevertheless, comparative studies on uterine and umbilical artery Doppler indices in singleton versus multiple pregnancies in goats remain scarce. Foetal well-being is intricately linked to dynamic circulatory adaptations during gestation. Therefore, continuous doppler monitoring of the maternal-foetal vasculature is vital for the early identification of foetal compromise and for optimising perinatal outcomes. Additionally, this study sheds light on the determination of reference values for doppler indices at various stages of gestation in Malabari goats.

Materials and methods

The experimental group consisted of Malabari goats, including primiparous and pluriparous, with parity levels from 1 to 5, having body condition scores between 2.5- 3.5, and body weight ranging between 27 to 35 kg. The oestrous cycle was synchronised using double prostaglandin injections (Inj. Cloprostenol, 125 µg intramuscular) administered 11 days apart. The goats were subjected to natural service and the day of the last successful mating was considered as day 0 of gestation. Transrectal (TRUS) B-mode ultrasonography was carried out on day 21 of gestation after successful mating to confirm pregnancy. Pregnant goats were categorised into two groups based on number of foetus or gestational sac: Group I (singleton pregnancy, n = 32) and Group II (multiple pregnancy, n = 36). Transabdominal ultrasonography (TAUS) was performed on days 21, 30, 45 and 60 of gestation, further it was confirmed at kidding.

The Doppler index, PI is the difference between peak systolic velocity (PSV) and end diastolic velocity (EDV) of blood flow in a vessel at the level of examination gate. Expressed as PI=PSV-EDV/TAMV (Time averaged mean velocity), whereas RI is calculated as ratio of difference between PSV and EDV to PSV and expressed as, RI = PSV-EDV/PSV. The PI and RI of umbilical artery and the left (LT) and right (RT) uterine arteries were measured in both the groups at different stages of gestation, *viz*. on days 45 (Stage I), 90 (Stage II) and 120 (Stage III) and compared between the groups. The umbilical artery was imaged at an intermediate location along the freely suspended portion of the umbilical cord by TAUS. The uterine artery was identified craniolateral to the urinary bladder using the external iliac artery as a reference *via* TRUS, with its position confirmed by colour Doppler imaging. Rotating the transducer 90° clockwise and counterclockwise allowed visualisation of left and right uterine arteries in cross-section (Beltrame *et al*., 2017). The PI and RI of UMA and UTA were obtained by averaging seven to eight consecutive uniform waveforms and each index was calculated three times (Fig. 1a to 3b). As PI and RI are angle-independent, insonation angle correction was not applied (Elmetwally, 2012). At each gestational stage, singleton *versus* multiple pregnancies were compared using independent t- tests and within the group changes across gestational stages were assessed using repeated measures ANOVA.

Results and discussion

Pulsatility index (PI) of umbilical artery (UMA)

The mean PI values of UMA on days 45, 90 and 120 in singleton pregnancies were 1.91 ± 0.04, 1.45 ± 0.02 and 1.24 ± 0.01, respectively and in multiple pregnancies were 1.51 ± 0.03, 1.29 ± 0.02 and 1.17 ± 0.02, respectively (Table 1). Significant difference (P<0.01) in the mean PI of UMA was found between the groups in all the three stages of gestation with significantly higher PI in singleton pregnancy compared to multiple in Malabari goats. This observation was consistent with the findings of Vinayak (2019), where the PI of the UMA ranged from 2.79±0.13 to 1.60±0.08 in singleton pregnancies and from 2.70±0.10 to 1.37±0.06 in multiple pregnancies between days 30 to 135 of gestation in Malabari goats. The variation in the mean values of UMA PI might be due to the different days of ultrasound examination conducted. In a comparative study of singleton and multiple pregnancies in Karya ewes

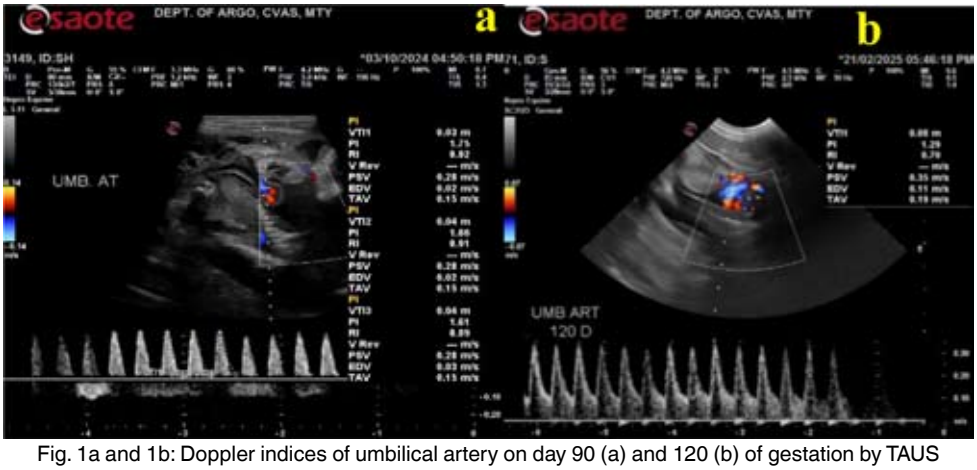

Fig. 1a and 1b: Doppler indices of umbilical artery on day 90 (a) and 120 (b) of gestation by TAUS

Fig. 2a and 2b: Left (a) and right (b) uterine artery in colour Doppler by TRUS on day 90 of gestation

during the first and third trimesters, Erdogan *et al*. (2016) reported a significantly lower mean PI of the UMA in twin pregnancies, specifically on days 40 and 130 of gestation. This reduction in PI reflects enhanced anatomical flexibility and distensibility of the umbilical vessels in multiple foetal gestations. Such vascular adaptations appeared to facilitate the elevated blood flow demands necessary to support multiple foetuses. In singleton pregnancies, the umbilical vessels are less distensible because the circulatory demand is lower. The increased stretchability of the umbilical cord in multiple foetal gestations may prolong the duration of peak systolic velocity (PSV), which in turn, elevates the time-averaged maximum velocity (TAMV) and manifests as a reduced PI in multiple pregnancies.

In the present study, a significant reduction ($P<0.05$) in the PI of the UMA was observed within the group as gestation progressed from the first to the final stage (Fig. 4). This consistent decline in PI indicated a progressive decrease in vascular resistance within the placental circulation, which in turn facilitated an increase in umbilical blood flow to meet the growing metabolic demands of the developing foetus. Similar findings were reported by Serin *et al*. (2010) in Saanen goats, Kumar *et al*. (2015) in Beetal goats, Elmetwally and Meinecke-Tillmann (2018) in German Merino ewes and German Improved Fawn goats and Vinayak (2019) in Malabari goats, where the mean PI values decreased as gestation advanced. This physiological adaptation played a crucial role in enhancing placental perfusion, ensuring the efficient exchange of oxygen and nutrients required for foetal growth during late pregnancy.

However, Silva *et al*. (2022) observed a transient increase in the PI of the umbilical artery between days 63 and 84 of gestation in Saanen goats, followed by a subsequent decline. This temporary elevation was associated with a brief reduction in tissue perfusion during mid-gestation. In addition, their study reported a positive correlation between PI and gestational age ($P<0.05$), indicating dynamic adjustments in umbilical artery haemodynamics throughout the gestational period.

Resistance index (RI) of umbilical artery (UMA)

The mean RI values of UMA on days 45, 90 and 120 of gestation in singleton pregnancies were 0.90 ± 0.01, 0.83 ± 0.01 and 0.75 ± 0.01 respectively and in multiple

Fig. 3a and 3b: Left (a) and right (b) uterine artery in colour Doppler by TRUS on day 120 of gestation

Table 1: Mean umbilical PI and RI values in singleton (GI) and multiple (GII) Malabari goat pregnancies at different stages of gestation

Stages of gestation	UMA PI				UMA RI			
	Group I (n=32)	Group II (n=36)	t value	p value	Group I (n=32)	Group II (n=36)	t value	p value
Stage I (45)	$1.91^{Aa} \pm 0.04$	$1.51^{Ba} \pm 0.03$	**8.07****	**< 0.001**	$0.90^{a} \pm 0.01$	$0.89^{a} \pm 0.01$	1.21^{ns}	0.231
Stage II (90)	$1.45^{Ab} \pm 0.02$	$1.29^{Bb} \pm 0.02$	**5.06****	**< 0.001**	$0.83^{b} \pm 0.01$	$0.82^{b} \pm 0.01$	1.10^{ns}	0.277
Stage III (120)	$1.24^{Ac} \pm 0.01$	$1.17^{Bc} \pm 0.02$	**3.25****	**< 0.002**	$0.75^{c} \pm 0.01$	$0.74^{c} \pm 0.01$	0.78^{ns}	0.437
F value	**191.94****	**56.28****			**75.17****	**82.27****		
P value	**<0.001**	**<0.001**			**<0.001**	**<0.001**		

Means bearing different superscripts within a column (a-c) differ significantly at 5% level and within rows (A-B) at 1% level. ns- non-significant.

Table 2. Mean uterine artery PI values in singleton (GI) and multiple (GII) Malabari goat pregnancies at different stages of gestation

Stages of gestation	LT UTA PI				RT UTA PI			
	Group I (n=32)	Group II (n=36)	t value	p value	Group I (n=32)	Group II (n=36)	t value	p value
Stage I (45)	$1.69^{a} \pm 0.08$	$1.69^{a} \pm 0.07$	0.03	0.974^{ns}	$1.77^{a} \pm 0.07$	$1.78^{a} \pm 0.07$	0.06	0.951^{ns}
Stage II (90)	$1.37^{b} \pm 0.04$	$1.40^{b} \pm 0.03$	0.73	0.468^{ns}	$1.40^{b} \pm 0.05$	$1.41^{b} \pm 0.05$	0.17	0.867^{ns}
Stage III (120)	$1.23^{c} \pm 0.01$	$1.24^{c} \pm 0.01$	0.51	0.613^{ns}	$1.24^{c} \pm 0.02$	$1.25^{c} \pm 0.02$	0.42	0.676^{ns}
F value	**23.72****	**31.25****			**35.26****	**39.11****		
P value	**<0.001**	**<0.001**			**<0.001**	**<0.001**		

Means bearing different superscripts within a column (a-c) differ significantly at 5% level and within rows is non-significant (ns).

Table 3. Mean uterine artery RI values in singleton (GI) and multiple (GII) Malabari goat pregnancies at different stages of gestation

Stages of gestation	LT UTA RI				RT UTA RI			
	Group I (n=32)	Group II (n=36)	t value	p value	Group I (n=32)	Group II (n=36)	t value	p value
Stage I (45)	$0.76^{a} \pm 0.01$	$0.78^{a} \pm 0.01$	1.09	0.279^{ns}	$0.78^{a} \pm 0.01$	$0.79^{a} \pm 0.01$	-0.90	0.373^{ns}
Stage II (90)	$0.73^{b} \pm 0.01$	$0.75^{b} \pm 0.01$	1.39	0.169^{ns}	$0.69^{b} \pm 0.01$	$0.70^{b} \pm 0.01$	-0.58	0.563^{ns}
Stage III (120)	$0.71^{c} \pm 0.01$	$0.72^{c} \pm 0.01$	1.13	0.261^{ns}	$0.63^{c} \pm 0.01$	$0.63^{c} \pm 0.01$	-0.46	0.647^{ns}
F value	**17.58****	**23.79****			**101.21****	**122.35****		
P value	**<0.001**	**<0.001**			**<0.001**	**<0.001**		

Means bearing different superscripts within a column (a-c) differ significantly at 5% level and within rows is non-significant (ns).

pregnancies, 0.89 ± 0.01, 0.82 ± 0.01 and 0.74 ± 0.01, respectively (Table 1). There was no significant difference observed between singleton and multiple pregnancies in different stages of gestation (Fig. 4). Compared to the PI, mean RI values remained more stable throughout the gestation. Vinayak (2019), also observed no significant difference in mean RI of UMA between the singleton and multiple gestations in Malabari goats between 30 to 135 days, which aligned with the current findings. Silva *et al*. (2022) also reported that PI values varied more prominently across gestational stages, while RI showed minimal fluctuation. The stability of RI is due to its reflection of vascular resistance, which is less affected by changes in blood flow volume. In contrast, PI, which incorporates time-averaged maximum velocity (TAMV), is more sensitive to alterations in vessel distensibility and flow dynamics, making it a better indicator of haemodynamic adaptations in multiple pregnancies. However, there was a significant difference ($P<0.05$) noticed between the stages in both the groups, which was consistent with the findings of Nautrup (1998), Serin *et al.* (2010) in Saanen goats, Kumar *et al.* (2015) in Beetal goats, Elmetwally and Meinecke-Tillman (2018) in ewes and Vinayak (2019) in Malabari goats.

In contrast, Erdogan *et al*. (2016) observed that, Karya ewes carrying twin pregnancies exhibited a significantly lower RI of the umbilical artery compared to those with singleton gestations ($P < 0.05$). This reduction in RI further supports the notion that foetal development and umbilical hemodynamics are modulated by both the number of foetuses and the gestational stage. Silva *et al.* (2022) found a negative correlation ($P < 0.001$) between gestational age and the RI of UMA in Saanen goats. On comparing the Doppler index values with the number

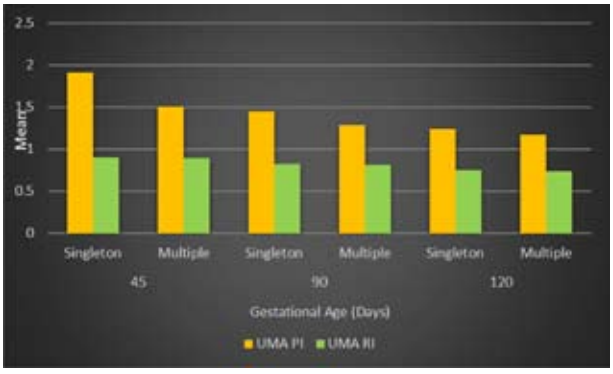

Fig. 4. Umbilical artery PI and RI in different stages of gestation between singleton and multiple pregnancies in Malabari goats

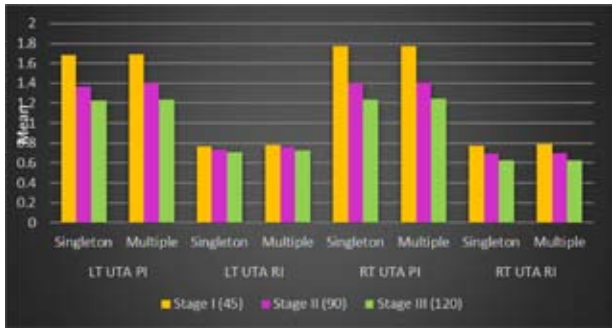

Fig. 5. Uterine artery of PI and RI in different stages of gestation between singleton and multiple pregnancies in Malabari goats

of foetuses per pregnancy, they concluded that the RI obtained was greater (P=0.016) in pregnancies with one or two foetuses than in pregnancies with three or five. This suggests that the higher the number of foetuses, the lower the RI value of UMA.

In the present study, the mean RI of UMA was significantly (P<0.05) decreased as gestation advanced, which was consistent with the findings of Vinayak (2019) and Thomas *et al*. (2023), the mean RI of UMA decreased from 0.88±0.04 to 0.70±0.03 in singleton pregnancies and 0.86±0.03 to 0.67±0.02 in multiple pregnancies in Malabari goats between days 30 to 135 of pregnancy. The progressive decrease throughout gestation may reflect the increasing demand for oxygen and nutrients by the developing foetus. This elevated demand appeared to enhance umbilical blood flow, thereby decreasing vascular resistance and resulting in a reduced RI.

The evaluation of Doppler indices such as the PI and RI of the umbilical artery provides valuable insights into placental perfusion and foetal well-being in prolific Malabari goats. These indices can serve as non-invasive markers to differentiate singleton from multiple pregnancies, assess placental sufficiency, and potentially detect early signs of gestational complications such as placental insufficiency or uterine torsion. Integrating umbilical artery Doppler assessments into routine prenatal monitoring protocols in goats could aid in improving reproductive management and neonatal outcomes in high prolificacy breeds like Malabari.

Pulsatility index (PI) of uterine artery (UTA)

The mean PI of LT and RT UTA in singleton and multiple pregnancy is represented in Table 2. There was no significant difference between singleton and multiple pregnancies in Malabari goats in the mean PI of either LT or RT UTA at any of the stages of gestation (Fig. 5). But a significant difference was observed (P<0.05) from stage I to III in both the groups. A significant reduction in the PI of both left and right UTA highlighted the enhanced blood supply to the uteroplacental unit as the pregnancy progressed. The increase in EDV resulted in decreased PI and RI values (Elmetwally, 2012). This was consistent with findings of Elmetwally *et al.* (2016) in sheep and goats and Beltrame *et al.* (2017) in Santa Ines ewes.

Vinayak (2019) also found such reduction in Malabari goats, in the PI values of RT and LT uterine arteries. The mean PI values of RT UTR reduced from 2.47±0.14 to 0.98±0.03 in singleton and 2.69±0.11 to 0.99±0.03 in multiple foetal gestation during 30 to 135 days of gestation. While the left UTA PI values reduced from 2.57±0.21 to 0.95±0.05 and 2.40±0.16 to 0.95±0.04 in singleton and multiple pregnancies, respectively. At any point during the gestation, there was no discernible difference in the mean RT and LT UTA PI between singleton and multiple gestations. A non-significant difference in the present study might be due to the fact that the side of pregnancy in the goats carrying the singleton pregnancy would have negated the overall statistical result. Beltrame *et al.* (2017) also found no discernible variation in PI of UTA between ewes with singleton and multiple foetal gestations.

Resistance index (RI) of uterine artery (UTA)

The mean RI of LT and RT UTA in singleton and multiple pregnancies is represented in Table 3. There was no significant variation observed in the mean RI in both LT and RT UTA at any of the stages of gestation in both the groups of Malabari goats (Fig. 5). However, there was significant difference in RI of UTA (P<0.001) between the stages in both the groups. This could be because of the rise in EDV and the increased blood flow to foetuses as gestation progressed. This was consistent with the findings of Elmetwally (2012), Elmetwally *et al.* (2016), Beltrame *et al.* (2017) and Vinayak (2019) in various breeds of sheep and goats.

In twin or triplet pregnancies, foetuses were present in both horns, whereas in singletons, the side of gravid could not be identified. Beltrame *et al.* (2017) also observed no discernible difference between singleton and multiple foetal gestations in ewes and opined that the lack of variation between uterine sides to the predominance of

twin pregnancies, where blood flow was evenly distributed to both horns. Akkus *et al.* (2023) determined the changes in uterine artery blood flow of Awassi ewes after the second half of pregnancy and they observed that day 135 had a significantly lower RI value ($P < 0.001$) than days 90, 105 and 120 and concluded that, blood flow through the uterine arteries of Awassi ewes varied significantly after the second half of pregnancy which is in agreement with the present study. The lower RI likely reflects decreased vascular resistance, consistent with the increased demand for nutrient and oxygen exchange in advanced stages of pregnancy.

In a clinical setting, uterine artery Doppler parameters, particularly declining PI and RI, can serve as indicators of healthy gestational progression. Conversely, abnormal or stagnant trends in these indices may signal compromised uterine blood flow, potentially associated with gestational accidents such as uterine torsion, placental insufficiency, or foetal distress. Therefore, serial assessment of UTA Doppler indices offers a promising, non-invasive approach for early detection of uteroplacental dysfunctions and supports more effective management of high-risk pregnancies in prolific breeds like the Malabari goat.

Conclusion

The Doppler evaluation of umbilical and uterine arteries provides a reliable, non-invasive means to assess uteroplacental blood flow and monitor haemodynamic changes during pregnancy. The distinct differences in the mean PI of umbilical artery between singleton and multiple pregnancies highlights the importance for specific foetal surveillance strategies in multiples to ensure optimal growth and early intervention.

The present study also establishes stage specific reference values for Doppler indices of the umbilical and uterine arteries in Malabari goats, highlighting significant gestational trends associated with placental vascular adaptation. The progressive changes in these indices reflects increasing placental perfusion essential for foetal development. These reference ranges not only serve as valuable benchmarks for normal gestation but also offer clinical utility in the early detection of gestational accidents such as uterine torsion or placental insufficiency, enabling timely intervention and improved perinatal outcomes.

Conflict of interest

The authors declare no conflicts of interest.

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