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Effects of oxygen supplementation in ewes subjected to laparoscopic ovum pick-up under total intravenous anesthesia

Efeitos da suplementação de oxigênio em ovelhas submetidas à aspiração de folículos por laparoscopia sob anestesia intravenosa total

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ABSTRACT: Laparoscopy procedures are useful tools to perform some assisted reproductive biotechnologies in ewes, it requires general anesthesia and manoeuvres that might result in alteration of the cardiopulmonary function. For this reason, this study aimed to investigate the effects of oxygen supplementation as a therapeutic measure to mitigate these alterations in ewes submitted to laparoscopic ovum pick-up (LOPU) under total intravenous anesthesia (TIVA). Twenty-four healthy adult ewes were submitted to two LOPUs with a 21 days interval, under ketamine-midazolam anesthesia, and receiving each of the two experimental in random order, oxygen treatment (OT) 50 mL/kg/min of oxygen via endotracheal tube and control treatment (CT) not receive any inhalation treatment. Heart rate (HR), respiratory rate (f_R), peripheral oxygen saturation (SpO_2), mean arterial pressure (MAP), rectal temperature (RT), end-tidal CO_2 concentration ($EtCO_2$) and recovery anesthesia time were evaluated during LOPU, arterial blood gases and electrolytes were evaluated after induction of anesthesia and at the end of the LOPU. Variables were compared between groups and moments using ANOVA. MAP, SpO_2, PaO_2, SaO_2 and pH were higher in OT, while $EtCO_2$, $PaCO_2$, temperature loss and recovery time were lower. These results allow to conclude that oxygen supplementation in ewes submitted to LOPU under TIVA provides benefits in order to mitigate physiological alterations.

KEYWORDS: Biotechnology; hypercapnia; hypoxia; ketamine.

RESUMO: Os procedimentos de laparoscopia são ferramentas úteis para realizar algumas biotecnologias de reprodução assistida em ovelhas, requer anestesia geral e manobras que podem resultar em alteração da função cardiopulmonar. Por esse motivo, este estudo teve como objetivo investigar os efeitos da suplementação de oxigênio como medida terapêutica para atenuar as alterações em ovelhas submetidas à Aspiração Folicular guiada por Laparoscopia (LOPU) sob anestesia venosa total (TIVA). Vinte e quatro ovelhas adultas saudáveis foram submetidas a duas LOPUs com intervalo de 21 dias, sob anestesia com cetamina-midazolam, recebendo cada um dos dois experimentos em ordem aleatória, tratamento com oxigênio (OT) 50 mL/kg/min de oxigênio via tubo endotraqueal e tratamento de controle (CT) não recebem nenhum tratamento por inalação. Frequência cardíaca (FC), frequência respiratória (FR), saturação periférica de oxigênio (SpO_2), pressão arterial média (PAM), temperatura retal (TR), concentração expirada de CO_2 ($EtCO_2$) e tempo de recuperação da anestesia foram avaliados durante LOPU, arterial gasometria e eletrólitos foram avaliados após a indução da anestesia e ao final da COL. As variáveis foram comparadas entre grupos e momentos por meio de ANOVA. PAM, SpO_2, PaO_2, SaO_2 e pH foram maiores no TO, enquanto $EtCO_2$, $PaCO_2$, perda de temperatura e tempo de recuperação foram menores. Estes resultados permitem concluir que a suplementação de oxigênio em ovelhas submetidas a LOPU sob TIVA proporciona benefícios no sentido de atenuar as alterações fisiológicas.

PALAVRAS-CHAVE: Biotecnologia; hipercapnia; hipóxia; cetamina.

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INTRODUCTION

Ewes were probably the first livestock animal to be domesticated (ZEDER; HESSE, 2000) and specially in Brazil is a great alternative with strong potential for socioeconomic development. In this context, reproductive biotechnologies become essential to promote adequate productivity of herds (BASSO et al., 2008). Among reproductive biotechnologies applied to small ruminants, artificial insemination and embryo transfer stand out, due to the positive impact that promotes in the reproductive and genetic improvement. However, the anatomical peculiarity of the cervix in ewes makes transvaginal application of these biotechnologies almost impossible (VARAGO et al., 2009), and for this reason, laparoscopy appeared as an alternative for its application, resulting in higher reproductive rates (CORDEIRO et al., 2014; FONSECA et al., 2014).

Laparoscopy promotes tissues trauma and consequently requires adequate anesthetic/analgesic management to ensure animal welfare during and after procedure; it is also necessary to position the animals in dorsal decubitus, with head-down inclination (Trendelenburg position) and the abdominal cavity has to be inflated with carbon dioxide (capnoperitoneum) in order to better visualize and manipulate the genitourinary organs (ISHIZUKA et al., 2000). These manoeuvres are associated with considerable cardiopulmonary depression in ewes, due to anesthetic effects (ODEBERG et al., 1998) and to abdominal organs cranial displacement causing diaphragm and great vessels overpressure (BRASESCO et al., 2002; TEIXEIRA et al., 2011; WIECZOREK et al., 2010). It is important to note that general anesthesia decreases immune response to stress during laparoscopy, helping to minimize aforementioned side effects. However, in most cases, these procedures are performed in the field, only under deep sedation, without appropriated physiological monitoring and/or oxygen supplementation (LIJIAN et al., 2008; TEKIN; EVRUKE; DEVECI, 2009).

With these precepts, we hypothesized that oxygen supplementation during laparoscopic ovum pick up (LOPU) under total intravenous anesthesia (TIVA) in ewes is a therapeutic measure that mitigates the adverse effects arising from these procedures, allowing a better surgical recovery. Considering that in this regard to the authors acknowledgement no reports were found in the literature, this study was considered relevant in an attempt to provide information that can improve the health and animal welfare. Therefore, in this study we evaluated the cardiopulmonary changes derived from the LOPU under TIVA in ewes supplemented or not with oxygen.

MATERIAL AND METHODS

This study followed the guidelines of the Brazilian Council for Control of Animal Experimentation, was approved by the Institutional Ethics Committee (002478/11) and were conducted in Jaboticabal, SP, Brazil. Twenty-four multiparous Santa Inês adult ewes (3.1 ± 1.1 years old) were used in this study. They were considered healthy by normality at physical examination, blood count, serum alanine-aminotransferase, creatinine and fibrinogen concentration dosages, body weight of 35.1 ± 6.2 kg, and with mean body score of 3 (range 1–5), partially following the previously published methodology of anesthetic study in small ruminants submitted to laparoscopy (CORDEIRO et., 2016). These animals were kept in a suitable sheep fold with adequate feeding conditions and were subjected to two repeated LOPUs with a 21 days interval. Before starting any procedure, the treatments order was randomly drawn (https://www.randomizer.org/) in a crossover design in which each animal received both treatments, control (CT, n = 12) or oxygen (OT, n = 12).

Following feed (36h) and water (12h) fasting, the animals were sedated with the association midazolam 0.25 mg/kg (Dormire, Cristália, Brazil) and tramadol 4.0 mg/kg (Tramadol, Hipolabor, Brazil) intramuscularly (IM). After 15 min, general anesthesia was induced with ketamine 5.0 mg/kg (Dopalen, Sespo, Paulinia, Brazil) intravenously and orotracheal intubation was performed with endotracheal Magill probe. Anesthesia was maintained using ketamine (10.0 mg/kg/h) and midazolam (0.25 mg/kg/h) association, diluted in saline, at variable rate infusion (initial rate 10.0 ml/kg/h of prepared solution), according to the needs to maintain a surgical anesthetic plan, defined by the absence of protective reflexes or motor response to digit clamping or to surgical stimulus. At this moment the oxygen (FiO_2 = 1.0) delivery started through a circular anesthetic circuit at a rate of 50 ml/kg/min in the animals of OT group. The animals of CT group did not receive any treatment by inhalation route.

Once established surgical anesthetic plan, the animals were placed in dorsal decubitus with a 30 to 45-degree head-down inclination ("Trendelenburg"), and the LOPU started, following protocol of Teixeira et al. (2011). Immediately after sedation (0), after anesthesia induction (10) and every 10 minutes until the end of the procedure (20 - 50) the following parameters were measured using a multiparametric monitor (iPM-9800, Mindray, China): heart rate (HR), respiratory rate (f_R), peripheral oxygen saturation (SPO_2), mean arterial pressure (MAP; through a catheter inserted in the caudal auricular artery), rectal temperature (RT) and end-tidal CO_2 concentration ($EtCO_2$; sensor side-stream positioned on the endotracheal tube connection).

After the end of the laparoscopic ovum pick-up, anesthetic infusion was discontinued, animals were removed from the surgical table, extubated and placed in the recovery room, where were observed until returned to quadrupedal position, being this time recorded as anaesthetic recovery time. Once the animals recovered, they received penicillin-G 20000 IU/kg combined with dihydrostreptomycin 2.0 mg/kg (Penfort PPU, Ourofino, Brazil), meloxicam 0.4 mg/kg IM (Maxicam 0.2%, Ourofino, Brazil), and returned to the sheep fold, where they received meloxicam 0.2 mg/kg once a day for 3 days and animals were clinically evaluated for 15 days to ensure their satisfactory recovery.

Additionally, after induction (M1) and at the end of the surgical procedure (M2; before removing the capnoperitoneum), arterial blood (1 mL) samples were collected from arterial catheter, identifying the animal rectal temperature and FiO2 (0.21 in CT and 1.00 in OT) for immediately measurement of partial pressure of oxygen (PaO_2) carbon dioxide ($PaCO_2$), oxygen saturation (SaO_2), base excess (BE), bicarbonate (HCO_3), anion Gap (AG), sodium (Na^+), potassium (K^+), ionized calcium (iCa), chlorine (Cl^-), osmolarity (Osm) and pH (Omni-CTM Roche Diagnostics GmbH, Germany).

Statistical analysis of all collected data was performed using the R software (R-Foundation for Statistical Computing, Austria). The experimental design corresponded to a crossover with repeated measures over the time. Normality distribution of the residues and homoscedasticity of variances was tested prior comparisons, by Shapiro-Wilk and Bartlett's test, respectively. Real or transformed variables were compared between treatments, moments and its interaction by repeated ANOVA and Tukey post-hoc and its results are presented as mean ± SD. The significance fixed as $P < 0.05$.

RESULTS

The HR was greater at moments 10, 20, 30 and 40 (p=0.0477) than at moment 0, with no difference (p=0.5051) between treatments. The f_R remained constant in both treatments (P=0,6721) and moments (P=0,1116). The SpO_2 was higher (P=0.0366) in the OT than in the CT throughout the LOPU. The MAP was greater (P = 0.0133) and the $EtCO_2$ was lower (P = 0.0122) in the OT at moments 10, 20, 30, 40 and 50 than in the CT. The RT decreased in all animals (P=0.0125); however, the OT had a lower temperature decrease (P = 0.0043) than the CT (Table 1). Animals in the OT had a faster anesthesia recovery (P=0.0001; 26.5 ± 11.5 min), than in the CT (42.9 ± 12.8 minutes).

Blood sodium (P = 0.0198) and osmolarity (P = 0.0109) were higher in M2 than in M1, while potassium was lower (P = 0.001) in both treatments. There was no difference in the levels of iCa or Chlorine between the treatments and moments (P > 0.05). The pH was lower at M2 in the animals of the CT (P = 0.0004) than in OT, while $PaCO_2$ was higher (P = 0.0370) in OT at the same moment. The CT obtained lower values of BE (P = 0.0397), PaO2 (P = 0.0001) and SaO2 (P = 0.0001) than the OT. The CaHCO3 and AG levels were similar between treatments (P = 0.3438 and P = 0.5092; respectively) and moments (P = 0.9799 and P = 0.1998; respectively; Table 2).

DISCUSSION

Ketamine as anesthetic in ewes cause a sympathetic effect, that resulting in HR increase (CRUZ et al., 2010), nonetheless, its association with midazolam minimize the cardiovascular effects and promote desired outcomes, such respiratory stimulation, bronchodilation and maintenance of functional residual capacity (ÖZKAN et al., 2010), as observed in our study. Another aspect that can be associated to heart rate increase is the venous compression caused by the Trendelenburg position, which reduces venous return, preload and cardiac output (LOPES, 2014). These changes lead to baroreceptors activation, sympathetic response, HR and MAP increase (MARIANO et al., 2019; ODEBERG et al., 1998). Our results corroborate with both assertions, since HR remained above baseline levels in most of the procedure, only decreasing at the end of the LOPU in both treatments, suggesting that the cardiac function remains similar regardless of oxygen supplementation.

It has been reported, that LOPU leads to CO_2 absorption in ewes (MARIANO et al., 2019) and in humans, it leads to vasodilation, catecholamines release, HR increasing, and decrease of MAP due to limited vascular receptors sensitivity to catecholamines by hypercapnia (ISHIZUKA et al., 2000; ODEBERG et al., 1998). In this sense, the MAP was higher in the animals supplemented with oxygen during entire laparoscopy, indicating that hemodynamic response to pneumoperitoneum was more effective when oxygen is supplemented, factor related to respiratory function discussed below.

Lung function in ruminants is more affected by capnoperitoneum than in other species, due to the progressive rumen gas-trap, which further displaces the diaphragm cranially, resulting in impaired oxygenation (RODRIGUES et al., 2017). Although the f_R did not change as a result of the procedure or treatments, our study revealed that animals not supplemented with oxygen had higher values of $EtCO_2$, suggesting pulmonary ventilation failure, as described previously (MARIANO et al., 2019; RODRIGUES et al., 2017). Consequently, this alteration was reflected in $PaCo_2$ increase at the end of the procedure. Odeberg et al. (1998) reported in humans that in order to perform laparoscopy adjustments in ventilation are necessary to maintain $EtCO_2$ and $PaCo_2$ within normal limits, suggesting that in addition to oxygen supplementation that has been shown to be beneficial, controlled ventilation is indicated for this type of procedure in animals. Essentially, $EtCO_2$ an $PaCO_2$ elevation remains as a constant alteration in our study, regardless that the oxygen supplementation apparently mitigated this effect.

The $EtCO_2$ has direct correlation with the $PaCO_2$, thus the elevation of these parameters above 45 mmHg during and after LOPU, is considered hypercapnia and ventilatory failure (ALMOSNY, 2003) respectively in both treatments. This alteration may be resultant from inadequate alveolar ventilation/perfusion, from anesthetic procedure, decubitus, or even abdominal CO_2 absorption. Hypercapnia causes major metabolic imbalances, pH reduction and pathophysiological consequences of respiratory acidosis (HAAN; HAY-KRAUS;

Table 1. Mean ± SD of cardiopulmonary variables evaluated in ewes (n = 24) submitted to laparoscopic ova collection under total intravenous anesthesia, supplemented (OT) or not (CT) with oxygen.

Variable	Moment	Treatments	P-Treatments	P-Treatments	P-Moments
		CT	OT		
SPO_2 (%)	0	98.0 ± 8.29	99.0 ± 1.71	0.0366	0.5342
	10	90.0 ± 13.0^{a}	93.2 ± 2.80^{b}		
	20	73.3 ± 20.0^{a}	97.0 ± 2.65^{b}		
	30	82.6 ± 7.12^{a}	98.8 ± 8.53^{b}		
	40	87.7 ± 4.74^{a}	99.1 ± 1.73^{b}		
	50	85.4 ± 5.13^{a}	100 ± 0.00^{b}		
HR (beats/min)	0	88.0 ± 22.4^{A}	87.4 ± 18.6^{A}	0.5051	0.0477
	10	100 ± 19.8^{B}	99.7 ± 21.3^{B}		
	20	112 ± 35.6^{B}	99.2 ± 21.9^{B}		
	30	100 ± 21.3^{B}	100 ± 18.4^{B}		
	40	105 ± 24.4^{B}	104 ± 18.6^{B}		
	50	116 ± 29.2^{B}	107 ± 27.4^{B}		
f_R (resp/min)	0	40.0 ± 15.5	46.2 ± 17.7	0.1116	0.6721
	10	40.6 ± 14.0	40.5 ± 20.2		
	20	38.0 ± 15.7	41.8 ± 19.9		
	30	35.9 ± 13.6	40.6 ± 19.0		
	40	37.1 ± 13.2	35.2 ± 15.2		
	50	40.5 ± 13.3	43.3 ± 29.2		
PAM (mmHg)	0	83.9 ± 14.1^{A}	88.4 ± 17.4^{A}	0.0451	0.0033
	10	79.8 ± 13.1^{aB}	85.6 ± 18.0^{b}		
	20	74.4 ± 10.7^{aB}	83.6 ± 18.4^{b}		
	30	72.0 ± 10.8^{aB}	78.1 ± 15.1^{bB}		
	40	68.0 ± 12.6^{aB}	75.7 ± 16.6^{bB}		
	50	64.0 ± 18.7^{aB}	81.9 ± 14.4^{b}		
$EtCO_2$ (mmHg)	0	39.8 ± 13.2	36.9 ± 8.40	0.0092	0.5315
	10	42.5 ± 17.0^{a}	36.9 ± 8.88^{b}		
	20	47.5 ± 18.7^{a}	41.2 ± 7.80^{b}		
	30	48.4 ± 18.8^{a}	39.8 ± 6.88^{b}		
	40	42.5 ± 15.7^{a}	39.2 ± 7.58^{b}		
	50	43.0 ± 8.60^{a}	38.6 ± 7.50^{b}		
RT (°C)	0	37.7 ± 0.66^{aA}	37.7 ± 0.59^{aA}	0.0043	0.0125
	10	37.3 ± 0.62^{aA}	37.4 ± 0.51^{aA}		
	20	37.1 ± 0.65^{aA}	37.2 ± 0.48^{aA}		
	30	36.8 ± 0.73^{aB}	37.1 ± 0.51^{bA}		
	40	36.5 ± 0.75^{aB}	37.0 ± 0.59^{bA}		
	50	36.6 ± 0.77^{aB}	36.9 ± 0.31^{bB}		

SpO2: peripheral oxygen saturation; HR: heart rate; fR: respiratory rate; MAP: mean arterial pressure; EtCO2: end-tidal CO2 concentration; RT: rectal temperature. Different lowercase letters indicate significance between treatments and different uppercase letters between moments ($P < 0.05$).

Table 2. Mean ± SD of arterial gas analysis variables assessed after anesthesia induction (M1) and at the end of the laparoscopy (M2; before removing the capnoperitoneum) in ewes (n = 24) submitted to laparoscopic ova collection under total intravenous anesthesia, supplemented (OT; FiO2 = 1.00) or not (CT; FiO2 = 0.21) with oxygen.

Variable	Moment	Treatments		P-Treatments	P-Moments
		CT	OT		
Na^+ (Meq/L)	M1	148 ± 2.20^{A}	149 ± 3.35^{A}	0.9790	0.0198
	M2	153 ± 2.11^{B}	153 ± 2.80^{B}		
K^+ (Meq/L)	M1	3.54 ± 0.73^{A}	3.17 ± 1.01^{A}	0.3070	0.0001
	M2	2.64 ± 0.49^{B}	2.53 ± 0.45^{B}		
iCa^+ (Meq/L)	M1	0.79 ± 0.18	0.70 ± 0.15	0.1230	0.3836
	M2	0.79 ± 0.17	0.74 ± 0.12		
Cl^- (Meq/L)	M1	103 ± 21.8	105 ± 24.0	0.5330	0.9443
	M2	109 ± 3.17	111 ± 4.65		
pH	M1	7.27 ± 0.07^{aA}	7.34 ± 0.06^{aA}	0.0004	0.0101
	M2	7.22 ± 0.07^{aB}	7.31 ± 0.09^{bA}		
PaO_2 (mmHg)	M1	61.6 ± 12.5^{a}	259 ± 82.1^{b}	0.0001	0.0987
	M2	59.1 ± 14.1^{a}	237 ± 80.0^{b}		
SaO_2 (%)	M1	79.9 ± 9.45^{a}	98.7 ± 0.97^{b}	0.0001	0.0987
	M2	81.8 ± 10.4^{a}	97.5 ± 2.97^{b}		
$PaCO_2$ (mmHg)	M1	52.5 ± 13.5^{aA}	45.6 ± 7.97^{bA}	0.0370	0.0431
	M2	57.1 ± 12.1^{aB}	48.7 ± 10.9^{bA}		
$CaHCO_3$ (Meq/L)	M1	22.8 ± 4.52	23.6 ± 2.85	0.3438	0.9799
	M2	22.6 ± 3.96	23.7 ± 3.28		
BE (Meq/L)	M1	-4.02 ± 3.90^{aA}	-1.90 ± 2.91^{bA}	0.0397	0.0212
	M2	-4.95 ± 3.93^{aB}	-2.68 ± 3.79^{bB}		
AG (Meq/L)	M1	17.9 ± 3.10	18.7 ± 1.64	0.5092	0.1983
	M2	18.6 ± 2.89	18.9 ± 1.80		
Osm (Meq/L)	M1	293 ± 4.44^{A}	294 ± 6.19^{A}	0.5760	0.0109
	M2	295 ± 3.94^{B}	298 ± 5.21^{B}		

Na^+: sodium; K^+: potassium; iCa: ionized calcium; Cl^-: chlorine; PaO_2: partial pressure of oxygen; $PaCO_2$: carbon dioxide; SaO_2: oxygen saturation; BE: base excess; HCO_3: bicarbonate; AG: anion Gap; osmolarity (Osm). Different lowercase letters indicate significance between treatments and different uppercase letters between moments ($P < 0.05$).

SATHE, 2018; LOPES, 2014; RODRIGUES et al., 2017), and in our study that was lighter in OT. Nevertheless, although studies reported anesthetized ruminants leaning to hypoventilate (SEDDIGHI; DOHERTY, 2016), the reduction in $PaCO_2$ and the consequent maintenance of a more physiological pH in the animals supplemented with oxygen, indicate the need for this therapeutic measure. Additionally, and as expected, the metabolic compensation (changes in HCO3) of acidosis was not observed because it is an acute change (SEDDIGHI; DOHERTY, 2016).

In our study, PaO_2, SaO_2 and SpO_2 values were higher in the animals supplemented with oxygen during LOPU, indicating greater efficiency in the capture and distribution of oxygen to the tissues. These findings corroborated with previously studies in ewes submitted to laparoscopy under general anesthesia (HORR, 2019; LOPES, 2014). Hypoxemia is defined as PaO_2 <60 mmHg (RODRIGUES et al., 2017) and occurred in the animals of CT at the M2. Several factors may contribute to the development of hypoxemia, however the inadequate CO_2 elimination by alveolar hypoventilation is the main factor associated with the positioning, capnoperitoneum, and general anesthesia (RODRIGUES et al., 2017), and appears to be mitigated by oxygen supplementation, because all animals studied had some degree of hypoventilation, but only the animals of the CT presented hypoxemia. The alteration of the alveolar ventilation/perfusion ratio led to hypoxemia (LUMB, 2005; RODRIGUES et al., 2017) and might be associated to the greatest hemodynamic impairs in animals of the CT. Physiopathologically, this alteration has already been related to reduced lung compliance and less residual capacity in animals submitted to capnoperitoneum (MARIANO et al., 2015), leading to atelectasis. These findings suggesting that gas exchange occurs more effectively when oxygen was supplemented.

Surgical trauma, lead to secretion of catabolic hormones and inflammatory cytokines, consequently, there is a Na^+ retention (MELO et al., 2005). This mechanism allows to understand the changes observed in blood sodium concentration and osmolarity in both treatments. Besides that, in ewes going under anesthesia, an increase in Na^+ by increased hypotonic fluid losses frequently occurs, and the increase in osmolarity that is accompanied by the sodium increase, indicates that there was a relative hydro electrolytic balance (LUKARSEWSKI, 2011; VERBALIS, 2003).

Contrary to sodium, potassium decreased after LOPU procedure in both treatments. The renin-angiotensin-aldosterone system activation in response to blood pressure drop and/or adrenaline release in response to hemodynamic alterations and surgical stress, may explain the potassium reduction, that promotes renal potassium excretion and the entry of this element into the cell, respectively, and these findings are in agreement with previous studies that described the consequences of stress during laparoscopy (ISHIZUKA et al., 2000; ODEBERG et al., 1998).

A decrease in body temperature is expected over anesthetic/surgical procedures, due to factors such as a decrease in basal metabolism, hypotension, peripheral vasodilation, among others (LOPES, 2014; HORR, 2019). This fact was observed in both treatments; however, the OT lost less temperature than the CT suggesting that oxygen supplementation contributes to metabolism maintenance, additionally, it could be a positive effect to anesthetic recovery time reduction, confirming that this therapeutic strategy provides better physiological conditions for animals that undergo this procedure. To the authors knowledge, similar findings have never been reported before in ewes.

CONCLUSIONS

These results allow to conclude that oxygen supplementation in ewes submitted to laparoscopic ovum pick up under total intravenous anesthesia provides benefits in order to mitigate physiological alterations, such as hypotension, respiratory acidosis, hypercapnia and hypoxemia, providing greater welfare to the animals and faster anesthetic recovery.

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