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## ■ Diagnostic approach of anemia in ruminants

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## ■ Διαγνωστική προσέγγιση της αναιμίας στα μηρυκαστικά

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**ABSTRACT.** Anemia in ruminants is an abnormal condition characterized by the decrease of the hematocrit (Packed Cell Volume, PCV), the mass of erythrocytes (Red Blood Cells, RBCs) and/or hemoglobin. Anemia is classified as hemolytic, hemorrhagic or anemia caused by the decreased production of erythrocytes; the first two categories are characterized by a regenerative response. Hemorrhagic anemia can be caused by ectoparasites or parasites of the gastrointestinal system, hemorrhagic bowel syndrome, abomasal ulcers, vena cava thrombosis as well as from the genitourinary tract. In addition, primary and secondary hemostatic disorders can be accompanied by hemorrhagic anemia. Hemoparasites, toxins produced from *Clostridium perfringens* type D and *Clostridium hemolyticum* and leptospirosis are some of the causes of hemolytic anemia. Furthermore, certain plants, drugs or heavy metals and lack of certain trace elements can cause hemolysis. Immune-mediated hemolytic anemia has also been reported in ruminants. The reduced production of erythrocytes can be caused by deficiency of vitamin B12 or iron, as well as by chronic diseases. Pathologic conditions of bone marrow like inflammatory or neoplastic cells filtration and hypoplasia or aplasia of bone marrow are related to reduced production of erythrocytes. After laboratory confirmation by complete blood count analysis, history taking, clinical examination

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of the animal and specific test depending on the case, are required for the diagnostic approach of anemia and especially for etiological diagnosis. Tachycardia, tachypnea, icterus, mucosal pallor as well as specific symptoms of the underlying disease are observed during the clinical examination of the animal. FAMACHA technique is widely used for the clinical diagnosis and the assessment of the severity of anemia. With respect to complete blood count, apart from the hematocrit, hemoglobin concentration, erythrocytes indices as Mean Corpuscular Volume (MCV) and Mean Corpuscular Hemoglobin Concentration (MCHC) are contributing to the classification of anemia. The size and the shape of the erythrocytes, the appearance of inclusions and reticulocytes, which are indicative of regenerative anemia, are evaluated in blood smear. Rarely, examination of bone marrow is carried out, for the differentiation of anemia as regenerative or non-regenerative. In particular, the confirmation of immune- mediate anemia is based on Coomb's test for the detection of autoagglutination. Except from hemorrhage, blood loss is detected at urinalysis or feces microscopy for the presence of blood and/or parasites. Finally, serological and molecular techniques for the detection of infectious agents, as well as specific toxicological analysis are performed in various biological materials.

**Keywords:** anemia, ruminants, diagnostic approach

**ΠΕΡΙΛΗΨΗ.** Η αναιμία στα μηρυκαστικά είναι παθολογική κατάσταση, η οποία χαρακτηρίζεται από τη μείωση του αιματοκρίτη (Packed Cell Volume, PCV), του αριθμού των ερυθροκυττάρων (Red Blood Cells, RBCs) ή/και της αιμοσφαιρίνης. Η αναιμία χαρακτηρίζεται ως αιμολυτική, αιμορραγική ή αναιμία που οφείλεται στη μειωμένη παραγωγή των ερυθροκυττάρων, με τις δύο πρώτες κατηγορίες να χαρακτηρίζονται από αναγεννητικότητα. Η αναιμία λόγω απώλειας αίματος μπορεί να οφείλεται σε εξωπαρασίτωση ή ενδοπαρασίτωση του γαστρεντερικού σωλήνα, στο σύνδρομο του αιμορραγικού εντέρου, σε έλκη του ηνύστρου, σε έμφραξη της οπίσθιας κοίλης φλέβας καθώς και σε αιμορραγία από το ουρογεννητικό σύστημα. Ακόμη, πρωτογενείς και δευτερογενείς διαταραχές της αιμόστασης μπορεί να συνοδεύονται από αιμορραγική αναιμία. Στα αίτια της αιμολυτικής αναιμίας περιλαμβάνονται τα αιμοπαράσιτα, οι τοξίνες που παράγονται από τα *Clostridium perfringens* τύπου D και *Clostridium hemolyticum* και η λεπτοσπείρωση. Επιπλέον, ορισμένα φυτά, φάρμακα ή βαρέα μέταλλα μπορούν να προκαλέσουν αιμόλυση των ερυθροκυττάρων καθώς και η έλλειψη ιχνοστοιχείων. Η ανοσολογικής αιτιολογίας αιμολυτική αναιμία έχει επίσης αναφερθεί στα μηρυκαστικά. Η μειωμένη παραγωγή ερυθροκυττάρων οφείλεται σε έλλειψη της βιταμίνης B12 ή του σιδήρου, καθώς και σε χρόνια νοσήματα. Παθολογικές καταστάσεις του μυελού των οστών όπως η διήθηση από φλεγμονικά ή νεοπλασματικά κύτταρα όπως και η υποπλασία ή απλασία του μυελού των οστών σχετίζονται με μειωμένη παραγωγή ερυθροκυττάρων. Για τη διαγνωστική προσέγγιση της αναιμίας μετά την εργαστηριακή επιβεβαίωση με τη γενική εξέταση του αίματος και κυρίως για την αιτιολογική διάγνωση απαιτείται η λήψη ιστορικού, η κλινική εξέταση του ζώου, και ειδικές κατά περίπτωση εξετάσεις. Κατά την κλινική εξέταση του ζώου παρατηρούνται ταχυκαρδία, ταχύπνοια, ίκτερος, ωχροί βλεννογόνοι αλλά και τα ειδικότερα συμπτώματα του υποκείμενου νοσήματος. Η τεχνική FAMACHA έχει ευρέως χρησιμοποιηθεί για την κλινική διάγνωση και τον προσδιορισμό της βαρύτητας της αναιμίας. Από τις παραμέτρους της αιματολογικής εξέτασης, πέρα από τον αιματοκρίτη, η συγκέντρωση της αιμοσφαιρίνης, οι δείκτες των ερυθροκυττάρων μέσος όγκος ερυθροκυττάρων (Mean Corpuscular Volume, MCV), και μέση συγκέντρωση αιμοσφαιρίνης (Mean Corpuscular Hemoglobin Concentration, MCHC) συμβάλλουν στην ταξινόμηση της αναιμίας. Στο επίχρισμα του αίματος αξιολογείται το σχήμα και το μέγεθος των ερυθροκυττάρων, η παρουσία εγκλειστών, καθώς και η παρουσία δικτυοερυθροκυττάρων ενδεικτικών αναγεννητικής αναιμίας. Για τη διαφοροποίηση της αναιμίας σε αναγεννητική ή μη σπανιότερα γίνεται εξέταση μυελού των οστών. Ειδικότερα, η επιβεβαίωση ανοσολογικής αιτιολογίας αναιμίας στηρίζεται στην εξέταση Coomb's για την διαπίστωση αυτοαιμοσυγκόλλησης. Η απώλεια αίματος πέραν της αιμορραγίας διαπιστώνεται επίσης με την ανάλυση του ούρου και την κοπρανολογική εξέταση για την παρουσία αίματος ή/και παρασίτων. Τέλος στα διάφορα βιολογικά υλικά πραγματοποιούνται ορολογικές και μοριακές τεχνικές για την ανίχνευση παθογόνων παραγόντων καθώς και ειδικές εξετάσεις για την ανίχνευση τοξινών.

**Λέξεις ευρητηρίας:** αναιμία, μηρυκαστικά, διαγνωστική προσέγγιση.

## INTRODUCTION

Anemia, by definition, corresponds to the reduction of blood oxygen and it is characterized by a decrease in hematocrit, erythrocyte mass and/or hemoglobin concentration leading to tissue hypoxia. In practice anemia is defined as the concentration of hemoglobin below the lower reference limit.

Anemia can be classified either based on the ensuing pathogenetic mechanisms thus characterized as hemorrhagic, hemolytic and anemia caused by the decreased production of erythrocytes or based on the regenerative response of bone marrow and consequently characterized as regenerative or non-regenerative anemia.

The presence of hypoxia in renal erythropoietin producing cells, as a consequence of anemia, dynamically alters the concentration of circulating erythropoietin. Erythropoietin is an early identified humoral factor, an erythropoietic glycoprotein hormone that induces proliferation and differentiation of erythroid progenitors, leading to red blood cell production (Souma et al., 2015).

At first, anemia is always non-regenerative because it takes some days for mature erythrocytes to be released to the peripheral blood. Therefore, evidence of regeneration should become apparent within 4-5 days.

Regeneration is mainly observed in acute blood loss or in hemolytic anemia while it is rather unlikely in cases where anemia is related to a chronic disease or by impaired erythrocyte production by the bone marrow (Ogilvie, 1998).

## ETIOLOGY

### Hemorrhagic anemia

Anemia due to blood loss can be caused by intense ectoparasitism (Stromberagn and Gyillot, 1987; Shemanchuk et al., 1960). Similarly, parasitism of the gastrointestinal track is a common cause of blood loss anemia in ruminants as in other species. Different parasitic phyla have been identified as causative agents of anemia such as nematodes in small ruminants (Baldissera et al., 2015; Bordoloi et al., 2012; Vatta et al., 2002) and in cattle (Favero et al., 2016; Van Aken et al., 1997) with *Haemonchus contortus* referred as the most common species causing blood loss anemia as well as trematodes including *Fasciola hepatica* in

small ruminants (Saleh, 2008; Maltinez- Moreno et al., 1997; Knight, 1980) and in cattle (Lotfollahzadeh et al., 2008; Ross et al., 1966) and *Paramphistomum cervi*, as well (Dorny et al., 2011). In severe cases of winter dysentery, a disease with unconfirmed causative agent, fresh blood clots have been reported to be evidenced in the feces of affected calves (Divers and Peek, 2008). Other clinical conditions of the gastrointestinal tract associated with blood loss anemia are the hemorrhagic bowel syndrome caused by *Clostridium perfringens* type A (Braun et al., 2010) and abomasal ulcers (Ok et al., 2001; Vatn and Ulvund, 2000).

Vena cava thrombosis in adult dairy cattle or in feedlot cattle fed a high-carbohydrate diet is also clinically manifested by pale mucous membranes, hemoptysis, and epistaxis (Breeze et al., 1976). Blood loss is also evident from the genitourinary tract presented as hematuria as in the case of enzootic hematuria caused by urinary bladder tumors secondary to chronic bracken fern toxicity (McKenzie, 1978) as well as in pyelonephritis caused by *Corynebacterium renale* and *E.coli* in cows (Braun et al., 2008). Moreover, acute blood loss, sometimes severe, can result from injuries caused by obstetrical manipulations more often in cows that have been in labor for several hours and when the birth canal is dry and non-lubricated (Radostits et al., 2006). In addition, anemia can be caused by tumors (Stock et al., 2011). Rupture of an ovarian granulosa cell tumor followed by hemoperitoneum or spleen rupture after infiltration by lymphosarcoma (Divers and Peek, 2008), is a rather uncommon condition in cows (Masseau et al., 2004). Body cavity effusions usually result from hemostatic disorders (Radostits et al., 2006). Internal hemorrhages caused by massive thrombocytopenia have been attributed to Bovine Virus Diarrhea- Mucosal Disease (BVD- MD) virus (Dabak et al., 2007). Secondary hemostatic disorders such as rodenticide intoxication are very rarely reported in ruminants. A case of rodenticide toxicity in lambs that accidentally gain access to baits for rodent control was reported as sudden death followed epistaxis, respiratory distress and edemas in different body parts (Del Piero and Poppenga, 2006). Experimentally dosing of carbon tetrachloride, in goats resulted in hepatic damage and decreased of blood clotting activity (Smith and Sherman, 2009).

The most frequent causes of blood loss anemia per ruminant species are presented in Table 1.

**Table 1.** Causes of blood loss anemia in sheep, goats and cattle

	Sheep	Goats	Cattle
<b>Ectoparasites</b>			
<i>Linognathus spp</i>			A, Y
<b>Gastrointestinal tract</b>			
<i>Haemonchus contortus</i>	A, Y	A	Y
<i>Mecistocirrus spp</i>			Y
<i>Fasciola hepatica</i>	A, Y	A	A, Y
<i>Paramphistomum cervi</i>			A, Y
Abomasal ulceration	Y		
Hemorrhagic bowel syndrome			A
Winter dysentery			Y
<b>Respiratory tract</b>			
Caudal vena cava thrombosis and pulmonary embolism			A
<b>Genitourinary tract disease</b>			
Enzoonotic hematuria			A
<b>Others</b>			
Injuries			A
Tumor			A, Y
Hemostatic disorders	Y		A
Carbon tetrachloride		A	

\*Sheep: Young (Y) < 12 months, Adult (A) >12 months; Goats: Young (Y) < 12 months, Adult (A) >12 months; Cattle: Young (Y) < 12 months, Adult (A) >12 months

## Hemolytic anemia

Anemia due to hemolysis can be caused by parasites implicated in tick born fever including piroplasms that invade red blood cells like *Babesia spp* in small (Esmailnejad et al., 2012; Yeruham et al., 1998) and large ruminants (Bal et al., 2016; Trueman and Blight, 1978) and *Theileria spp* in lambs (Alani and Herbert, 1988) and cattle (Omer et al., 2002; Moll et al., 1986) and rickettsiae, mainly *Anaplasma spp* that infect granulocytes up to 90% in the peak of bacteremia as it is referred in sheep (Yasini et al., 2012), goats (Gokce and Woldehiwet, 1999) and cattles (Ashuma et al., 2013; Henniger et al., 2013). Furthermore, protozoa like *Trypanosoma* (Biryomumaisho et al., 2013; Katunguka- Rwakishaya et al., 1997; Anosa et al., 1992) and certain *Mycoplasma* species (Genova et al., 2011; Suzuki et al., 2011) can also be found in plasma and/or in erythrocytes. In addition, microfilaria, the larval stage of stephanofilarial worm, the causative agent of the bovine stephanofilarial dermatitis, enters peripheral blood circulation causing anemia by increasing erythrocytic fragility (Singh et al., 2011).

Hemolysis also results from toxins produced by *Clostridium perfringens* type D causing yellow lamb disease (Gianniti et al., 2014) and *Clostridium hemolyticum* that causes bacillary hemoglobinuria in sheep and cows (Tagaki et al., 2009; Randhawa et al., 1995).

The primary lesions of the pathogenic *Leptospira spp* circulating in the bloodstream, concern the endothelium of small blood vessels, which leads to localized ischemia in organs mainly kidney and liver. Apart from vasculitis, *Leptospira spp* hemolysins have been implicated in the pathogenesis of anemia; in calves *Leptospira spp* hemolysin has been reported as responsible for yielding holes in the erythrocyte cellular membrane (Lee et al., 2002).

Toxicity from grazing plants *Allium spp* including onion and garlic (Heidarpour et al., 2013; Aslani et al., 2005; Rae, 1999), *Brassica spp* with the most known the broccoli and the cabbage (Xu, 1992) and *Ipomoea carnea*, a flowery plant (Tartour et al., 1973), have been associated with hemolytic anemia in ruminants. Although, long acting oxytetracycline compounds have been widely used in ruminant medicine only

experimentally induced toxicosis has been reported. It seems that oxytetracycline may penetrate erythrocytes interacting with hemoglobin and thereby significantly reducing the erythrocyte count and hemoglobin concentration (Chi et al., 2010).

Moreover, natural occurring cases of anemia associated with toxicosis by heavy metals such as copper (Cregar et al., 2012; Bundza et al., 1982; Stogdale, 1978), zinc (Allen et al., 1983) and arsenic (Keshavarzi et al., 2015; Rana et al., 2010) have been reported in ruminants. Although, anemia has been reported in natural cases of lead poisoning in cows (Schlerka et al., 2004), it has not been observed in experimentally lead poisoned sheep where low doses of lead were administered (Polizopoulou, 1991). In addition, poisoning by nitrate resulted in methemoglobinemia with

methemoglobinuria, in sheep (Hindson and Winter, 1996). On the other hand, nutritional deficiency in copper and selenium has been associated with formation of Heinz bodies indicative of erythrocyte oxidative damage in lambs. Moreover, copious exercise seems to further reveal the hematological impact of these trace element deficiencies (Draksler et al., 2002; Suttle et al., 1987). Similarly, anemia with Heinz body presence has been reported in hypophosphatemic cows (Jubb et al., 1990).

Rarely autoimmune hemolytic anemia is reported in young, as well in adult ruminants after vaccinations; a polyvalent botulism vaccine has been incriminated for such a condition in a cow (Yeruham et al., 2003). Similarly, antigens of the BVD- MD vaccine seem to elicit antibodies that bind not only to peripheral blood

**Table 2.** Causes of hemolytic anemia in sheep, goats and cattle

	Sheep	Goats	Cattle
<b>Infectious Agents</b>			
<i>Babesia spp</i>	A, Y	A	A, Y
<i>Theileria spp</i>	Y		A, Y
<i>Anaplasma spp</i>	A	A	A, Y
<i>Trypanosoma spp</i>	A, Y	A	A, Y
<i>Mycoplasma spp</i>	A		A
Bovine stephanofilarial dermatitis			A
Yellow lamb disease	Y		
Bacillary hemoglobinuria	A		A
<i>Leptospira spp</i>	Y		A
<b>Toxic agents</b>			
<i>Allium spp</i>	A	A	A, Y
<i>Brassica spp</i>			A
<i>Ipomoea carnea</i>	A		Y
Long-acting oxytetracycline	A		
Copper	Y	A	
Zinc	A		
Arsenic	A		A
Lead			A
<b>Nutrition deficiency</b>			
Copper	Y	Y	
Selenium	Y		
Phosphorus	Y		
<b>Immune Mediated Conditions</b>			
Vaccination			A, Y
Bovine colostrum fed to sheep	Y	Y	
IMHA			A, Y

\*Sheep: Young (Y) < 12 months, Adult (A) >12 months; Goats: Young (Y) < 12 months, Adult (A) >12 months; Cattle: Young (Y) < 12 months, Adult (A) >12 months

cells but also to the stem cells in the bone marrow of neonates (Deutskens et al., 2011). These antigens cause opsonization of the affected cells which enhance phagocytosis by bovine macrophages. After vaccination with Lumpy Skin Disease Virus in cows, mild regenerative hypochromic macrocytic anemia has recently been reported, probably because of slight hemolysis (Katsoulos et al., 2017). Immune-mediated hemolytic anemia has been reported in juvenile lambs fed with cow colostrum (Winter and Clarkson, 1992) while idiopathic immune mediated anemia has been diagnosed in cases where hemolysis could not be attributed to any of the above-mentioned agents (Nasiri et al., 2011).

The causes of hemolytic anemia in ruminants are presented in Table 2.

### Anemia due decreased production of RBCs

Decrease of RBCs production is metabolically relative to essential nutrients such as cobalt which is converted by ruminal microflora to vitamin B12. Vitamin B12 acts as an essential cofactor of several enzyme systems promoting red blood cell synthesis. Thus, a vitamin B12 deficiency results to anemia. In case of sheep, it has been reported (Ulvund, 1990) that white liver disease attributed either to B12 deficiency or to hepatotoxic disease in deficient lambs was associated with a decrease in hemoglobin concentration. Similar findings have been reported in cobalt deficient goats (Al-Habsy et al., 2007). Iron deficiency is usually

observed in young animals, because of their rapid growth and the large amount of iron needed for the production of hemoglobin, myoglobin and other iron-containing compounds (Green et al., 1997) as well as in ewes after parturition (Cihan et al., 2016). The most frequent cause of iron deficiency is endo- and ectoparasitism (Singh et al., 2014).

However, iron is also implicated in the pathogenesis of anemia of the chronic disease. Although, iron stores are adequate for erythropoiesis, they are sequestered making iron unavailable for hematopoiesis leading to normocytic, normochromic non regenerative anemia. (Radostits et al., 2006). Anemia of chronic disease has been reported in cattle affected by lumpy skin disease due to the chronic inflammatory response to *Capripoxvirus* infection, that disturbs iron metabolism. Therefore, anemia is usually mild and slowly progressive and the main hematological abnormalities concern the indexes Mean Corpuscular Volume (MCV), Mean Corpuscular Hemoglobin (MCH) and Mean Corpuscular Hemoglobin Concentration (MCHC) (Abutarbush, 2015). Similarly, ovine paratuberculosis is associated with macrocytic normochromic anemia due to the chronic inflammation (Hemalatha et al., 2013), while in goats, anemia is non-regenerative (Smith and Sherman, 2009). Although, anemia is not a common finding in Bluetongue infected sheep, few cases have been reported in sheep attributed either in vasculitis caused by the virus or chronic disease (Vasileiou et al., 2016). Apart from inflammation, neoplasia has been reported to cause anemia of chronic disease. Bracken

**Table 3.** Causes of anemia of decreased erythrocyte production in ruminants

	Sheep	Goats	Cattle
<b>Nutrition deficiency anemia</b>			
Cobalt/ folate	Y	A	
Iron	A, Y		A, Y
<b>Anemia of chronic disease</b>	A		A
Lumpy skin disease			A
Mycoplasma paratuberculosis	A		
Chronic toxicity			A, Y
Bluetongue	A		
<b>Anemia secondary to bone marrow dysfunction or dysplasia</b>			
Neoplasia			A
Bovine neonatal pancytopenia			Y

\* Sheep: Young (Y) < 12 months, Adult (A) >12 months; Goats: Young (Y) < 12 months, Adult (A) >12 months; Cattle: Young (Y) < 12 months, Adult (A) >12 months

**Table 4.** Infectious agents that have been associated with anemia \* in ruminants in Greece

Infectious agents	Species	References
<i>Haemonchus contortus</i>	sheep, goats	Kouam et al., 2014
<i>Besnoitia besnoiti</i>	cattle	Papadopoulos et al., 2014
<i>Fasciola hepatica</i>	sheep, goats	Kantzoura et al., 2011; Katsoulos et al., 2011
<i>Anaplasma spp</i>	sheep, cattle	Giadinis et al., 2011; Giadinis et al., 2015
<i>Babesia spp</i>	sheep, goats, cattle	Papadopoulos et al., 1996
<i>Theileria spp</i>	sheep, cattle	Papadopoulos et al., 1996
<i>Mycobacterium paratuberculosis</i>	goats	Angelidou et al., 2014
<i>Leptospira spp</i>	sheep, cattle	Burriel et al., 2003
Yellow lamb disease	sheep	Gkiourtzidis et al., 2001
<i>BVDV</i>	cattle	Billinis et al., 2005
Bluetongue	sheep	Vasileiou et al., 2016
Lumpy skin disease	cattle	Tasioudi et al., 2016 Katsoulos et al., 2017

\* Although the documentation of a cause- effect relationship between infection agent and anemia was not the main objective of all these publications, anemia has been observed in the affected ruminants.

fern toxicity mostly in cattle but also in sheep results to the development of tumors and consequently to this type of anemia. Bone marrow examination revealed aplasia of the hematopoietic tissues, in these animals (Prakash et al., 1996). Neoplastic tissue seems to infiltrate bone marrow as in a case of hemophagocytic histiocytic sarcoma in a cow where neoplastic histiocytes primarily proliferated in the spleen and bone marrow (Matsuda et al., 2010). A recently observed syndrome in calves is the bovine neonatal pancytopenia in which bone marrow is aplastic and hemopoietic tissues were replaced by fat cells (Fukunaka et al., 2010).

Conditions associated with anemia of reduced erythrocyte production are presented in Table 3, while the most common condition associated with anemia in ruminants in Greece are presented in Table 4.

## DIAGNOSTIC APPROACH

Anemia is mostly a diagnosis confirmed by laboratory testing. However, diagnostic approach should include history and environmental assessment. Demographic data, such as age and breed, the prevalence of the causative agents in each geographic area along with nutrition and breeding conditions including vaccinations and antiparasitic control should be taken into consideration (Deutskens et al., 2011; Dabak et al., 2007; Aslani et al., 2005). Apart from the clinical sus-

picion of anemia, clinical manifestations of anemia as well as other laboratory findings are essential in order to reach etiological diagnosis. Furthermore, classification of anemia offers clinicians a diagnostic algorithm to compile a list of differentials with the ultimate goal to reach a definite diagnosis of the underlying cause (Figure 1).

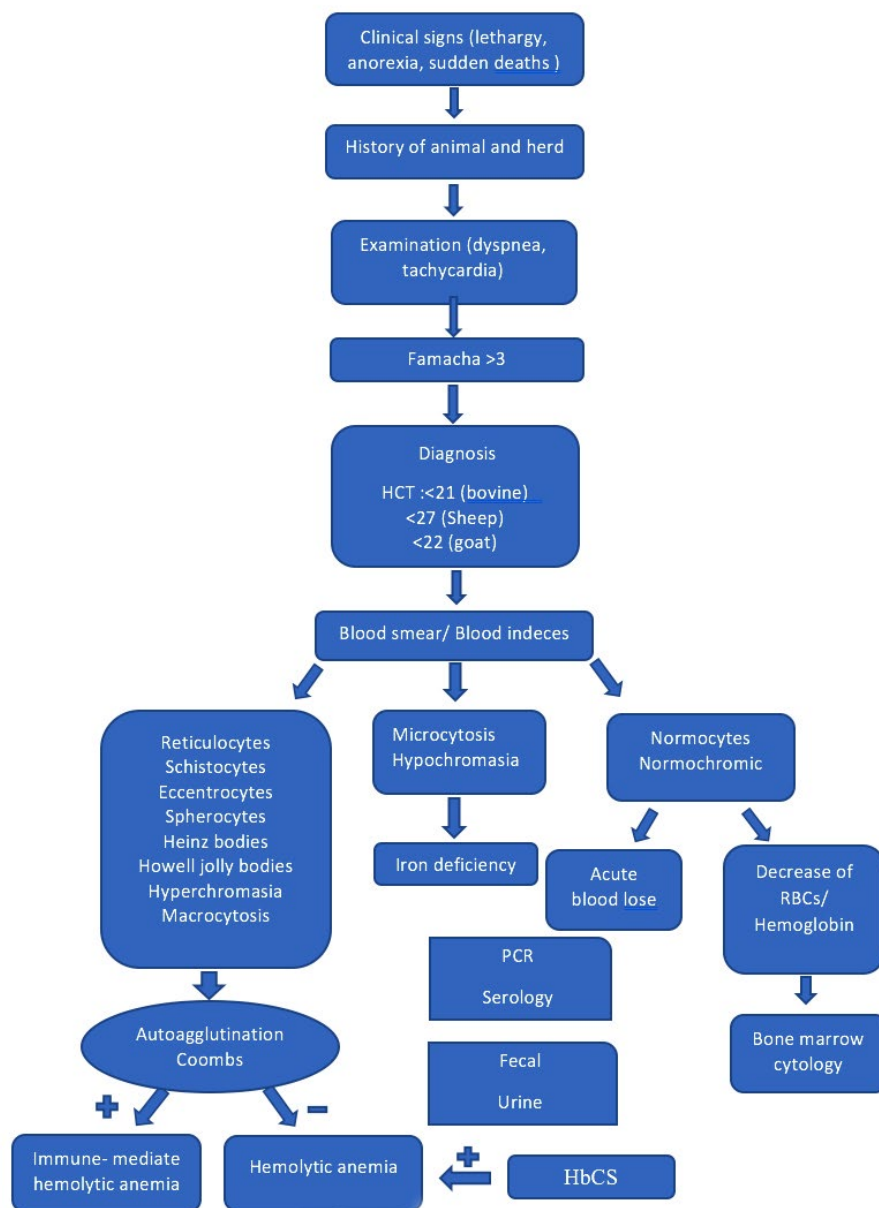
## Clinical manifestations and severity

Clinical signs derive from inadequate oxygen supply when compensatory mechanisms fail or even because of these mechanisms. Among them, mucous membrane pallor, exercise intolerance, tachypnea and/or dyspnea are the most commonly signs observed in anemic ruminants. Heart auscultation reveals an increased heart rate as well as functional murmurs due to blood cell turbulence disturbances (Radostits et al., 2006).

Symptoms of the underlying disease are also present and they can be either non-specific such as anorexia, fever and weight loss or specific to the certain disease.

The severity of clinical signs is negatively related to the chronicity of anemia and positively to the amount of blood loss. Therefore, chronic diseases as well as bone marrow insults are manifested by mild symptoms such as weight loss in adults and decrease of weight gain in lambs, reduction of foraging or





**Figure 1.** Algorithm for investigation of anemia in ruminants

grazing, reduced exercise tolerance and subcutaneous edema (Gianniti et al., 2014).

To the contrary severe acute hemorrhage or blood destruction is usually presented with a more severe clinical picture, even sudden deaths, depending on the cause of anemia.

Hemorrhage is evidenced during physical examination as epistaxis, hematuria and melena (Ok et al., 2001; Xu, 1992) or denoted by the presence of ectoparasites. Hemolysis is manifested by icterus, splenomegaly and abnormal urine color (Gianniti et al., 2014; Ashuma et al., 2013; Braun et al., 2008) due

to hemoglobinuria or bilirubinuria. Moreover, in case of hemostatic disorders, petechiae and ecchymoses or body cavity effusions are observed (Dabak et al., 2007).

Scoring systems of the severity of clinical patent anemia as manifested by mucous membrane pallor have been developed in ruminants. The most widely used system is called FAMACHA (FAO, 1998), an acronym of the name of the originator of the system. This system had been initially developed to identify small ruminants with anemia caused by haemonchosis, in order to selectively administer antiparasitic

compounds only in the infected and not all animals of an infected farm. This system is an easy to perform and of low cost method.

FAMACHA is based on the examination of the lower eyelid mucous membrane color against a laminated color chart presenting 5 color categories where 1 is the normal mucous membrane color and 5 is the white color. The score 3 is the borderline for starting medical treatment. The system has been validated using PCV as gold standard. The sensitivity was found to be higher in sheep than in goats negatively related to the cut off value of the PCV that was used to differentiate anemic from non-anemic animals (Sotomaior et al., 2012). Furthermore, conjunctiva color varies in different breeds therefore; modifications of the color in the chart based on breed specific colors are suggested (Moors and Gauly, 2009)

In bovine, FAMACHA was used to score anemia predominantly caused by *Trypanosoma congolense*. The system was found adequate to identify moderate and severely anemic cattle with a FAMACHA score of 4 and 5, respectively (Grace et al., 2007).

Despite the subjectivity of color estimate, FAMACHA remains a convenient rough estimate of anemia in ruminants prior to laboratory testing.

## Laboratory evaluation

### Blood testing

#### Complete blood count (CBC)

Clinical suspicion of anemia is confirmed by a complete blood count, mainly the hematocrit and red blood cell count. It is worth mentioning that in neonates, hematocrit value is relatively high at birth, while, till the age of 6 months, it decreases below the lower reference interval for adults. Different reference intervals are provided in literature reflecting differences in populations and equipment used for their determination. For instance, according to Schalm's hematology textbook (Weiss and Wardrop, 2010), hematocrit reference interval is 21-30%, 27-45% and 22-38% for cow, sheep and goat, respectively.

For the classification of anemia and the assessment of regenerative response, reticulocyte count along with blood smear evaluation should be performed. In regenerative anemia, the number of reticulocytes is

increased in peripheral blood therefore serial monitoring of blood parameters is required. In case of low number of reticulocytes, monitoring is essential to find out if the anemia is non-regenerative or if there is an acute regenerative anemia. Repeating of CBC analysis is important as well as in the case of high number of reticulocytes, in order to see if the anemia does no anymore exists or if the anemia is changing from regenerative to non-regenerative. Reticulocytes in sheep and goats with basophilic stippling are easily detected in EDTA anticoagulated blood stained by Giemsa. Regeneration in ruminants is also demonstrated by macrocytosis and polychromasia while anisocytosis is quite common in healthy ruminants (Weiss and Wardrop, 2010). In response to severe anemia red blood cells contain nuclear fragments, the Howell-Jolly bodies (Alani and Herbert, 1988). Macrocytosis, is determined by calculating the Mean Corpuscular Volume (MCV) (Alani and Herbert, 1988). To the contrary, microcytosis (decreased MCV) is indicative of chronic disease (Abutarbush, 2015) as well as nutrition deficiencies. Furthermore, a diagnosis of iron deficiency anemia is very likely when microcytosis coexists with a decreased mean cell hemoglobin concentration (MCHC) (Green et al., 1997). On the other hand, an increase in the MCHC is observed in hemolytic anemia because of the released of hemoglobin from the ruptured erythrocytes in blood (Radostits et al., 2006).

Apart from the detection of reticulocytes and the presence of polychromasia, blood smear evaluation is needed in order to identify morphological abnormalities such as spherocytosis in case of both immune mediated hemolytic anemia and toxicity (Bundza et al., 1982). In diseases that cause physical injury to red blood cells, usually hemoparasitoses (*Trypanosoma* spp, *Mycoplasma* spp), schistocytes are observed (Gladden et al., 2016; Anosa et al., 1992). Moreover, oxidative damage of hemoglobin associated with onion toxicosis (Heidarpour et al., 2013) is denoted by the presence of Heinz bodies in the cytoplasm of red blood cells and/or eccentrocytes, where hemoglobin has been eccentrically accumulated (Borrelli et al., 2009).

Finally, parasitic inclusions such *Babesia* spp, *Theileria* spp, *Mycoplasma* spp and *Anaplasma* spp (Gladden et al., 2016; Henniger et al., 2013; Izzo et

al., 2010) can be found.

Alterations in the number and/or morphology of white blood cells are also observed in case of anemia and they are associated with the underlying disease. Similarly, anemia caused by hemostatic disorders can affect the number and/or morphology of platelets. For instance, thrombocytopenia has been reported in anemic calves with BVD-MD (Dabak et al., 2007).

#### *Agglutination testing*

Aggregation of erythrocytes forming irregular shapes is observed either in inflammatory reactions especially in bovine known as rouleaux formation (Weiss and Wardrop, 2010) or in autoimmune diseases where red blood cell clumps are not dissolved if blood is diluted with 0.9% saline (Nassir et al., 2011). Suspected immune-mediated hemolytic anemia is confirmed by direct Coombs' test which becomes positive when anti-immunoglobulin and anti-complement antibodies are mixed with host erythrocytes (Nassir et al., 2011). Both IgG and IgM reactive antibodies have been implicated in the pathogenesis of idiopathic immune-mediated hemolytic anemia, however, IgG is much more common than IgM. They are mostly considered as warm hemagglutinins since they are reactive at body temperature. Cold hemagglutinin disease (IgM antibodies that bind to erythrocytes below body temperature) results in thrombi formation that lead to ischemic necrosis usually observed at the tips of the ears.

While immune mediated anemia is usually regenerative, it can rarely be non-regenerative when bone marrow progenitor cells are targeted instead or along with mature erythrocytes.

#### *Scoring of anemia without using a blood count analyzer*

Efforts to estimate haemoglobin without the use of laboratory equipment and consumables have been made in human medicine and the Haemoglobin Colour Scale (HbCS) has been developed (WHO, 2004). The test requires a drop of blood that is applied on a special chromatographic paper which is compared to a laminated card with different colours related to different haemoglobin concentrations. The performance of this test in cattle was reported to be good for the

detection of moderate to severe anemia and less sensitive in cases of mild anemia (Grace et al., 2007).

#### *Other biological material testing*

##### *Fecal examination*

Feces of anemic ruminants should be examined for color change due to the presence of blood, consistency, amount, shape, odor and the presence of mucous (Braun et al., 2008). Laboratory examination of feces includes microscopy for the detection of parasites, presence of occult blood and microbiology including molecular techniques for the detection of causative agents of the underlying disease (Bott et al., 2009).

##### *Urinalysis*

A strong indication for urinalysis in anemic ruminants is the red or dark brown color in urine. Urine sediment microscopy reveals the presence of red blood cells (hematuria). The red color of the supernatant after urine centrifugation either due to the presence of hemoglobin or myoglobin should be further differentiated by chemical analysis (Giannitti et al., 2014; Braun et al., 2008). Certain microorganisms can also be detected in urine employing either microscopy or molecular techniques (Denipitiya et al., 2017).

##### *Bone marrow evaluation*

Bone marrow evaluation is not routinely performed in ruminant medicine as it requires sample referral to a specialized laboratory. Bone marrow cytology is used to determine the regenerative response. If there is an increased cellularity in bone marrow, anemia is regenerative, while if there are few cells with morphological abnormalities, bone marrow dysfunction and dyserythropoiesis as well as non-regenerative anemia is more likely to occur (Fukunaka et al., 2010; Steffen et al., 1992). Bone marrow samples can be used for the detection of the causative agents of the underlying diseases.

##### *Additional tests*

Serological and molecular techniques are widely used for the etiological diagnosis of diseases that are associated with anemia in ruminants (Sonawane and Tripathi, 2015; Yang et al., 2015; Grova et al., 2011).

Moreover, chemical analysis is used for the detection of heavy metals and toxins in biological material as well as in feed and water (Keshavarzi, 2015).

## CONCLUSION

Anemia is a frequent abnormal condition in ruminants. It is usually associated with pathological state of other tissues or organs rather than reflecting primary defects in erythropoiesis. A complete blood count is the indispen-

sable part of the laboratory investigation of every case of anemia. However, a systematic approach includes history taking and clinical examinations followed by laboratory testing targeted to the clinical findings in order to identify possible etiologic factors.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## REFERENCES

- Abutarbush SM (2015) Hematological and serum biochemical findings in clinical cases of cattle naturally infected with lumpy skin disease. *J Infect Dev Ctries* 9(3):283-288.
- Al-Habsi K, Johnson HE, Kadim TI, Srikanthakumar A, Annamalai K, Al-Busaidy R, Mahgoub O (2007) Effects of low concentrations of dietary cobalt on liveweight gains, haematology, serum vitamin B12 and biochemistry of Omani goats. *Vet J* 173:131-137.
- Alani AJ, Herbert IV (1988) Pathogenesis of Infection with *Theileria recondite* (Wales) isolated from *Haemaphysalis punctate* from North Wales. *Vet Parasitol* 28:293-301.
- Allen JG, Masters HG, Peet RL, Mullins KR, Lewis RD, Skirrow SZ, Fry J (1983) Zing toxicity in ruminants. *J Comp Path* 93:363-377.
- Angelidou E, Kostoulas P, Leontides L (2014) Flock-level factors associated with the risk of *Mycobacterium avium* subsp. *paratuberculosis* (MAP) infection in Greek dairy goat flocks. *Prevent Vet Med* 117:233-241.
- Anosa VO, Logan-Henfrey LL, Shaw MK (1992) A light and electron microscopic study of changes in blood and bone marrow in acute hemorrhagic *Trypanosoma vivax* infection in calves. *Vet Pathol* 29:33-45.
- Ashuma, Sharma A, Das Singla L, Kaur P, Bal MS, Batth BK, Juyal PD (2013) Prevalence and haemato-biochemical profile of *Anaplasma marginale* infection in dairy animals of Punjab (India). *Asian Pac J Trop Med* pp 139-144.
- Aslani MR, Mohri M, Movassaghi AR (2005) Heinz body anaemia associated with onion (*Allium cepa*) toxicosis in a flock of sheep. *Comp Clin Path* 14:118-120.
- Bal MS, Mahajan V, Folia G, Kaur P, Singh A (2016) Diagnosis and management of bovine babesiosis outbreaks in cattle in Punjab state. *Vet World* 9(12):1370-1374.
- Baldissera MD, Pivoto FL, Bottari NB, Tonin AA, Machado G, Aires AR, Rocha JFX, Pelinson LP, Dalenogare DP, Schetinger MRC, Morsch VM, Leal MLR, Da Silva AS (2015) Effect of zinc supplementation on ecto-adenosine deaminase activity in lambs infected by *Haemonchus contortus*: Highlights on acute phase of disease. *Exp Parasitol* 151:34-38.
- Billinis C, Leontides L, Amiridis GC, Spyrou V, Kostoulas P, Sofia M (2005) Prevalence of BVDV infection in Greek dairy herds. *Prevent Vet Med* 72:75-79.
- Biryomumaisho S, Rwakishaya EK, Melville SE, Cailleau A, Lubega GW (2013) Livestock trypanosomosis in Uganda: parasite heterogeneity and anaemia status of naturally infected cattle, goats and pigs. *Parasitol Res* 112:1443-1450.
- Bordoloi G, Jas R, Ghosh JD (2012) Changes in the haemato-biochemical pattern due to experimentally induced haemonchosis in Sahabadi sheep. *J Parasit Dis* 36(1):101-105.
- Borelli V, Luciola J, Furlan FH, Hoepers PG, Roveda JF, Traverso SD, Gava A (2009) Fatal onion (*Allium cepa*) toxicosis in water buffalo (*Bubalus bubalis*). *J Vet Diagn Invest* 21:402-405.
- Bott NJ, Campbell BE, Beveridge I, Chilton NB, Rees D, Hunt PW, Gasser RB (2009) A combined microscopic-molecular method for the diagnosis of strongylid infections in sheep. *Int J Parasitol* 39:1277-1287.
- Braun U, Nuss K, Wehrbrink D, Rauch S, Pospischil A (2008) Clinical and ultrasonographic findings, diagnosis and treatment of pyelonephritis in 17 cows. *The Vet Journal* 175(2):240-248.
- Braun U, Schmid T, Muggli E, Steininger K, Previtali M, Gerspach C, Pospischil A, Nuss K, (2010) Clinical findings and treatment in 63 cows with hemorrhagic bowel syndrome. *Schweiz Arch Tierheilk (Nov)*:515-522.
- Breeze RG, Pirie HM, Selman IE, Wiseman A (1976) Pulmonary arterial thrombo-embolism and pulmonary arterial mycotic aneurysms in cattle with vena caval thrombosis: a condition resembling the hungenstovin syndrome. *Path* 119:229-237.
- Bundza A, Sugden EA, Nielsen K, Hartin KE (1982) Copper toxicosis in lambs fed milk replacer. *Can Vet J* 23:102-105.
- Burriel AR, Dalley C, Woodward MJ (2003) Prevalence of *Leptospira* species among farmed and domestic animals in Greece. *Vet Rec* 153:146-148.
- Chi Z, Liu R, Yang B, Zhang H (2010) Toxic interaction mechanism between oxytetracycline and bovine hemoglobin. *J Hazard Mater* 180:741-747.
- Cihan H, Temizel EM, Yilmaz Z, Ozarda Y (2016) Serum iron status and its relation with haematological indexes before and after parturition in sheep. *Kafkas Univ Vet Fak Derg* 22(5):679-683.
- Cregar LC, Wiedmeyer CE, Ringen DR, Evans TJ, Johnson GC, Kuroki K (2012) Copper toxicosis in a Boer goat. *Vet Clin Pathol* 41(4):502-508.
- Dabak M, Karapinar T, Gulacti I, Bulut H, Kizil O, Aydin S (2007) Hemorrhagic syndrome-like disease in calves with bovine viral diarrhoea and mucosal disease complex. *J Vet Intern Med* 21:514-518.
- Del Piero F, Poppenga RH (2006) Chlorophacinone exposure causing an epizootic of acute fatal hemorrhage in lambs. *J Vet Diagn Invest* 18:483-485.

- Denipitiya DTH, Chandrasekharan NV, Abeyewickreme W, Hartskeer RA, and M. D. Hapugoda MD (2017) Identification of cattle, buffaloes and rodents as reservoir animals of *Leptospira* in the District of Gampaha, Sri Lanka. *BMC Res Notes* 10:134.
- Deutskens F, Lamp B, Riedel CM, Wentz E, Lochnit G, Doll K, Thiel HJ, Rümnapf T (2011) Vaccine-induced antibodies linked to bovine neonatal pancytopenia (BNP) recognize cattle major histocompatibility complex class I (MHC I). *Vet Res* 42:97.
- Divers TJ and Peek SF (2008) *Rebhun's disease of dairy cattle*. 2<sup>nd</sup> Edition, Saunders, Philadelphia
- Dorny P, Stolaroff V, Charlier J, Meas S, Sorn S, Chea B, Holl D, Van Aken D, Vercruyse J (2011) Infections with gastrointestinal nematodes, *Fasciola* and *Paramphistomum* in cattle in Cambodia and their association with morbidity parameters. *Vet Parasitol* 175:293-299.
- Drakslar D, Nunez M, Apella MC, Aguero G, Gontalez S (2002) Copper deficiency in Creole goat kids. *Reprod Nutr* 42:243-249.
- Esmailnejad B, Tavassoli M, Asri-Rezaei S (2012) Investigation of hematological and biochemical parameters in small ruminants naturally infected with *Babesia ovis*. *Vet Res Forum* 3(1):31-36.
- FAO (1998), *FAMACHA Information guide*, <http://www.fao.org/docs/eims/upload/agrotech/1906/FAMACHA%20InfoGuide-FEB04v4final.pdf> [accessed 4 September 2017]
- Favero FC, Buzzulini C, Cruz BC, Felippelli G, Maciel WG, Salatta B, Siniscalchi B, Lopes WZ, Teixeira WFP, Soares VE, de Oliveira GP, da Costa AJ (2016) Experimental infection of calves with *Haemonchus placei* or *Haemonchus contortus*: Assessment of clinical, hematological and biochemical parameters and histopathological characteristics of abomasums. *Exp Parasitol* 170:125-134.
- Fukunaka M, Toyoda Y, Kobayashi Y, Furuoka H, Inokuma H (2010) Bone Marrow aplasia with pancytopenia and hemorrhage in a Japanese black calf. *J Vet Med Sci* 72(12):1655-1656.
- Genova SG, Streeter RN, Velguth KE, Snider TA, Kocan KM, Simpson KM (2011) Severe anemia associated with *Mycoplasma wenyonii* infection in a mature cow. *Can Vet J* 52:1018-1021.
- Giadinis ND, Chochlakis D, Ioannou I, Kritsepi-Konstantinou M, Papadopoulos E, Psaroulaki A, Karatzias H (2011) Haemorrhagic Diathesis in a Ram with *Anaplasma phagocytophilum* Infection. *J Comp Path* 144:82-85.
- Giadinis ND, Katsoulos PD, Chochlakis D, Tselentis Y, Ntais P, Lafi SQ, Karatzias H, Psaroulaki A (2015) Serological investigation for West Nile virus, *Anaplasma ovis* and *Leishmania infantum* in Greek cattle. *Vet Ital* 51(3):205-209.
- Giannitti F, Macias Rioseco M, Garcia GP, Beingesser J, Woods LW, Puschner B, Uzal FA (2014) Diagnostic exercise: Hemolysis and sudden death in lambs. *Vet Pathol* 51(3):624-627.
- Gkiourtzidis K, Frey J, Bourtzi- Hatzopoulou E, Iliadis N, Sarris K (2001) PCR detection and prevalence of  $\alpha$ -,  $\beta$ -,  $\beta$ 2-,  $\epsilon$ -,  $\iota$ - and enterotoxin genes in *Clostridium perfringens* isolated from lambs with clostridial dysentery. *Vet Microb* 82:39-43.
- Gladden N, Haining H, Henderson L, Marchesi F, Graham L, McDonald M, Murdoch FR, Bruguera Sala A, Orr J, Ellis K (2016) A case report of *Mycoplasma wenyonii* associated immune-mediated haemolytic anaemia in a dairy cow. *Irish Vet J* 69:1.
- Gokce HI, Woldehiwet Z (1999) Differential haematological effects of tick-borne fever in sheep and goat. *J. Vet. Med.* 46:105-115
- Grace D, Himsted H, Sidibe I, Randolph T, Clausen PH (2007) Comparing FAMACHA® eye color chart and Hemoglobin Color Scale tests for detecting anemia and improving treatment of bovine trypanosomiasis in West Africa. *Vet Parasitol* 147:26-39.
- Green LE, Graham M, Morgan KL (1997) Preliminary study of the effect of iron dextran on a non-regenerative anaemia of housed lambs *Vet Rec* 140:219-222.
- Grova L, Olesen I, Steinshamn H Stuen S (2011) Prevalence of *Anaplasma phagocytophilum* infection and effect on lamb growth. *Acta Vet Scand* 53:30.
- Heidarpour M, Fakhrieh M, Aslani MR, Mohri M, Keywanloo M (2013) Oxidative effects of long-term onion (*Allium cepa*) feeding on goat erythrocytes. *Comp Clin Pathol* 22:195-202.
- Hemalatha S, Parimal Roy, Purushothaman V, Iyue M (2013) Paratuberculosis in different breeds of sheep: A retrospective study of cases. *Int J Mycobacteriol* 2:166-170.
- Henniger T, Henniger P, Grossmann T, Distl O, Ganter M, von Loewenich FD (2013) Congenital infection with *Anaplasma phagocytophilum* in a calf in northern Germany. *Acta Vet Scand* 55:38.
- Hindson JC and Winter AC (1996) *Outline clinical diagnosis in sheep*. Wiley-Blackwell, London
- Izzo MM, Poe I, Horadagoda N, De Vosd AJ, JK (2010) Housea Haemolytic anaemia in cattle in NSW associated with *Theileria* infection. *Aust Vet J* 88:45-51.
- Jubb TF, Jerrett IV, Browning JW, Thomas KW (1990) Haemoglobinuria and hypophosphataemia in postparturient dairy cows without dietary deficiency of phosphorus. *Australian Vet J* 67:86-89.
- Kantzoura V, Kuam MK, Demiris N, Feidas H, Theodoropoulos G (2011) Risk factors and geospatial modelling for the presence of *Fasciola hepatica* infection in sheep and goat farms in the Greek temperate Mediterranean environment. *Parasitol* 138:926-938.
- Katsoulos PD, Christodoulopoulos G, Karatzia MA, Pourliotis K, Minas A (2011) Liver flukes promote cholelithiasis in sheep. *Vet Parasitol* 179:262-265.
- Katsoulos PD, S. C. Chaintoutis SC, Dovas CI, Polizopoulou ZS, Brellou GD, Agianniotaki EI, Tasioudi KE, Chondrokouki E, Papadopoulos O, Karatzias H, Boscoc C (2017). Investigation on the incidence of adverse reactions, viraemia and haematological changes following field immunization of cattle using a live attenuated vaccine against lumpy skin disease. *Transbound Emerg Dis.* 1-12.
- Katunguka-Rwakishaya E, Murray M, Holmes PH (1997) Pathophysiology of *Trypanosoma congolense* infection in two breeds of sheep, Scottish blackface and Finn Dorset. *Vet Parasitol* 68:215-225.
- Keshavarzi B, Seradj A, Akbari Z, Moore F, Shahraiki AR, Pourjafar M (2015) Chronic arsenic toxicity in sheep of Kurdistan province, Western Iran. *Arch Environ Contam Toxicol* 69:44-53.
- Knight RA (1980) Response of lambs to challenge infections after repeated inoculations with *Fasciola hepatica* cysts. *Proc Helminthol Soc Wash* 47(2):186-191.
- Kouam MK, Diakou A, Kantzoura V, Feidas H, Theodoropoulos H, Theodoropoulos G (2014) An analysis of seroprevalence and risk factors for parasitic infections of economic importance in small ruminants in Greece. *Vet J* 202:146-152.
- Lee SH, Kim S, Park SC, Kim MJ (2002) Cytotoxic Activities of *Leptospira interrogans* Hemolysin SphH as a Pore-Forming Protein on Mammalian Cells. *Infect Immun* 70:315-322
- Lotfollahzadeh S, Mohri M, Bahadori ShR, Dezfouly MRM, Tajik P (2008) The relationship between normocytic, hypochromic anaemia and iron concentration together with hepatic enzyme activities in cattle infected with *Fasciola hepatica*. *J Helminthol* 82:85-88.
- Martinez-Moreno A, Jimenez V, Martinez-Cruz MS, Martinez-Moreno FJ, Becerra C, Hernfindez S (1997) Triclabendazole treatment in experimental goat fasciolosis: anthelmintic efficacy and influence in antibody response and pathophysiology of the

- disease. *Vet Parasitol* 68:57-67.
- Masseau I, Fecteau G, Desrochers A, Francoz D, Lanthier I, Vailancourt D (2004) Hemoperitoneum caused by the rupture of a granulosa cell tumor in a Holstein heifer. *Can Vet J* 45:504-506.
- Matsuda K, Nomoto H, Kawamura Y, Someya Y, Koiwa M, Taniyama H (2010) Hemophagocytic histiocytic sarcoma in a Japanese black cow. *Vet Pathol* 47(2):339-342.
- McKenzie RA (1978) Bovine enzootic haematuria in Queensland. *Aust Vet J* 54:61-64.
- Moll, G, Lohding A, Young AS, Keitch BL (1986) Epidemiology of Theileriosis in calves in an endemic area of Kenya. *Vet Parasitol* 19:255-273.
- Moors E, Gauly M (2009) Is the FAMACHA® chart suitable for every breed? Correlations between FAMACHA® scores and different traits of mucosa colour in naturally parasite infected sheep breeds. *Vet Parasitol* 166:108-111.
- Nassiri SM, Darvishi S, Khazraeiinia P (2011) Bovine immune-mediated hemolytic anemia: 13 cases (November 2008–August 2009). *Vet Clin Pathol* 40(4):459-466.
- Ogilvie TH (1998) Hematopoietic and hemolymphatic disorders. In *Large animal, internal medicine* 1st Edition. Williams and Wilkins, London: pp 321-347.
- Ok M, Sen I, turgut K, Irmak K (2001) Plasma gastrin activity and the diagnosis of bleeding abomasal ulcers in cattle. *J Vet Med A* 48:563-568.
- Omer OH, El-Malik KE, Mahmouda OM, Haroun EM, Hawas A, Sweeney D, Magzoub M (2002) Haematological profiles in pure bred cattle naturally infected with *Theileria annulata* in Saudi Arabia. *Vet Parasitol* 107:161-168.
- Papadopoulos B, Perie NM, Uilenberg G (1996) Piroplasms of domestic animals in the Macedonia region of Greece 1. Serological cross-reactions *Vet Parasitol* 63:41-56.
- Papadopoulos E, Arsenos G, Ptochos S, Katsoulos P, Oikonomou G, Karatzia MA, Karatzias H (2014) First report of *Besnoitia besnoiti* seropositive cattle in Greece. *J Hellenic Vet Med* 64(2):115-120.
- Polizopoulou ZS (1991) Subclinical lead poisoning in sheep: epidemiologic and experimental study. Doctoral thesis, Faculty of Veterinary Medicine, Aristotelian University of Thessaloniki. (<https://www.didaktorika.gr>)
- Prakash AS, Pereira TN, Smith BL, Shaw G, Seawright AA (1996) Mechanism of bracken fern Carcinogenesis: Evidence for H-ras activation via initial adenine alkylation by ptaquiloside. *Nat toxins* 4:221-227.
- Radostits OM, Gay CC, Hinchcliff KW, Constable PD (2006) Diseases of the hemolymphatic and immune systems. In *Veterinary Medicine: A textbook of the diseases of cattle, horses, sheep, pigs and goats*. 10th Edition, Saunders Ltd, Philadelphia: pp 439-469.
- Rae HA (1999) Onion toxicosis in a herd of beef cows. *Can Vet J* 40:55-57.
- Rana T, Bera AK, Das S, Bhattacharya D, Bandyopadhyay D, Pan D, Das AK (2010) Effect of chronic intake of arsenic-contaminated water on blood oxidative stress indices in cattle in an arsenic-affected zone. *Ecotoxicol Environ Saf* 73:1327-1332.
- Randhawa SS, Sharma DK, Randhawa CS, Gill BS, Brar RS, Singh J (1995) An outbreak of Bacillary haemoglobinuria in sheep in India. *Trop Anim Health Prod* 27:31-36.
- Ross JG, Todd JR, Dow C (1966) Single experimental infection of calves with the liver fluke, *Fasciola hepatica* (Linnaeus 1758). *J Comp Path* 76:67-81.
- Saleh MA (2008) Circulating oxidative stress status in desert sheep naturally infected with *Fasciola hepatica*. *Vet Parasitol* 154:262-269.
- Schlerka G, Tataruch F, Hogler S, Url A, Krametter R, Kossler D, Schmidt P (2004) Acute lead poisoning in cows due to feeding of lead contaminated ash residue. *Berl Munch Tierarztl Wochenschr* 117(1-2):52-6.
- Shemanchuk JA, Haufe WO, Thompson COM (1960) Anemia in range cattle heavily infested with the short-nosed sucking louse, *Haematopinus eurysternus* (NITZ) (Anoplura: Haematopinidae). *Can J Comp Med Vet Sci* 24:158-161.
- Singh J, Gupta SK, Singh R, Hussain RA (2014) Etiology and haemato-biochemical alterations in cattle of Jammu suffering from anaemia. *Vet World* 7(2):49-51.
- Singh KS, Mukhopadhyay SK, Ganguly S, Niyogi D, Thiyagaseelan C, Ali I (2011) Hematological and biochemical studies of stephanofilarial dermatitis in naturally infected cattle of West Bengal, India. *Res Vet Sci* 91:194-195.
- Smith MC and Sherman DM (2009) *Goat medicine*. 2<sup>nd</sup> Edition, Wiley-Blackwell.
- Sonawane GG, Tripathi BN (2013) Comparison of a quantitative real-time polymerase chain reaction (qPCR) with conventional PCR, bacterial culture and ELISA for detection of *Mycobacterium avium* subsp. *paratuberculosis* infection in sheep showing pathology of Johne's disease. *Sonawane and Tripathi Springer-Plus* 2:45.
- Sotomaior CS, Rosalinski-Moraes F, da Costa LRB, Maia D, Monteiro ALG, van Wyk JA (2012) Sensitivity and specificity of the FAMACHA® system in Suffolk sheep and crossbred Boer goats. *Vet Parasitol* 190:114-119.
- Souma T, Suzuki N, Yamamoto M (2015) Renal erythropoietin-producing cells in health and disease. *Front Physiol* 6:167.
- Steffen DJ, Elliott GS, Leipold HW, Smith JE (1992) Congenital dyserythropoiesis and progressive alopecia in Polled Hereford calves: hematologic, biochemical, bone marrow cytologic, electrophoretic, and flow cytometric findings. *J Vet Diagn Invest* 4:31-37.
- Stock ML, Smith BI, Engiles JB (2011) Disseminated hemangiosarcoma in a cow. *Can Vet J* 52:409-413.
- Stogdale L (1978) Chronic copper poisoning in dairy cows. *Australian Vet J* 54:139-141.
- Stromberagn PC, Gyillot FS (1987) Hematology in the regressive phase of bovine psoroptic scabies. *Vet Pathol* 24:371-377.
- Suttle BF, Jones DG, Woolliams C, Woolliams JA (1987) Heinz body anaemia in lambs with deficiencies of copper or selenium. *Brit J Nutr* 58:539-548.
- Suzuki J, Sasaoka F, Fujihara M, Watanabe Y, Asaki T, Oda S, Kobayashi S, Sato R, Nagai K, Harasawa R (2011) Molecular identification of 'Candidatus *Mycoplasma haemovis*' in sheep with hemolytic anemia. *J Vet Med Sci* 73(8):1113-1115.
- Takagi M, Yamato O, Sasaki Y, Mukai S, Fushimi Y, Yoshida T, Mizukami K, Shoubudani T, Amimiti K, Chuma T, Shahada F, Endo Y, Deguchi E (2009) Successful treatment of bacillary hemoglobinuria in Japanese black cows. *J Vet Med Sci* 71(8):1105-1108.
- Tartour G, Obeid HM, Adam SEI, Idris OF (1973) Haematological changes in sheep and calves following prolonged oral administration of *Ipomoea carnea*. *Trop Anita Health Prod* 5:284-292.
- Tasioudi KE, Antoniou SE, Iliadou P, Sachpatzidis A, Plevraki E, Agianniotaki EI, Fouki C, Mangana-Vougiouka O, Chondrokouki E, Dile C (2016) Emergence of Lumpy Skin Disease in Greece, 2015. *Transbound Emerg Dis* 63:260-265.
- Trueman KF, Blight GW (1978) The effect of age on resistance of

- cattle to *Babesia bovis*. *Aust Vet J* 54:301-305.
- Ulvund JM (1990) Ovine White-Liver Disease (OWLD). Changes in Blood Chemistry. *Acta Vet. Scand.* 31:277-286.
- Van Aken V, Verduyck J, Dargantes AP, Lagapa JT, Raes S, Shaw DJ (1997) Pathophysiological aspects of *Mecistocirrus digitatus* (Nematoda: Trichostrongylidae) infection in calves. *Vet Parasitol* 69:255-263.
- Vasileiou NGC, Fthenakis GC, Amiridis GS, Athanasiou LV, Birtsas P, Chatzopoulos DS, Chouzouris TM, Giannakopoulos A, Ioannidi KS, Kalonaki SN, Katsafadou AI, Kyriakis CS, Mavrogianni VS, Papadopoulos E, Spyrou V, Valiakos G, Venianaki AP, Billinis C (2016) Experiences from the 2014 outbreak of bluetongue in Greece. *Small Rum Res* 142:61-68.
- Vatn S, Ulvund MJ (2000) Abomasal bloat, haemorrhage and ulcers in young Norwegian lambs *Vet Rec* 146:35-39.
- Vatta AF, Krecek RC, Letty BA, van der Linde MJ, Grimbeek RJ, de Villiers JF, Motswatswe PW, Molebiemang GS, Boshoff HM, Hansen JW (2002) Incidence of *Haemonchus* spp. and effect on haematocrit and eye colour in goats farmed under resource-poor conditions in South Africa. *Vet Parasitol* 103:119-131.
- Weiss DJ, Wardrop KJ (2010) Normal hematology of cattle. In *Schalm's Veterinary hematology*, 6th Edition, Wiley- Blackwell, pp 829-835.
- WHO (2004) Hemoglobin color scale: Operational research agenda and study design. World Health Organisation, Geneva, Switzerland, pp 16.
- Winter A, Clarkson M (1992) Anaemia in lambs and kids caused by feeding cow colostrum. *In Practice* 14:283-286.
- Xu LR (1992) Bracken poisoning and enzootic haematuria in cattle in China. *Res Vet Sci* 53:116-121.
- Yang J, Liu Z, Guan G, Li Y, Chen Z, Ma M, Liu A, Q Ren, Wang J, Luo J, Yin H (2015) Comprehensive surveillance of the antibody response to *Borrelia burgdorferi* s.l. in small ruminants in China. *Ann Agric Environ Med* 22(2):208-211.
- Yasini SP, Khaki Z, Rahbari S, Kazemi B, Salar Amoli J, Gharabaghi A, Jalali SM (2012) Hematologic and clinical aspects of experimental ovine anaplasmosis caused by *Anaplasma ovis* in Iran. *Iranian J Parasitol* 7(4):91-98.
- Yeruham I, Avidar Y, Harrus S, Fishman Z, Aroch I (2003) Immune-mediated thrombocytopenia and putative haemolytic anaemia associated with a polyvalent botulism vaccination in a cow. *Vet Rec* 153:502-504.
- Yeruham I, Hadani A, Galker F, Avidar Y, Bogin E (1998) Clinical, clinico-pathological and serological studies of *Babesia ovis* in experimentally infected sheep. *J Vet Med B* 45:385-394.