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Case Study

Characterization of bone marrow aspirate reports in dogs and cats: A retrospective study

Caracterización de informes de aspirado de médula ósea en perros y gatos: Estudio retrospectivo

Caracterização de laudos de aspirados de medula óssea em cães e gatos: Estudo retrospectivo

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Abstract

Background: Bone Marrow Aspirate (BMA) allows for the study, staging, and monitoring of multiple conditions involving bone marrow. The BMA report is a crucial component of the post-analytical stage and significantly influences the veterinarian's understanding and decision-making process. **Objective:** To describe the zoogeographic, clinical, and quality characteristics of BMA reports, as well as the frequency of diagnoses and associated factors in dogs and cats treated at veterinary centers in Colombia from 2012 to 2023. **Methods:** This was a cross-sectional descriptive study. Data on zoogeographic and clinical variables were extracted from BMA reports and consultations; the frequency of diagnoses and associated factors were determined. Adherence to reporting quality was evaluated using established guidelines for BMA in dogs, cats, and humans. **Results:** A total of 135 BMA reports were reviewed from eight veterinary institutions: 116 for dogs and 19 for cats, with a mean age of 5.22 ± 3 years; 53% were male. The most common indication for BMA was anemia, alone or in combination with other abnormalities. The least frequently reported elements were puncture site (91.9%), relevant clinical data (85.2%), and morphological evaluation by cell line (52.6%). Additionally, 27.4% of the reports were excluded due to poor sample quality. The most frequent diagnosis in dogs was hypoplasia (36.1%), while in cats, it was neoplasia (40.0%). Erythroid hyperplasia and neoplasms were more prevalent in males, whereas granulocytic hypoplasia was more common in females. **Conclusions:** BMA is rarely used as a diagnostic tool for dogs and cats in Colombia. A significant proportion of samples did not meet quality criteria, and adherence to reporting guidelines was low.

Keywords: *bone marrow; bone marrow aspirate; cat diseases; dog diseases; hematology; hyperplasia; neoplasms; pets.*

Resumen

Antecedentes: El aspirado de médula ósea permite el estudio, estadificación y seguimiento de múltiples enfermedades con compromiso medular. El informe de resultados es un componente esencial de la etapa posanalítica y los ítems establecidos por cada institución influyen significativamente en la comprensión y toma de decisiones del médico tratante. **Objetivo:** Describir las características zoogeográficas, clínicas y de calidad, así como la frecuencia de diagnósticos y sus factores asociados en informes de aspirado de médula ósea de perros y gatos atendidos en centros veterinarios de Colombia durante el período 2012-2023. **Métodos:** Estudio transversal descriptivo. A partir de los informes de aspirado de médula ósea e interconsultas, se extrajeron variables zoogeográficas y clínicas, y se determinó la frecuencia de diagnósticos y sus factores asociados. Se evaluó la adherencia a los criterios de calidad del reporte, contrastando con las directrices para el informe de aspirados de médula ósea en perros, gatos y humanos. **Resultados:** Se analizaron 135 informes de aspirado de médula ósea provenientes de ocho instituciones veterinarias (116 de perros y 19 de gatos), con una edad promedio de 5.22 ± 3 años. El 53% eran machos. La indicación más frecuente fue anemia persistente, sola o en combinación con otras alteraciones. Los ítems con menor adherencia en el reporte de resultados fueron: sitio de punción (91.9%), datos clínicos relevantes (85.2%) y valoración morfológica por línea celular (52.6%). Además, el 27.4% de los informes fue excluido debido a una calidad inadecuada de la muestra. El diagnóstico más común en perros fue hipoplasia (36.1%), mientras que en gatos fue neoplasia (40.0%). La hiperplasia eritroide y las neoplasias fueron más frecuentes en machos, mientras que la hipoplasia granulocítica fue más común en hembras. **Conclusiones:** El estudio de médula ósea como herramienta diagnóstica en perros y gatos es poco frecuente en Colombia. Se encontró un porcentaje significativo de muestras que no cumplían con criterios de calidad, así como una baja adherencia a las guías para el reporte de resultados.

Palabras clave: *aspirados de médula ósea; enfermedades de los gatos; enfermedades de los perros; hematología; hiperplasia; mascotas; médula ósea; neoplasias.*

Resumo

Antecedentes: A aspiração de medula óssea permite o estudo, estadiamento e monitoramento de múltiplas doenças com envolvimento medular. O laudo é um componente essencial da etapa pós-analítica, e os itens estabelecidos por cada instituição influenciam significativamente o entendimento e a tomada de decisão do médico veterinário responsável. **Objetivo:** Descrever as características zoogeográficas, clínicas e de qualidade, bem como a frequência dos diagnósticos e seus fatores associados nos laudos de aspirados de medula óssea de cães e gatos atendidos em centros veterinários na Colômbia durante o período 2012-2023. **Métodos:** Estudo transversal descritivo. Dos laudos de aspirados de medula óssea e das interconsultas, foram extraídas variáveis zoogeográficas e clínicas, e determinada a frequência dos diagnósticos e seus fatores associados. A adesão às variáveis de qualidade do relato foi avaliada com base nas diretrizes para a notificação de aspirados de medula óssea em cães, gatos e humanos. **Resultados:** Foram analisados 135 laudos de aspirados de medula óssea provenientes de oito instituições veterinárias (116 de cães e 19 de gatos), com idade média de 5,22 ± 3 anos. Do total, 53% eram machos. A indicação mais frequente foi anemia persistente, isolada ou associada a outra alteração. Os itens com menor adesão na notificação dos resultados foram: local da punção (91,9%), dados clínicos relevantes (85,2%) e avaliação morfológica por linhagem celular (52,6%). Além disso, 27,4% dos laudos foram excluídos devido à qualidade inadequada da amostra. O diagnóstico mais comum em cães foi hipoplasia (36,1%), enquanto em gatos foi neoplasia (40,0%). A hiperplasia eritroide e as neoplasias foram mais comuns em machos, enquanto a hipoplasia granulocítica foi mais frequente em fêmeas. **Conclusões:** A aspiração de medula óssea como ferramenta diagnóstica em cães e gatos na Colômbia é pouco utilizada. Foi encontrada uma percentagem significativa de amostras que não atendiam aos critérios de qualidade, bem como baixa adesão às diretrizes para notificação dos resultados.

Palavras-chave: *animais de estimação; aspirados de medula óssea; doenças do cão; doenças do gato; hematologia; hiperplasia; medula óssea; neoplasias.*

Introduction

Bone Marrow Aspirate (BMA) is an essential tool for studying, staging, and monitoring various conditions involving the bone marrow in veterinary medicine (Javinsky, 2012; Stacy and Harvey, 2017). This technique offers a reliable means of obtaining accurate diagnoses and is relatively safe, with minimal risks and few complications (Woods et al., 2021). The effective use of BMA in routine veterinary practice requires proper sample collection, accurate smear interpretation, and comprehensive reporting that provides clear diagnostic information (Messick, 2023).

The BMA report is a crucial component of the post-analytical stage and significantly influences the veterinarian's understanding and decision-making process (Hawkins, 2012; Sciacovelli et al., 2016). A thorough report must include essential elements such as sample traceability, patient identification, correlation with complete blood count, and clinical history or prior diagnostic tests. Additionally, it should compare findings with reference values and, when necessary, suggest additional tests such as immunophenotyping, cytochemistry, cytogenetics, and molecular biology. These components are critical for differential diagnosis and a deeper understanding of bone marrow findings (Stacy and Harvey, 2017).

Advancements in human and veterinary hematology have prompted the development of standardized guidelines aimed at optimizing processes from test requests to result interpretation and reporting (Riley et al., 2021; Ritt, 2022). In veterinary medicine, these guidelines frequently draw from human models, leveraging physiological similarities across species such as dogs, cats, and humans (Comazzi et al., 2017; Rütgen et al., 2022).

In Colombia, research on BMA in companion animals remains scarce, leading to the underestimation of key factors related to its application in dogs and cats, whose combined population exceeded eleven million in 2022 (Ministerio de Salud y Protección Social, 2022).

The objective of this study was to describe the zoogeographic, clinical, and quality characteristics of BMA reports, as well as the frequency of diagnoses and associated factors, in dogs and cats treated in veterinary centers in Colombia between 2012 and 2023.

Materials and Methods

Ethical considerations

This study was approved by the Animal Experimentation Ethics Committee of the University of Antioquia (Act No. 146 of 2022).

Study design

A descriptive cross-sectional study was conducted using convenience sampling of veterinary medical centers and laboratories from various municipalities in Colombia. The study focused on collecting BMA reports for dogs and cats from January 2012 to October 2023.

Description of Reports

The zoogeographic, clinical, and quality characteristics of the BMA reports were described using univariate statistical analysis. Qualitative variables were assessed through relative and absolute frequencies, while measures of central tendency and dispersion were applied to quantitative variables.

Four age groups were defined based on the American Animal Hospital Association (AAHA) guidelines. For cats: kitten (0–1-year-old), young adult (1-6 years old), mature adult (7-10 years old), and senior (>10 years old). For dogs: puppy (0–1-year-old), adult (1-6 years old), senior (7-11 years old), and geriatric (>12 years old) (Creevy et al., 2019). Dog breeds were grouped into small, medium, and large categories, as described by Posada et al. (2014).

Quality characteristics of reports

The quality characteristics of the reports were established by compiling guidelines from the International Council for Standardization in Hematology (Lee et al., 2008), the Royal College of Pathologists of Australasia (2014), and veterinary literature encompassing criteria for evaluating and reporting BMA in dogs and cats (Abella-Bourgès et al., 2005; Cowell and Valenciano, 2023; Grindem et al., 2002; Mylonakis and Hatzis, 2014; Raskin and Messick, 2012; Stacy and Harvey, 2017).

To ensure adherence to these criteria in the reports issued by the institutions, the required

data had to be included directly within the report itself, regardless of any additional information provided in clinical history by the requesting veterinarian. The variables were categorized into two groups: basic and analytical.

Basic variables include essential information that should be present in the report regardless of the bone marrow sample quality. These include patient identification, details of the requesting veterinarian, a summary of the patient's clinical history, specifics about the bone marrow puncture site, the presence or absence of bone marrow particles or spicules, and a concluding summary.

Analytical variables include aspects directly associated with the bone marrow sample analysis. These variables include assessments of cellularity, differential counts, morphological evaluations, and cellular indices.

Frequency of diagnoses

Reports were excluded if they lacked essential data for interpretation or if the sample quality was compromised due to factors such as absence of particles, hemodilution, mechanical damage, or poor preservation. In this context, a diagnosis was defined as a judgment or conclusion derived from the comprehensive analysis of the sample, as documented by the interpreting professional. This encompassed both neoplastic and non-neoplastic conditions, as well as cases where no abnormalities were detected, for estimating both relative and absolute frequencies.

Factors associated with diagnoses

Fisher's exact test was applied to compare the zoogeographic and clinical characteristics with BMA diagnoses in the study population, using a significance level of $p < 0.05$. The analyses were conducted using Jamovi® software, version 2.3.

Results

A total of 139 veterinary centers across 19 provinces (25 municipalities) in Colombia were contacted. Of these, 32% (45/139) offered BMA collection, reading, or both. However, half of these outsourced the service. Out of the remaining 22 institutions, eight agreed to participate. Most of these were pathology laboratories that received samples from 46 veterinary centers in capital municipalities of seven provinces (Table 1).

Table 1. Distribution of BMA reports from dogs and cats by province in Colombia (2012–2023).

Province	Number of reports (%)
Antioquia	76 (56.3%)
Cundinamarca	1 (0.7%)
Valle del Cauca	16 (11.8%)
Atlántico	7 (5.1%)
Tolima	3 (2.2%)
Casanare	1 (0.7%)
Meta	13 (9.6%)
Missing	*18 (13.3%)*
Total	135 (100%)

A total of 135 BMA reports were obtained; 73.3% of these were reported between 2018 and 2023. The dataset included 116 dogs and 19 cats, with an average age of 5.2 ± 3 years (dogs 5.5 ± 3.2 years, median 6; cats 3.1 ± 3.0 years, median 2). Of these, 53.3% were male.

Table 2. Hematological and clinical abnormalities reported in dogs and cats' consultations.

Abnormalities (n = 83)	n	%
Hematological (n = 75)		
Pancytopenia	13	17.3
Anemia and thrombocytopenia	13	17.3
Thrombocytopenia	11	14.7
Anemia	8	10.7
Anemia and leukocytosis	7	9.3
Anemia, thrombocytopenia, and leukocytosis	5	6.7
Leukopenia	5	6.7
Leukocytosis	5	6.7
Thrombocytopenia and leukopenia	4	5.3
Anemia and thrombocytosis	2	2.7
Anemia, thrombocytosis, and leukopenia	1	1.3
Thrombocytopenia and leukocytosis	1	1.3
History of infectious agents (n = 17)		
Dogs (n = 14)		
Ehrlichia spp.	3	17.6
Anaplasma spp.	3	17.6
Ehrlichia spp. and Anaplasma spp.	2	11.8
Babesia spp.	1	5.9
Hepatozoon spp.	1	5.9
Mycoplasma spp.	1	5.9
Missing	3	17.6
Cats (n = 3)		
Mycoplasma spp.	2	11.8
Bartonella spp.	1	5.9
*Clinical signs (n = 41)**		
Fever	11	26.8
Constitutional syndrome	21	51.2
Lymphadenopathy	5	12.2
Organomegaly	12	29.2

**One patient may be classified into multiple categories concurrently.*

Among the patients with consultations (n = 83/135; 61.4%), 75/83 (90%) presented hematological alterations, 17/83 (20%) had a history of hemotropic agent infections, and 41/83 (49%) exhibited clinical signs (Table 2).

Additional findings included musculoskeletal abnormalities, respiratory signs, ascites, and petechiae. Blast cells were reported in three blood smears, and one cat tested positive for feline leukemia virus.

The aspirate samples were mostly taken from live patients (130/135; 96.3%), but the sample collection site was reported in only 36/135 (26.6%) of cases. The reported collection sites were the sternum (n=1), femur (n=4), humerus (n=27), ilium (n=2), and tibia (n=2).

A total of 39 dog breeds were identified. The most frequent breeds (≥3 individuals) included Beagle, Golden Retriever, French Poodle, Labrador, German Shepherd, Shih Tzu, Springer Spaniel, Yorkshire Terrier, Schnauzer, Pinscher, Pitbull, and mixed breeds. Among cats, nine breeds were identified, including Bombay, British Shorthair, Domestic Shorthair, European Shorthair, Balinese, Russian Blue, Exotic, and Persian. However, 8/19 (42%) were mixed breeds.

The distribution of dog breeds by size was: small (22/116; 19%), medium (69/116; 59%), and large (24/116; 21%). Additionally, adults of both species were the most common age group (Table 3). Additionally, adults of both species were the most common age group (Table 3).

Table 3. Frequency of patients by species and age group (2012–2023).

Group		n	%
Dogs (n = 116)			
Puppy	(0 – 1-year-old)	8	6.9
Adult	(1 – 6-year-old)	59	50.8
Senior	(7 – 11-year-old)	38	32.7
Geriatric	(>12-year-old)	4	3.4
Missing		*7*	*6.0*
Cats (n = 19)			
Kitten/puppy	(0 – 1-year-old)	4	21.0
Young adult	(1 – 6-year-old)	12	63.1
Mature adult	(7 – 10-year-old)	2	10.5
Senior	(>10-year-old)	1	5.2

Quality characteristics of reports

The variables detailed in Tables 4 and 5 were analyzed to evaluate the quality of the reports. Among the fundamental elements comprising the header of a BMA report, two reports lacked data regarding the requesting physician or institution. However, all reports adequately identified the institution providing the service, included internal coding, specified the sample type, and provided dates of receipt or result issuance, as well as the owner's name and the patient's species. Notably, some reports failed to record the name, age, sex, and breed of certain patients (Table 4).

Additionally, only 11/135 (8.1%) of the reports specified the puncture site for the aspirate. Relevant clinical data were missing in 115/135 (85.2%) of cases. Furthermore, the presence or absence of particles was not reported in 36/135 (26.7%) of cases, and 7/135 (5.2%) of the reports lacked a conclusion (Table 4).

Table 4. Quality characteristics of dogs and cats BMA reports: basic variables.

Variable	Reported n = 135	
	Yes n (%)	No n (%)
Patient's name	133 (98.5)	2 (1.4)
Age	126 (93.3)	9 (6.7)
Sex	133 (98.5)	2 (1.5)
Breed	134 (99.3)	1 (0.7)
Requester information	133 (98.5)	2 (1.5)
Puncture site	11 (8.1)	124 (91.9)
Relevant clinical data	20 (14.8)	115 (85.2)
Presence of marrow particles	99 (73.3)	36 (26.7)
Conclusion or interpretation	128 (94.8)	7 (5.2)

Regarding the analytical variables, many reports were missing data on cellularity, differential count, morphological evaluation, and indices (Table 5). Out of the 104 reports that included the differential count, only 90 presented it in relative values. Furthermore, out of the 85 reports that reported the total number of counted cells, 18 indicated counts performed on fewer than 300 cells.

Table 5. Quality characteristics of dogs and cats' BMA reports: analytical variables.

Variables of report	Reported n = 135		
	Yes n (%)	No n (%)	Not applicable n (%)
Cellularity	97 (71.9)	25 (18.5)	13 (9.6)
Differential count	104 (77.0)	18 (13.3)	13 (9.6)
Number of cells evaluated	85 (63.0)	37 (27.4)	13 (9.6)
Morphological assessment by cell line	50 (37.0)	71 (52.6)	14 (10.4)
Indice	95 (70.4)	17 (12.6)	23 (17.0)
Myeloid/erythroid	95 (100)	0 (0)	
Maturation	73 (76.8)	22 (23.2)	

Diagnosis frequency

Out of the total BMA reports, 37/135 (27.4%) (4 from cats and 33 from dogs) were excluded due to sample quality issues. The diagnostic frequency was established for both species based on the remaining 98/135 reports (72.6%). Neoplastic, hyperplastic, and hypoplastic groups were subclassified according to the affected cell line (Table 6). The male-to-female ratio was maintained, with 54/98 (55.1%) being males.

The most common diagnoses in dogs were erythroid, granulocytic, or combined hypoplasia, while neoplasia was more prevalent in cats. Infectious agents were identified as the sole alteration in five reports (Table 6). However, they were found in 16 BMA: *Anaplasma* spp. in three, *Ehrlichia* spp. in seven, *Babesia* spp. in two, *Hepatozoon* spp. in one, *Leishmania* spp. in one, and co-infection by *Anaplasma* spp. and *Ehrlichia* spp. in two cases. In three cases, the species of hemotropic parasite reported in the

BMA matched the initial consultation report. Likewise, in eight cases of hematopoietic tissue infections, patients presented with concurrent marrow alterations, including decreased cellularity, myelodysplasia, medullary aplasia, and hypoplasia, while three of these cases also exhibited hyperplasia and reactive bone marrow.

Table 6. Diagnosis frequency in dogs and cats' BMA reports.

Diagnostic	Dogs n=83		Cats n=15		Total n=98	
	n	%	n	%	n	%
Hypoplasia	*30*	*36.1*	*1*	*6.7*	*31*	*31.6*
Erythroid	7	23.3	0	0.0	7	22.6
Granulocytic	11	36.7	0	0.0	11	35.5
Erythroid and granulocytic	12	40.0	1	100.0	13	41.9
Neoplasia	*14*	*16.8*	*6*	*40.0*	*20*	*20.4*
Lymphoproliferative						
Acute	3	21.4	1	16.7	4	20.0
Chronic	3	21.4	1	16.7	4	20.0
Myeloproliferative						
Acute	1	7.1	2	33.3	3	15.0
Chronic	2	14.3	1	16.7	3	15.0
Myelodysplasia						
Granulocytic	4	28.6	1	16.7	5	25.0
Erythroid	1	7.1	0	0.0	1	5.0
Hyperplasia	*13*	*15.7*	*4*	*26.4*	*17*	*17.3*
Erythroid	3	23.1	3	75.0	6	35.3
Granulocytic	8	61.5	0	0.0	8	47.1
Granulocytic and erythroid	2	15.4	1	25.0	3	17.6
Reactive Bone Marrow	8	9.6	2	13.3	10	10.2
Medullary Aplasia	7	8.4	2	13.3	9	9.2
Normal Bone Marrow	6	7.2	0	0.0	6	6.1
Infectious agents	5	6.0	0	0.0	5	5.1

Chronic lymphoproliferative disorders included one case of plasma cell neoplasia in a dog, while chronic myeloproliferative disorders included chronic eosinophilic leukemia in a cat. Myelodysplastic neoplasms were characterized by maturation changes in the nucleus and cytoplasm exceeding 10%. Prussian blue staining for ring sideroblast identification was not reported. Among the five patients with lymphadenopathy, one was diagnosed with chronic myeloproliferative leukemia and two with acute lymphocytic leukemia.

Factors associated with diagnoses

Granulocytic hypoplasia was more common in females (9/44; 20.5%) than in males (2/54; 3.7%; p = 0.011). However, neoplasms were more common in males (16/54; 29.6%) than in females (4/44; 9.1%; p = 0.013), and erythroid hyperplasia was only present in males (6/54; 11.1%; p = 0.031;

Table 7). Hypoplasia occurred more frequently in dogs (30/83; 36.1%) than in cats (1/15; 6.7%; p = 0.032). However, erythroid hyperplasia was more common in cats (3/15; 20.0%) than in dogs (3/83; 3.6%; p = 0.044). Granulocytic hyperplasia was more frequent in small-breed individuals (4/13; 30.8%; p = 0.013). There was no breed predominance in cats for any diagnosis, nor was there in the disaggregated dog breeds. Four of the patients who presented with medullary aplasia had pancytopenia (4/9; 44.4%; p = 0.002). Other individuals with pancytopenia were diagnosed with hypoplasia, myelodysplasia, and *Ehrlichia* spp. infection.

Table 7. Factors associated with bone marrow diagnoses in dogs and cats from Colombia (2012–2023).

Factors		Diagnostic				p-value
		Yes		No		
		n	%	n	%	
				Medullary Aplasia		
Pancytopenia	Yes	4	44.4	5	55.6	0.002
	No	3	5.7	50	94.3	
				Granulocytic Hypoplasia		
Sex	Female	9	20.5	35	79.5	0.011
	Male	2	3.7	52	96.3	
				Hypoplasia		
Species	Dogs	30	36.1	53	63.9	0.032
	Cats	1	6.7	14	93.3	
				Hyperplasia erythroid		
Species	Dogs	3	3.6	80	96.4	0.044
	Cats	3	20.0	12	80.0	
Sex	Female	0	0	44	100	0.031
	Male	6	11.1	48	88.9	
				Hyperplasia granulocytic		
Breed	Small	4	30.8	9	69.2	0.013
	Medium	2	3.8	51	96.2	
	Large	2	12.5	14	87.5	
				Neoplasia		
Sex	Female	4	9.1	40	90.9	0.013
	Male	16	29.6	38	70.4	

Discussion

The total number of BMA reports obtained during the study period from eight institutions differs significantly with findings reported by Weiss (2006a, 2006b) and Turinelli et al. (2015, 2018). Weiss (2006a) compiled 203 samples from cats and 717 from dogs in a single American institution over eight years. Similarly, Turinelli et al. (2015) gathered 295 dog samples over two years and 152 cat samples over three years in a European laboratory. These comparisons suggest that BMA is less commonly performed in Colombia than in other countries. Additionally, prior studies have reported that bone marrow evaluations are more frequent in dogs than in cats, a trend consistent with our study, where the dog-to-cat ratio was 8:1. This discrepancy in Colombia may be attributed to the higher population of dogs compared to cats (Ministerio de Salud y Protección Social, 2022). Furthermore, given that hematological alterations in cats are frequently associated with highly prevalent viral infections, BMA may not be routinely performed as a differential diagnostic tool (Molina, 2020; Ortega et al., 2020; Santisteban et al., 2021).

Persistent anemia, either alone or accompanied by other hematological abnormalities, was the most common indication for BMA, followed by thrombocytopenia. This aligns with the findings of Turinelli et al. (2015), where 37.6% of patients underwent BMA for persistent anemia. This hematological condition is frequently encountered in veterinary practice and is often associated with solid tumors, hematopoietic malignancies, inflammatory diseases, immune-mediated disorders, and renal dysfunction (Chervier et al., 2012; Grzelak and Fry, 2022). Therefore, BMA is crucial for the differential diagnosis of non-regenerative, persistent anemia of unknown origin (Raskin and Messick, 2012).

Several BMA reports lacked essential information such as patient sex, age, clinical history, marrow particle description, cellularity assessment, morphological evaluation, and differential count. These omissions hinder the proper interpretation of BMA findings. Experts in human hematopathology have demonstrated the advantages of implementing structured reports, which gather both essential and analytical elements, avoiding unstructured narrative formats (Sever et al., 2016). This approach facilitates the analysis of the results against established diagnostic criteria, especially considering that the final report directly impacts the decision-making of the treating physician (Mylonakis and Hatzis, 2014; Stacy and Harvey, 2017).

As previously described, sample quality is a well-known limiting factor in the analytical process of BMA (Trejo-Ayala et al., 2015). This study excluded 27.4% of samples due to quality issues. This finding aligns with Turinelli et al. (2015, 2018), who reported a percentage of non-diagnostic samples in dogs and cats of 30.5% and 26.5%, respectively. However, these rates contrast with Weiss (2006a, 2006b), who reported significantly lower non-diagnostic sample rates of 2.5% (cats) and 1.6% (dogs).

Hemodilution has been described as the primary cause of BMA rejection, and deficiencies associated with this error can be mitigated through technical improvements, such as particle selection and proper smear preparation (Riley et al., 2021). However, the responsibility for the sampling process lies primarily with the clinician, as demonstrated by Siddon et al. (2021).

The most frequent diagnosis in dogs was bone marrow hypoplasia (36.1%), a rate closely aligned with findings by Girardi et al. (2017) in Brazil, where 26.2% of 65 dogs with pancytopenia presented with hypoplasia. However, this rate differs from the findings of Weiss (4.3%) and Turinelli et al. (7.8%) (Turinelli et al., 2015; Weiss, 2006b). This group of abnormalities has been linked to medication use, chemical substances, radiation, infections, immune disorders, and neoplasms in both humans and animals (Grimes and Fry, 2015; Javinsky, 2012; Moore and Krishnan, 2023). A more detailed investigation into the causes of these abnormalities was not possible due to the limited clinical history information available for the patients.

Moreover, hyperplasia was the second most frequent diagnosis, with a prevalence of 15.7% in dogs, a rate similar to those previously reported in the United States (20.2%) and Europe (25.1%) (Turinelli et al., 2015; Weiss, 2006b). Non-neoplastic hyperplasia must be correlated with clinical findings and diagnostic aids to determine the underlying causes, as it may be a temporary response to hemolytic anemias,

chronic inflammatory processes, or other factors (Haines et al., 2022; Orazi et al., 2006).

Despite the small sample size, neoplasms were the most frequent diagnoses in cats. No single cell line predominated, resulting in similar proportions of lymphoproliferative, myeloproliferative, and myelodysplastic disorders. For instance, Gilroy et al. (2011) documented a case of chronic eosinophilic leukemia in a male cat with persistent eosinophilia, mirroring findings in our study. Similarly, Campbell et al. (2013) described 18 cases of chronic lymphocytic leukemia in cats over a ten-year period, while Patel et al. (2005) identified 16 cases of multiple myeloma in cats over an eight-year period. Both studies applied diagnostic criteria to both peripheral blood samples and BMAs, revealing a higher number of cases than those found in our study, despite covering a longer period. This discrepancy suggests a potential underdiagnosis of marrow conditions in dogs and cats.

Additionally, vector-borne diseases have been associated with various hematological abnormalities, often manifesting as reductions in one or more cell lines (Bonilla-Aldana et al., 2022; Tommasi et al., 2014). This corresponds with our study's results, where eight patients with myelodysplasia, aplastic anemia, and hypoplasia had evidence of Ehrlichia spp., Babesia spp., and *Anaplasma* spp. in BMAs, which had not been previously detected in peripheral blood samples.

A higher frequency of males was observed in the neoplasm group, which differs from Turinelli et al. (2015, 2018), who reported similar sex distributions in malignant cases. Other studies in dogs have suggested a greater predisposition in males to various neoplasms; however, specific data regarding sex differences in hematopoietic neoplasms are scarce (Pinello et al., 2022). A study of 3,400 dogs showed that males tend to be diagnosed with cancer at an earlier age than females (Rafalko et al., 2023); however, in the present study, no association between age and diagnosis was found, despite most patients being adults at the time of aspiration.

Nine cases were identified in which females presented with granulocytic hypoplasia. It has been established that the bone marrow of dogs is highly sensitive to suppression caused by endogenous or exogenous estrogens (Sontas et al., 2009; Weiss, 2022). However, clinical history data were insufficient to identify whether treatments or underlying conditions may have contributed to this disorder.

No publications discussing sex-related predisposition in dogs or cats were found for erythroid hyperplasia; in this study, all cases occurred in males. This condition has been associated with peripheral causes of cell destruction and myelodysplastic neoplasms (Haines et al., 2022; Newman and Stokol, 2022; Weiss and Aird, 2001).

In addition, alterations in the megakaryocytic line were reported, but there were no descriptions of the use of BMAs in patient follow-up, lymphoma staging, or the application of molecular biology techniques, cytogenetics, microbiological cultures, and immunophenotyping in any of the reports as complementary studies for the final diagnosis. However, these techniques are commonly used in veterinary medicine to define lineage and clonality and establish prognoses (Evans, 2023; Rout et al., 2019). It should be noted that the availability of these tests is limited in Colombia.

To our knowledge, this is the first publication on the characterization of BMA reports in dogs and cats in Colombia. Therefore, it is likely the first report on the frequency of diagnoses in BMAs for both species. The study of BMA as a diagnostic tool in dogs and cats treated at participating veterinary centers in the country remains uncommon. The most frequent diagnosis in dogs was hypoplasia, while neoplasms were more common in cats, considering the sample size.

This study highlights the need to adhere to BMA reporting guidelines to improve diagnostic accuracy, shorten turnaround times, and avoid reprocessing. Likewise, sampling and slide preparation techniques must be optimized to reduce the number of particle-free and hemodiluted samples.

The use of BMA proved effective in diagnosing and ruling out central hematologic alterations in dogs and cats with multiple clinical and laboratory findings. Moreover, this tool enables differential diagnoses in cases where the BMA result is normal, thereby supporting a peripheral origin.

Declarations

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Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Roldán-Carvajal: Project design, institution search, manuscript writing. Alzate-Velásquez: Project design, institution search, manuscript editing. Muñoz-Duque: Project design, institution search, manuscript editing. Mesa-Oquendo: Institution search, manuscript editing. Salazar-Flórez: Statistical analysis, manuscript editing. Jaramillo-Arbeláez: Project design, manuscript writing.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

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