AJVR

AVMA

Investigation of a point-of-care viscoelastic coagulation monitor and its comparison to thromboelastography in 9 female southern white rhinoceros (*Ceratotherium simum simum*)

Ashlyn C. Heniff, DVM[1]*; Alex M. Lynch, BVSc, DACVECC[1]; Laura K. Ruterbories, BS, RVT, RLATG, VTS[1]; Larry J. Minter, DVM, MS, DACZM[1,2]; Timothy A. Georoff, VMD, DACZM[1,2]; Julie A. Balko, VMD, DACVAA[3]

[1]Department of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC
[2]North Carolina Zoo, Asheboro, NC
[3]Department of Molecular and Biomedical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC

*Corresponding author: Dr. Heniff (aheniffdvm@gmail.com)

Objective
To investigate a point-of-care viscoelastic coagulation monitor (VCM Vet; Entegrion Inc), compare the results to thromboelastography (TEG), and quantify traditional hemostatic analytes in southern white rhinoceros (*Ceratotherium simum simum*).

Methods
9 female rhinoceros (4 juveniles [2 to 3 years old], 4 adults [16 to 34 years old], and 1 geriatric [54 years old]) at the North Carolina Zoo were enrolled. Whole blood was collected using trained voluntary behavior and analyzed in duplicate via both VCM Vet and kaolin-activated TEG within 4 minutes or at 30 minutes following collection, respectively. Citrated plasma was used for ancillary coagulation testing.

Results
Both analyses generated quantifiable clotting reactions with variables (median [range]) related to clot formation rate (TEG: R = 9.4 minutes [5.1 to 10.8], K = 2.0 minutes [1.4 to 3.0], α angle = 66° [41° to 73°]; VCM Vet: CT = 882 seconds [758 to 1,252], CFT = 416 seconds [200 to 980], α = 24° [11° to 43°]), clot strength (TEG: MA = 71 mm [64 to 79], G = 11.9 kilodynes/s [9.0 to 18.9]; VCM Vet: MCF = 49 units [34 to 53]), and clot lysis (TEG: LY30 = 0.9% [0% to 1.7%], LY60 = 3.2% [0.9% to 4.9%]; VCM Vet: Li30 = 100% [99% to 100%], Li45 = 98% [93% to 100%]) recorded. Additional testing (median [range]) included D-dimer (221 ng/mL [138 to 577]), prothrombin time (21.4 seconds [19.6 to 23.7]), activated partial thromboplastin time (24.8 seconds [22.5 to 27.4]), and fibrinogen (336 mg/dL [280 to 429]).

Conclusions
Tracings generated by VCM Vet and TEG were clinically similar, and there was visual agreement and minimal difference between quantitative variables for duplicate tests.

Clinical Relevance
VCM Vet is a user-friendly, portable device that demonstrates promise for assessing coagulation in southern white rhinoceros.

Keywords: coagulation, hemostasis, southern white rhinoceros, thromboelastography, VCM Vet

Southern white rhinoceros (*Ceratotherium simum simum*) are illegally hunted for their horns, which has resulted in marked in situ population declines.[1,2] Individuals that survive poaching attacks commonly require emergency medical intervention for facial trauma and circulatory shock[3–5]; however, there is a paucity of literature describing rhinoceros emergency and critical care medicine, including coagulation testing. In humans and dogs, viscoelastic coagulation testing has demonstrated utility for the identification and management of acute trauma-induced coagulopathies, which are a major cause of preventable post-trauma death.[6–10]

Viscoelastic coagulation tests, such as thromboelastography (TEG), provide a global evaluation of coagulation from the initiation of clot formation through fibrinolysis and are frequently used in

Received October 30, 2024
Accepted March 12, 2025
Published online April 17, 2025

doi.org/10.2460/ajvr.24.10.0322

small animal and equine critical care specialty practice.[11–15] Although TEG has been successfully investigated in several nondomestic mammal species, including African elephants, Asian elephants, West Indian manatees, and pigtail macaques,[16–19] this technology presents challenges for use in zoological medicine settings.[20] Thromboelastography conventionally analyzes whole blood samples, which need to be processed shortly after collection as processing delays can result in storage artifacts and reduced testing sensitivity.[21,22] As TEG analyzers are typically only available for use at universities or specialty hospitals due to both analyzer expense and inability to easily transport them, this technology is not readily accessible in most zoo or field settings. Furthermore, a study of TEG in Asian elephants found that analyzing whole blood samples 24 hours after collection led to significant differences in all TEG parameters, limiting its clinical value.[19] Thus, shipping samples to an external facility for testing is also not advised. Considering these limitations, investigation of alternative viscoelastic coagulation technology in rhinoceros species is needed.

One promising alternative is VCM Vet (Entegrion Inc): a point-of-care, veterinary-specific viscoelastic coagulation monitor that provides an assessment of global coagulation similar to TEG. VCM Vet has been prospectively evaluated in dogs, cats, mice, horses, and African elephants with favorable results.[18,19,23–29] VCM Vet uses whole blood without clotting activators inserted into a user-friendly, cartridge-based system to analyze coagulation via a contact activation trigger.[12] This differs from TEG, which uses recalcified, citrated whole blood with the addition of a clotting activator to detect subtle changes in torque in a delicate cup and pin setup.[12] In comparison to TEG, VCM Vet is easy to transport, can be used patient-side, and is subjectively more user-friendly. For these reasons, as well as its clinically rapid processing speed (60 minutes), VCM Vet is well suited for use in zoo or field settings.

Aside from trauma, life-threatening coagulopathies in domestic species can accompany an array of disease processes, including various neoplasias, hepatopathies, sepsis, immune-mediated diseases, viral infections, enteritis, colic, toxicities, and cardiovascular diseases.[12,30–37] Hemostatic disorders have been minimally investigated in southern white rhinoceros, with only a single case report describing a fatal coagulopathy in a neonate (disseminated intravascular coagulation secondary to endotoxemia).[38] In black rhinoceros (*Diceros bicornis*), minimally more literature exists, with several live-threatening vascular disorders documented in this species, including idiopathic hemorrhagic vasculopathy syndrome, hemolytic anemia, and toxic hepatopathy.[39–43] While it could be possible that southern white rhinoceros are unlikely to develop coagulopathies, given the known prevalence of hemostatic disorders across a multitude of domestic species it is more likely that diagnostic limitations in zoo and field settings limit their diagnosis. As a result, hemostatic disorders may be more widespread in southern white rhinoceros and simply remain undocumented.

The primary objective of this study was to investigate the use of VCM Vet in female southern white rhinoceros and compare results to kaolin-activated TEG. Secondary study objectives were to establish preliminary values for quantitative variables of both technologies and concurrently evaluate traditional coagulation variables (platelet count, D-dimer and fibrinogen concentrations, activated partial thromboplastin time [aPTT], and prothrombin time [PT]) in female southern white rhinoceros.

Methods

Rhinoceros and husbandry

This study was approved by the North Carolina Zoo Animal Research Committee and conducted from March through June 2022. All 9 southern white rhinoceros housed at the North Carolina Zoo (Asheboro, North Carolina) were enrolled. This population was all female and included 4 juveniles (2 to 3 years old), 4 adults (16 to 34 years old), and 1 geriatric (54 years old) individual. The median weight was 1,546 kg (range, 1,068 to 2,527). No rhinoceros were receiving any medications at the time of the study. The 4 juveniles and 4 adults were all considered clinically healthy based on visual examination, limited physical examination under protected contact, and quarterly CBC and blood chemistry. The single geriatric rhinoceros had multiple comorbidities, including chronic mild anemia, intermittent mild hypoglycemia, chronic pressure sores, chronic osteoarthritis, and intermittent regurgitation; quarterly blood work had otherwise been unremarkable. She had previously received chronic phenylbutazone for osteoarthritis and had recently received a trial of flunixin meglumine but had not received any medications in the 4 days preceding sample collection.

The rhinoceros in this population are managed under protected contact and maintained on a daily diet of timothy hay and Mazuri Wild Herbivore Diet Hi-Fiber cubes (PMI Nutrition International LLC) with supplemental orchard grass and alfalfa offered sparingly. Rhinoceros are routinely dewormed as indicated based on pooled fecal samples and are prescribed 5 oz/450 kg of psyllium (SandClear; Farnam Companies Inc) every 3 months for 7 days.

Blood collection

On test days, voluntary positive reinforcement behavior training was used to station each rhinoceros for blood collection; rhinoceros could choose to end participation at any time. Blood samples of ≤ 20 mL were collected from the right medial radial vein using a 21-gauge, 0.75-inch butterfly needle and attached syringe. The number of venipuncture attempts, number of needle redirections, collection volume, and duration of collection (ie, time from blood entering the syringe to the end of collection) were recorded.

VCM Vet and TEG testing

A TEG analyzer (TEG 5000 Thromboelastograph; Haemonetics Corp) and 2 VCM Vet devices (Entegrion Inc) were transported to the study site

(North Carolina Zoo). Prior to testing, the TEG analyzer was calibrated using the internal e-test and system check materials supplied by the manufacturer, and system checks were performed on both VCM Vet devices. On test day, 2 VCM Vet cartridges were prewarmed to 37 °C using the manufacturer's heating plate. Collected blood was immediately loaded into 2 cartridges and subsequently 1 of 2 VCM Vet devices according to the manufacturer's instructions. The device loading order was alternated for successive patients. The time from the end of blood sample collection to testing start time was recorded for each device. The remaining blood was slowly injected through an 18-gauge, 1-inch needle into 3 1.4-mL plastic tubes with 3.2% sodium citrate (9:1 ratio; S-Monovette; SARSTEDT AG & Co KG), 2 8.5-mL plastic vacutainer tubes with serum separator (BD Vacutainer), and 1 3-mL glass tube with potassium EDTA (Coviden Monoject; Fisher Scientific); sodium citrate and EDTA tubes were gently inverted to ensure equal mixing of the anticoagulant.

Collected, citrated blood was held for 30 minutes in accordance with a previously described TEG testing protocol.[44,45] Next, 0.04 mL of kaolin activator (Haemonetics Corp) was added to 1.0 mL of citrated blood, and 2 0.34-mL aliquots of the mixture were each recalcified with 0.02 mL of 0.2M calcium chloride (Haemonetics Corp).[44,45] These aliquots were analyzed in duplicate on the TEG analyzer by a single investigator (LKR) in accordance with the manufacturer's instructions. Both VCM Vet and TEG testing generate quantitative variables **(Table 1)** and a trace curve demonstrating clot strength (amplitude; units [VCM Vet] or millimeters [TEG]) over time (seconds [VCM Vet] or minutes [TEG]).

Table 1—VCM Vet variables, corresponding thromboelastography (TEG) variables, and the clinical interpretation of these criteria.

VCM Vet variables	TEG variables	Interpretation
N/A	SP (min)	Onset of clot formation
CT (s)	R (min)	Initial fibrin formation
CFT (s)	K (min)	Rate of clot formation
α (slope of tracing; degrees)	α angle (slope of tracing; degrees)	Rate of clot formation
MCF (units)	MA (mm), G (kilodynes)	Maximum clot strength
A10, A20 (units)	N/A	Clot strength
Li30 and Li45 (percentage of clot strength remaining)	LY30 and LY60 (percentage of amplitude reduction)	Extent of fibrinolysis

A10 = Amplitude at 10 minutes. A20 = Amplitude at 20 minutes. CFT = Clot formation time. CT = Clot time. G = Shear modulus strength. K = Kinetics time. Li30 = Clot lysis index at 30 minutes. Li45 = Clot lysis index at 45 minutes. LY30 = Clot lysis index at 30 minutes after MA is reached. LY60 = Clot lysis index at 60 minutes after MA is reached. MA = Maximum amplitude. MCF = Maximum clot formation. N/A = Not applicable. R = Reaction time. SP = Split point.

Ancillary testing

The remaining citrated blood was centrifuged, and the plasma was separated and frozen (−80 °C) in plastic microcentrifuge tubes within 1 hour of blood collection. Prothrombin time, aPTT, fibrinogen concentration, and D-dimer concentration (STACompact; DiagnosticaStago) were analyzed using the frozen plasma samples at an external laboratory (Cornell University, College of Veterinary Medicine). Manual Hct, serum chemistry (VETSCAN VS2, Equine Profile Plus; IDEXX Laboratories), and manual WBC differential were performed within 24 hours of blood collection. Automated (flow cytometry; ADVIA 120 Hematology System; Siemens Medical Solutions) and manual platelet counts (hemocytometer and manual blood film estimation [the average of 10 1,500X magnification fields multiplied by 30,000]) were performed at an external laboratory (North Carolina State University, College of Veterinary Medicine) using the prepared blood smears and remaining EDTA blood.

Statistical analysis

Descriptive statistics (median and range) alone were used for VCM Vet and TEG quantitative variables due to the small sample size. Median (range) differences between duplicate tests for each analyzer were also calculated. Subjective visual and clinical comparisons were made between VCM Vet and TEG results as well as duplicate tracings of each analyzer.

Results

Quantifiable clotting reactions were generated in duplicate for each analyzer and in all individuals for a total of 36 separate results. Median (range) VCM Vet and TEG quantitative variables are presented in **Tables 2 and 3**, respectively, and these tables also include median (range) differences between duplicate test results. Overlay duplicate VCM Vet and TEG trace curves for each rhinoceros are displayed in **Figure 1**. One 3-year-old rhinoceros (orange tracings) had TEG tracings visually and quantitatively similar to the rest of the cohort but relatively hypocoagulable VCM Vet tracings, particularly in the clot kinetics stage (shallow α). Tracings and quantitative results for the single geriatric rhinoceros with multiple comorbidities (red tracings) were similar to the rest of the cohort.

A single TEG test for a 16-year-old rhinoceros was excluded from LY30 and LY60 analysis due to a suspected analytical error leading to an abnormal TEG tracing with a precipitous drop in clot strength during the lysis stage that was not consistent with other tracings for this individual (yellow tracings, Figure 1). The hemostatic pattern prior to the lysis stage for the suspected errant test result was similar to other samples.

Phlebotomy was achieved in 1 to 3 attempts. Samples were collected without redirection for 7 of the 9 rhinoceros; phlebotomy for the 2 remaining animals required a single redirection. The median duration and volume of blood collection was 60 seconds (range, 40 to 108) and 15 mL (range, 10 to 20),

Table 2—Median (range) whole blood VCM Vet variables for 9 female southern white rhinoceros (*Ceratotherium simum simum*).

VCM Vet variable	All (n = 9)	Juvenile (2–4 y; n = 4)	Adult (16–54 y; n = 5)	Duplicate test difference
CT (s)	882 (758–1,252)	861 (784–1,252)	882 (758–1,023)	87 (4–177)
CFT (s)	416 (200–980)	288 (200–980)	432 (399–647)	37 (15–341)
α (°)	24 (11–43)	33 (11–43)	23 (14–25)	2 (1–12)
MCF (units)	49 (34–53)	42 (34–50)	50 (44–53)	1 (0–8)
A10 (units)	20 (5–39)	27 (5–39)	18 (8–22)	2 (1–11)
A20 (units)	42 (15–49)	41 (15–49)	43 (37–46)	2 (1–14)
Li30 (%)	100 (99–100)	100 (99–100)	100 (100–100)	0 (0–0)
Li45 (%)[a]	98 (93–100)	95 (93–96)	99 (97–100)	1 (1–1)

[a]Li45 values could not be obtained when test CT exceeded 900 seconds (6 of 18 tests; 3 from juveniles, 3 from adults).

All tests were run in duplicate and are reported as all rhinoceros, juveniles only, and adults only. Median (range) differences between duplicate tests are also presented.

Table 3—Median (range) citrated, kaolin-activated whole blood TEG variables for 9 female southern white rhinoceros (*C simum simum*).

TEG variable	All (n = 9)	Juvenile (2–4 y; n = 4)	Adult (16–54 y; n = 5)	Duplicate test difference
SP (min)	7.9 (0.3–10.1)	5.4 (0.8–9.6)	8.9 (0.3–10.1)	0.5 (0–9.8)
R (min)	9.4 (5.1–10.8)	8.3 (5.1–9.7)	10.2 (8.3–10.8)	0.5 (0.1–1.6)
K (min)	2.0 (1.4–3.0)	1.8 (1.4–3.0)	2.1 (1.8–2.4)	0.1 (0.1–1.4)
A angle (degrees)	66 (41–73)	65 (45–73)	66 (41–70)	3.4 (0–27.5)
MA (mm)	71 (64–79)	68 (64–72)	72 (65–79)	3.9 (1.9–7.4)
G (kilodynes/s)	11.9 (9.0–18.9)	10.8 (9.0–12.6)	13.1 (9.2–18.9)	1.7 (1.2–4.9)
LY30 (%)[a]	0.9 (0–1.7)	1.2 (0.3–1.7)	0.5 (0–1.7)	0.4 (0.2–0.8)
LY60 (%)[a]	3.2 (0.9–4.9)	3.8 (1.9–4.5)	2.4 (0.9–4.9)	0.8 (0.2–1.5)

[a]LY30 and LY60 from a single test from 1 juvenile rhinoceros excluded.

All tests were run in duplicate and are reported as all rhinoceros, juveniles only, and adults only. Median (range) differences between duplicate tests are also presented.

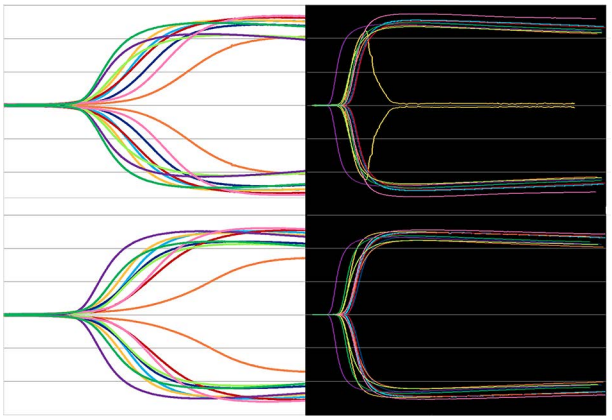

Figure 1—Overlays of clot strength (amplitude) over time trace curves generated via VCM Vet (white background) and thromboelastography (TEG; black background), each performed in duplicate for 9 female southern white rhinoceros (*Ceratotherium simum simum*; 2 to 54 years old). Each rhinoceros is represented by a different color. A suspected analytical error resulted in a precipitous drop in clot strength during the lysis phase for a single TEG test for 1 rhinoceros (upper right yellow tracing) that was inconsistent with other tracings from this individual.

respectively. The median times from completion of blood collection to test start time for the VCM Vet devices were 135 (range, 70 to 210) and 165 (range, 67 to 186) seconds. The median run times for VCM Vet and TEG tests were 60 (range, 60 to 60) and 84 (range, 77 to 87) minutes, respectively. No system check errors were encountered for either VCM Vet device or the TEG analyzer. All plasma samples were clear, with no visual evidence of hemolysis.

The median (range) fibrinogen and D-dimer concentrations and prothrombin and activated partial thromboplastin times are presented in **Table 4**. Three of 9 EDTA samples were visibly clotted at the time of platelet analysis; these individuals had blood collection times of 60, 60, and 70 seconds (consistent with the study average). The median platelet counts for the remaining 6 individuals (3 juveniles, 2 adults, and 1 geriatric) via flow cytometry, hemocytometer, and slide estimates were 460 (range, 385 to 1,566), 487 (range, 380 to 1,300), and 575 (range, 423 to 1,328) X 10^3/µL, respectively. Of these, 4 individuals (2 juveniles, 1 adult, and 1 geriatric) had normal platelet counts of 380 to 600 X 10^3/µL, and the 2 remaining animals (1 juvenile and 1 adult) had elevated platelet counts between 1,260 and 1,570 X 10^3/µL for all 3 methods.

Table 4—Median (range) plasma D-dimer and fibrinogen concentrations and activated partial thromboplastin (aPTT) and prothrombin (PT) times for 9 female southern white rhinoceros (*C simum simum*).

Variable	Value
D-dimers (ng/mL)	221 (138–577)
Fibrinogen (mg/dL)	336 (280–429)
aPTT (s)	24.8 (22.5–27.4)
PT (s)	21.4 (19.6–23.7)

The results of chemistry and WBC differentials for each rhinoceros were clinically unremarkable based on published reference intervals and previous values for individuals at the North Carolina Zoo.[46–49] The median range manual Hct was 33% (28% to 38%). Mild anemia (Hct 28%) was identified in the single geriatric rhinoceros, though this was consistent with her historic values. Hematocrits for all rhinoceros fell within a published reference range (28% to 46%; mean, 37%).[47] None of the rhinoceros were pregnant or demonstrated any overt signs of acute clinical disease 1 month before, during, or 1 month after the study. Five months after this study, the geriatric rhinoceros was euthanized due to progressive decline and quality-of-life concerns. Necropsy revealed multiple malignant neoplasms (adrenocortical carcinoma, multiple pheochromocytomas, leiomyosarcoma, and squamous cell carcinoma) and chronic kidney disease.

Discussion

Both VCM Vet and TEG successfully generated quantifiable clotting reactions for the 9 female southern white rhinoceros enrolled in this study. With the exception of a single probable analytical error obtained via TEG, there was visual agreement between duplicate tracings for each sample on each device as well as minimal clinical difference between quantitative variables for duplicate tests. While the small sample size did not permit the establishment of reference intervals, these preliminary data may aid researchers and clinicians in the interpretation of viscoelastic test results and improve the identification and clinical management of coagulopathies in this species.

As previously mentioned, the mechanisms by which VCM Vet and TEG induce and analyze coagulation differ considerably. Consequently, direct comparison of results between these devices is precluded in principle.[12,15,25,27,50] Additionally, recent studies[24,51] suggest VCM Vet may be less sensitive for the detection of hypercoagulability than TEG and rotational thromboelastometry (ROTEM). Nevertheless, there is a precedent in recent veterinary literature for performing concurrent TEG when investigating VCM Vet in novel species to aid in clinical interpretation of this newer and less extensively studied viscoelastic technology.[18,24,25,27] Upon visual assessment of tracings generated in the present study, there was subjective clinical agreement between VCM Vet and TEG tracings for individual rhinoceros (Figure 1). This finding, paired with the consistency observed between duplicate VCM Vet tests, lends support to the potential suitability of VCM Vet for evaluating coagulation in southern white rhinoceros. Furthermore, as VCM Vet is a portable, patient-side device that does not require refrigeration, external reagents, or specialized training, it can be easily incorporated into zoo and wildlife medicine. Evaluation of this technology in southern white rhinoceros with acute traumatic injuries or other disease processes associated with coagulopathies is warranted.

Southern white rhinoceros in the present study generally displayed relatively long times to clot formation (CT, R) compared to other mammal species for which VCM Vet and TEG have been evaluated.[11,14,16–19,23,25,27,28,52] Lower bioavailability of clotting factors involved in the intrinsic pathway (factors XII, XI, IX, and VIII) could explain this feature; however, literature regarding the availability and function of clotting factors in rhinoceros is scarce. Alternatively, species differences in blood viscosity may be a contributing factor as at least 1 study has reported that increased blood viscosity can result in longer TEG clot reaction (R) times.[53] Similarly long times to clot formation have also been reported for VCM Vet and kaolin-activated TEG in clinically healthy horses, which have pronounced blood viscosity and erythrocyte aggregation among mammals and are among the closest living relatives of rhinoceros species.[14,23,54,55]

Another shared finding of VCM Vet and TEG testing in southern white rhinoceros was higher maximum clot strength (MCF; MA, G) relative to several other mammal species for which VCM Vet and TEG have been investigated, including dogs and horses.[11,14,16–19,23,25,27,28,50,55] This is likely at least partially explained by the relatively high platelet counts of southern white rhinoceros as platelet number and function play a preeminent role in determining maximum clot strength,[15] and similarly high clot strength has been reported in other species with relatively high platelet counts, including mice, African elephants, Asian elephants, Florida manatees, and pigtail macaques.[16–19,28]

The CFT and α values recorded for VCM Vet in southern white rhinoceros were generally longer and shallower, respectively, than values recorded in healthy dogs,[25] indicating a slower rate of clot formation in southern white rhinoceros relative to dogs. This was not the case with TEG as K and α angles for southern white rhinoceros typically fell within canine reference intervals established in our laboratory (58° to 75°; A. M. Lynch, BVSc, DACVECC, College of Veterinary Medicine, North Carolina State University, email, July 1, 2022). Given the aforementioned differences in mechanics and reagents between VCM Vet and TEG, this difference between analogous variables is not unexpected, and comparable studies[18,25,27] in dogs, cats, and African elephants have reported similar findings.

Little to no clot lysis was detected in southern white rhinoceros via both VCM Vet and TEG testing, indicating stable clot formation. Note that VCM Vet technology calculates the percentage of clot strength remaining, whereas TEG technology calculates the percentage of clot amplitude reduction. Thus, while these values are communicating similar information (ie, the extent of fibrinolysis), their scales and, subsequently, resultant values are the opposite of each other. As minimal fibrinolysis was documented in clinically healthy southern white rhinoceros in this study, decreases in VCM Vet lysis values (indicating hyperfibrinolysis) could be a candidate marker for the detection of coagulopathies in this species.

Investigations of age-related differences in coagulation in veterinary species are limited, but 1 study[56] of rotational thromboelastometry (ROTEM)

in dogs (beagles) detected hypercoagulable profiles with a decrease in fibrinolytic activity in geriatric animals compared to young adults. Despite a diverse age range in the present study cohort, viscoelastic coagulation variables were similar when visually compared between juveniles and adults, including the geriatric individual. Although the small sample size precludes definitive conclusions, these findings are suggestive that normal hemostatic patterns may not differ substantially by age in southern white rhinoceros; however, animals younger than 2 years of age were not evaluated in the current study, and only 1 geriatric animal was evaluated.

Sex-based differences in viscoelastic coagulation testing have also been noted in humans, with women generally being hypercoagulable compared to men.[57–59] Veterinary studies[11,16–19,28,60] in several mammal species have reported conflicting results as to the effects of sex on hemostasis. As all rhinoceros in the present study were female, sex-based differences could not be examined, but this may warrant consideration in future studies.

Differences in Hct can also significantly affect viscoelastic testing results. Studies[61,62] have documented that lower Hcts are associated with relative hypercoagulability and that higher Hcts are associated with relative hypocoagulability; this may be because RBCs act as a diluent for plasma coagulation factors. Rhinoceros in our study all had Hcts within published species references intervals. Given the small sample size and narrow Hct range in the present study (28% to 38%), we cannot assess the impact, if any, that Hct may have had on our results.

Automated and manual platelet counts and estimation were successfully performed for 6 of the 9 rhinoceros in the current study. Four rhinoceros (2 juveniles and 2 adults) had platelet counts consistent with species reference values[46,47] at approximately 400 to 500 X 10^3/µL. The 2 remaining individuals (1 juvenile and 1 adult) had moderate thrombocytosis (approx 1,300 to 1,500 X 10^3/µL); despite this, viscoelastic tracings for these 2 rhinoceros were consistent with the rest of the cohort. While platelet count and function are known to influence clot kinetics time (K; CFT) and clot strength (MA, G; MCF), this only applies to platelet counts that are within the reference intervals or decreased in humans and dogs as thrombocytosis does not result in faster clot kinetics times or increased clot strength beyond expected normal values.[13,37,63] This was consistent with findings in the present study. Although the reason for the high platelet counts in these 2 rhinoceros are unknown, given that these animals were clinically healthy with no other hematological abnormalities it may have been the result of epinephrine-mediated splenic contraction, a normal physiologic excitement response that can induce transient thrombocytosis.[64] Subclinical inflammation is also a possible explanation.[64]

Traditional plasma-based coagulation tests (PT, aPTT, and D-dimer and fibrinogen concentrations) were also evaluated in the study cohort to complement viscoelastic testing results. In contrast to whole blood viscoelastic testing, which provides a global overview of hemostasis, aPTT and PT assess components of the cascade model of coagulation. Though best suited for the detection of hypocoagulability (ie, prolonged clotting times), shortened aPTT and PT could also indicate hypercoagulability.[65] Southern white rhinoceros in the present study had shorter aPTT and longer PT relative to equine laboratory reference intervals (Cornell University, College of Veterinary Medicine, Comparative Coagulation Laboratory, email, 1 August 2022).

D-dimers are protein products of fibrinolysis, and increased concentrations are a sensitive indicator of excessive fibrinolysis in dogs and horses.[66,67] D-dimer concentrations in southern white rhinoceros in the present study were similar to reference range values from healthy dogs (80 to 390 ng/mL) but lower than values recorded in healthy horses (median, 695 ng/mL; IQR, 586 to 742).[66,67] Though fibrinogen concentration is more commonly measured in horses to assess for hyperfibrinogenemia, an indicator of inflammation, fibrinogen is also included in plasma-based coagulation panels to test for hypofibrinogenemia, which can indicate hyperfibrinolysis and/or hepatic insufficiency (decreased production).[68] Fibrinogen concentrations measured in the current study were similar to previously reported normal values for southern white rhinoceros and horses.[46,47,69] Quantification of D-dimer and fibrinogen concentrations in southern white rhinoceros with systemic disease may help determine if this testing could aid in the identification and management of coagulopathies in this species.

The limitations of this study include a small sample size and the inclusion of only female southern white rhinoceros of various ages from a single institution, 1 of which was geriatric with underlying chronic disease. Thus, data from this study may not be representative of all southern white rhinoceros. Investigation of viscoelastic technology in male southern white rhinoceros, other rhinoceros species, and rhinoceros with suspected coagulopathies is warranted.

This study provides a framework for VCM Vet and TEG testing in southern white rhinoceros. Both devices produced quantifiable clotting reactions for all rhinoceros involved, while demonstrating minimal variability in quantitative measures across duplicate tests and subjective clinical concordance between VCM Vet and TEG tracings for individual animals. VCM Vet, as a portable and user-friendly viscoelastic coagulation analyzer, should be considered for use in southern white rhinoceros. The data provided in this study can assist researchers and veterinarians in interpreting viscoelastic test results for white rhinoceros suffering from traumatic injuries or other disease processes associated with coagulopathies.

Acknowledgments

The authors would like to thank the veterinary and southern white rhinoceros husbandry teams at the North Carolina Zoo as well as the North Carolina State University College of Veterinary Medicine Clinical Pathology Laboratory and Cornell University College of Veterinary Medicine Comparative Coagulation Laboratory for study assistance.

Disclosures

Entergrion Inc provided VCM Vet devices and cartridges but had no role in study design, data collection, or data analysis.

No AI-assisted technologies were used in the composition of this manuscript.

Funding

The authors have nothing to disclose.

ORCID

A. C. Heniff https://orcid.org/0000-0003-4569-0896

References

1. Emslie R. *Ceratotherium simum* ssp. *simum*. *The IUCN Red List of Threatened Species.* 2020: e.T39317A45814320. Accessed November 1, 2024. https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T4185A45813880.en
2. Nhleko ZN, Ahrens R, Ferreira SM, McCleery RA. Poaching is directly and indirectly driving the decline of South Africa's large population of white rhinos. *Anim Conserv.* 2022;25(2):151–163. doi:10.1111/acv.12720
3. Gerard MP, Glyphis ZG, Crawford C, Blikslager AT, Marais J. Identification of a nasoconchal paranasal sinus in the white rhinoceros (*Ceratotherium simum*). *J Zoo Wildl Med.* 2018;49(2):444–449. doi:10.1638/2017-0185.1
4. Marais HJ, Glyphis ZG, Cremers NA. Medical grade honey: hope for wounded white rhinos. *Vet Anim Sci.* 2021;13:100196. doi:10.1016/j.vas.2021.100196
5. Meyer L, Bengis R, Fowlds W, et al. Treatment of rhinoceros which have been poached using opioids and are found recumbent. *South African Veterinary Association*. Accessed on October 27, 2023. https://www.sava.co.za/wp-content/uploads/2015/11/Opioid_poached_rhino_article.pdf
6. Abelson AL, O'Toole TE, Johnston A, Respess M, de Laforcade AM. Hypoperfusion and acute traumatic coagulopathy in severely traumatized canine patients. *J Vet Emerg Crit Care (San Antonio).* 2013;23(4):395–401. doi:10.1111/vec.12073
7. Hartmann J, Walsh M, Grisoli A, et al. Diagnosis and treatment of trauma-induced coagulopathy by viscoelastography. *Semin Thromb Hemost.* 2020;46(2):134–146. doi:10.1055/s-0040-1702171
8. Herrero Y, Schefer RJ, Muri BM, Sigrist NE. Prevalence of acute traumatic coagulopathy in acutely traumatized dogs and association with clinical and laboratory parameters at presentation. *Vet Comp Orthop Traumatol.* 2021;34(3):214–222. doi:10.1055/s-0040-1721707
9. Moore EE, Moore HB, Kornblith LZ, et al. Trauma-induced coagulopathy. *Nat Rev Dis Primers.* 2021;7(1):30. doi:10.1038/s41572-021-00264-3
10. Palmer L, Martin L. Traumatic coagulopathy—part 1: pathophysiology and diagnosis. *J Vet Emerg Crit Care (San Antonio).* 2014;24(1):63–74. doi:10.1111/vec.12130
11. Bauer N, Eralp O, Moritz A. Establishment of reference intervals for kaolin-activated thromboelastography in dogs including an assessment of the effects of sex and anticoagulant use. *J Vet Diagn Invest.* 2009;21(5):641–648. doi:10.1177/104063870902100508
12. Burton AG, Jandrey KE. Use of thromboelastography in clinical practice. *Vet Clin North Am Small Anim Prac.* 2020;50(6):1397–1409. doi:10.1016/j.cvsm.2020.08.001
13. Kol A, Borjesson DL. Application of thrombelastography/thromboelastometry to veterinary medicine. *Vet Clin Pathol.* 2010;39(4):405–416. doi:10.1111/j.1939-165X.2010.00263.x
14. Machackova K, Boselova M, Vanova I, Drabkova Z, Doubek J. Evaluation of kaolin-activated thromboelastography and sample stability in healthy horses. *Vet Med (Praha).* 2018;63(5):203–209. doi:10.17221/16/2018-VETMED
15. McMichael MA, Smith SA. Viscoelastic coagulation testing: technology, applications, and limitations. *Vet Clin Pathol.* 2011;40(2):140–153. doi:10.1111/j.1939-165X.2011.00302.x
16. Barratclough A, Floyd RF, Reep RL, Ball RL, Conner BJ. Thromboelastography in wild Florida manatees (*Trichechus manatus latirostris*). *Vet Clin Pathol.* 2018;47(2):227–232. doi:10.1111/vcp.12599
17. Fong DL, Ha JC, Hotchkiss CE. Thromboelastography values from pigtail macaques (*Macaca nemestrina*): effects of age and sex. *J Am Assoc Lab Anim Sci*. 2012;51(1):94–100.
18. Heniff AC, Lynch AM, Ruterbories LK, Minter LJ, Georoff TA, Balko JA. Investigation of a point-of-care viscoelastic coagulation monitor and its comparison to thromboelastography in clinically healthy African elephants (*Loxodonta africana*). *J Zoo Wildl Med.* 2024;55(1):164–172. doi:10.1638/2022-0158
19. Perrin KL, Krogh AK, Kjelgaard-Hansen M, et al. Thromboelastography in the healthy Asian elephant (*Elephas maximus*): references intervals and effects of storage. *J Zoo Wildl Med.* 2018;49(1):54–63. doi:10.1638/2017-0179R.1
20. Gerlach TJ, Barratclough A, Conner B. Coagulation assessment: underutilized diagnostic tools in zoo and aquatic animal medicine. *J Zoo Wild Med.* 2017;48(4):947–953. doi:10.1638/2016-0145R.1
21. Rossi TM, Smith SA, McMichael MA, Wilkins PA. Evaluation of contact activation of citrated equine whole blood during storage and effects of contact activation on results of recalcification-initiated thromboelastometry. *Am J Vet Res.* 2015;76(2):122–128. doi:10.2460/ajvr.76.2.122
22. Wiinberg B, Jensen AL, Rojkjaer R, Johansson P, Kjelgaard-Hansen M, Kristensen AT. Validation of human recombinant tissue factor-activated thromboelastography on citrated whole blood from clinically healthy dogs. *Vet Clin Pathol.* 2005;34(4):389–393. doi:10.1111/j.1939-165X.2005.tb00066.x
23. Bishop RC, McCoy AM, Kemper AM, Stewart RM, Wilkins PA. Short-term administration of flunixin meglumine or firocoxib does not alter viscoelastic coagulation profiles in healthy horses. *J Am Vet Med Assoc.* 2022;260(15):1963–1966. doi:10.2460/javma.22.08.0367
24. Buriko Y, Chalifoux NV, Clarkin-Breslin R, Silverstein DC. Comparison of a viscoelastic point-of-care coagulation monitor with thromboelastography in sick dogs with hemostatic abnormalities. *Vet Clin Pathol.* 2023;52(2):217–227. doi:10.1111/vcp.13198
25. Buriko Y, Drobatz K, Silverstein DC. Establishment of normal reference intervals in dogs using a viscoelastic point-of-care coagulation monitor and its comparison with thromboelastography. *Vet Clin Pathol.* 2020;49(4):567–573. doi:10.1111/vcp.12926
26. Fudge JM, Cano KS, Page B, Jeffrey U. Comparison of viscoelastic test results from blood collected near simultaneously from the jugular and saphenous veins in cats. *J Feline Med Surg.* 2021;23(6):598–603. doi:10.1177/1098612X20959612
27. Rosati T, Jandrey KE, Bruges JW, Kent MS. Establishment of a reference interval for a novel viscoelastic coagulometer and comparison with thromboelastography in healthy cats. *Vet Clin Pathol.* 2020;49(4):660–664. doi:10.1111/vcp.12916
28. Rigor RR, Schutzman LM, Galante JM, Brown IE. Viscoelastic coagulation monitor (VCM vet) references intervals and sex differences in mature adult mice. *Acta Haematol.* 2021;144(6):633–640. doi:10.1159/000516587
29. Wang WH, Lynch AM, Balko JA, Duffy DJ, Robertson JB, Posner LP. Point-of-care viscoelastic coagulation assessment in healthy dogs during the perianesthetic period. *BMC Vet Res.* 2022;18(1):346. doi:10.1186/s12917-022-03442-x
30. Atkins CE, Gallo AM, Kurzman ID, Cowen P. Risk factors, clinical signs, and survival in cats with a clinical diagnosis of idiopathic hypertrophic cardiomyopathy: 74 cases

(1985–1989). *J Am Vet Med Assoc.* 1992;201(4):613–618. doi:10.2460/javma.1992.201.04.613
31. Bentley AM, Mayhew PD, Culp WT, Otto CM. Alterations in the hemostatic profiles of dogs with naturally occurring septic peritonitis. *J Vet Emerg Crit Care (San Antonio).* 2013;23(1):14–22. doi:10.1111/vec.12013
32. de Laforcade A. Disease associated with thrombosis. *Top Companion Anim Med.* 2012;27(2):59–64. doi:10.1053/j.tcam.2012.07.002
33. Eralp O, Yilmaz Z, Failing K, Moritz A, Bauer N. Effect of experimental endotoxemia on thromboelastography parameters, secondary and tertiary hemostasis in dogs. *J Vet Intern Med.* 2011;25(3):524–531. doi:10.1111/j.1939-1676.2011.0698.x
34. Kristensen AT, Wiinberg B, Jessen LR, Andreasen E, Jensen AL. Evaluation of human recombinant tissue factor-activated thromboelastography in 49 dogs with neoplasia. *J Vet Intern Med.* 2008;22(1):140–147. doi:10.1111/j.1939-1676.2008.0030.x
35. Levi M, Schultz M, van der Poll T. Disseminated intravascular coagulation in infectious disease. *Semin Thromb Hemost.* 2010;36(4):367–377. doi:10.1055/s-0030-1254046
36. Smith SA, Tobias AH, Jacob KA, Fine DM, Grumbles PL. Arterial thromboembolism in cats: acute crisis in 127 cases (1992–2001) and long-term management with low-dose aspirin in 24 cases. *J Vet Intern Med.* 2003;17(1):73–83. doi:10.1111/j.1939-1676.2003.tb01326.x
37. Wagg CR, Boysen SR, Bédard C. Thromboelastography in dogs admitted to an intensive care unit. *Vet Clin Pathol.* 2009;38(4):453–461. doi:10.1111/j.1939-165X.2009.00161.x
38. Page CD, Schmidt RE. Disseminated intravascular coagulation in a neonatal white rhinoceros (*Ceratotherium simum simum*). *J Zoo Anim Med.* 1987;18(2/3):53–55. doi:10.2307/20460237
39. Murray S, Lung NP, Alvarado TP, et al. Idiopathic hemorrhagic vasculopathy syndrome in seven black rhinoceros. *J Am Vet Med Assoc.* 2000;216(2):230–233. doi:10.2460/javma.2000.216.230
40. Kock ND, Kock MD, Young KB. Hepatopathy in two black rhinoceroses (*Diceros bicornis*) in Zimbabwe: creosote toxicosis? *J Zoo Wildl Med.* 1994;25(2):270–273.
41. Chaplin H Jr, Malecek AC, Miller RE, Bell CE, Gray LS, Hunter VL. Acute intravascular hemolytic anemia in the black rhinoceros: hematologic and immunohematologic observations. *Am J Vet Res.* 1986;47(6):1313–1320. doi:10.2460/ajvr.1986.47.06.1313
42. Schmidt RE, Toft JD, Eason RL, Hartfiel DA. Possible toxic liver degeneration in black rhinoceroses (*Diceros bicornis*). *J Zoo Anim Med.* 1982;13(1):3–10. doi:10.2307/20094554
43. Paglia DE, Valentine WN, Miller RE, Nakatani M, Brockway RA. Acute intravascular hemolysis in the black rhinoceros: erythrocyte enzymes and metabolic intermediates. *Am J Vet Res.* 1986;47(6):1321–1325. doi:10.2460/ajvr.1986.47.06.1321
44. Fenty RK, DeLaforcade AM, Shaw SE, O'Toole TE. Identification of hypercoagulability in dogs with primary immune-mediated hemolytic anemia by means of thromboelastography. *J Am Vet Med Assoc.* 2011;238(4):463–467. doi:10.2460/javma.238.4.463
45. Lynch AM, deLaforcade AM, Meola D, et al. Assessment of hemostatic changes in a model of acute hemorrhage in dogs. *J Vet Emerg Crit Care (San Antonio).* 2016;26(3):333–343. doi:10.1111/vec.12457
46. Miller M, Buss P, Wanty R, Parsons S, van Helden P, Olea-Popelka F. Baseline hematologic results for free-ranging white rhinoceros (*Ceratotherium simum*) in Kruger National Park, South Africa. *J Wildl Dis.* 2015;51(4):916–922. doi:10.7589/2015-03-081
47. Miller MA, Buss PE. Rhinoceridae. In: Miller RE, Fowler ME, eds. *Fowler's Zoo and Wild Animal Medicine.* Vol 8. Elsevier; 2018:538–547.
48. Trivedi S, Burnham CM, Capobianco CM, et al. Analysis of blood biochemistry of free ranging and human-managed southern white rhinoceros (*Ceratotherium simum simum*) using the i-STAT Alinity v. *Vet Med Int.* 2021;2021:2665956. doi:10.1155/2021/2665956
49. Steyrer C, Pohlin F, Meyer LC, Buss P, Hooijberg EH. Comparison of three hematocrit measurement methods in the southern white rhinoceros (*Ceratotherium simum simum*). *Vet Clin Pathol.* 2022;51(2):225–230. doi:10.1111/vcp.13076
50. Salinas D. Viscoelastic studies: effective tools for trauma and surgical resuscitation efforts. *AORN J.* 2017;105(4):370–383. doi:10.1016/j.aorn.2017.01.013
51. Hennink I, Peters L, van Geest G, Adamik KN. Evaluation of a viscoelastic coagulation monitoring system (VCM vet) and its correlation with thromboelastometry (ROTEM) in diseased and healthy dogs. *Animals.* 2023;13(3):405. doi:10.3390/ani13030405
52. Cummings CO, Bedenice D, Wills SE, et al. Whole blood thromboelastrography in healthy adult camelids (*Vicugna pacos* and *Camelus dromedarius*). *J Zoo Wildl Med.* 2022;53(1):133–140. doi:10.1638/2021-0033
53. Brooks AC, Guillaumin J, Cooper ES, Couto CG. Effects of hematocrit and red blood cell-independent viscosity on canine thromboelastography tracings. *Transfusion.* 2014;54(3):727–734. doi:10.1111/trf.12354
54. Windberger U, Bartholovitsch A, Plasenzotti R, Korak KJ, Heinze G. Whole blood viscosity, plasma viscosity and erythrocyte aggregation in nine mammalian species: reference values and comparison of data. *Exp Physiol.* 2003;88(3):431–440. doi: 10.1113/eph8802496
55. Yucupicio SD, Bishop RC, Fick ME, et al. Prolonged holding time and sampling protocol affects viscoelastic coagulation parameters as measured by the VCM-Vet using fresh equine native whole blood. *Am J Vet Res.* 2023;84(6):ajvr.23.02.0039. doi:10.2460/ajvr.23.02.0039
56. Barthelemy A, Rannou B, Forterre M, et al. Differences between coagulation and cytokine profiles in dogs of different ages. *Vet J.* 2015;205(3):410–412. doi:10.1016/j.tvjl.2015.05.012
57. Roeloffzen WW, Kluin-Nelemans HC, Mulder AB, Veeger NJ, Bosman L, de Wolf FT. In normal controls, both age and gender affect coagulability as measured by thrombelastography. *Anesth Analg.* 2010;110(4):987–994. doi:10.1213/ANE.0b013e3181d31e91
58. Scarpelini S, Rhind SG, Nascimento B, et al. Normal range values for thromboelastography in healthy adult volunteers. *Braz J Med Biol Res.* 2009;42(12):1210–1217. doi:10.1590/S0100-879X2009007500002
59. Gorton HJ, Warren ER, Simpson NA, Lyons GR, Columb MO. Thromboelastography identifies sex-related differences in coagulation. *Anesth Analg.* 2000;91(5):1279–1281. doi:10.1213/00000539-200011000-00042
60. Hoareau GL, Barthélemy A, Goy-Thollot I, et al. Reference intervals for and the effects of sample handling and sex on rotational thromboelastometry in healthy adult pigs. *J Am Assoc Lab Anim Sci.* 2020:59(3);322–327. doi:10.30802/AALAS-JAALAS-19-000095
61. Smith SA, McMichael MA, Gilor S, Galligan AJ, Hoh CM. Correlation of hematocrit, platelet concentration, and plasma coagulation factors with results of thromboelastometry in canine whole blood samples. *Am J Vet Res.* 2012;73(6):789–798. doi:10.2460/ajvr.73.6.789
62. McMichael M, Smith SA, McConachie EL, Lascola K, Wilkins PA. In-vitro hypocoagulability on whole blood thromboelastometry associated with in-vivo expansion of red cell mass in an equine model. *Blood Coagul Fibrinolysis.* 2011;22(5):424–430. doi:10.1097/MBC.0b013e3283464f83
63. Bowbrick VA, Mikhailidis DP, Stansby G. Influence of platelet count and activity on thromboelastography parameters. *Platelets.* 2003;14(4):219–224. doi:10.1080/0953710031000118849

64. Allen J, Stokol T. Thrombocytosis and essential thrombocytopenia. In: Brooks MB, Harr KE, Seelig DM, Weiss DJ, eds. *Schalm's Veterinary Hematology.* 7th ed. John Wiley & Sons Inc; 2022:721–730.
65. Song J, Drobatz KJ, Silverstein DC. Retrospective evaluation of shortened prothrombin time or activated partial thromboplastin time for the diagnosis of hypercoagulability in dogs: 25 cases (2006-2011). *J Vet Emerg Crit Care (San Antonio).* 2016;26(3):398–405. doi:10.1111/vec.12478
66. Stokol T, Brooks MB, Erb HN, Mauldin GE. D-dimer concentrations in healthy dogs and dogs with disseminated intravascular coagulation. *Am J Vet Res.* 2000;61(4):393–398. doi:10.2460/ajvr.2000.61.393
67. Cesarini C, Monreal L, Armengou L, Delgado M, Ríos J, Jose-Cunilleras E. Association of admission plasma D-dimer concentration with diagnosis and outcome in horses with colic. *J Vet Intern Med.* 2010;24(6):1490–1497. doi:10.1111/j.1939-1676.2010.0618.x
68. Jackson KV. Immunohematology and hemostasis. In: Walton RM, Cowell RL, Valenciano AC, eds. *Equine Hematology, Cytology, and Clinical Chemistry.* 2nd ed. John Wiley & Sons; 2021:41–62.
69. Belgrave RL, Dickey MM, Arheart KL, Cray C. Assessment of serum amyloid a testing of horses and its clinical application in a specialized equine practice. *J Am Vet Med Assoc.* 2013;243(1):113–119. doi:10.2460/javma.243.1.113