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Jonathan Florentin
University Hospital of Martinique
Rishika Banydeen
University Hospital of Martinique
Marie-Daniela Dubois
University Hospital of Martinique
Florian Negrello
University Hospital of Martinique
Astrid Monfort
University Hospital of Martinique
Papa Gueye
University of the French West Indies, Université des Antilles)
Guy-Albert Rufin-Duhamel
Regional Health Agency of Martinique
Karim Fard
University Hospital of Martinique
Christina Iosif
University Hospital of Martinique (CHU Martinique)
Rémi Neviere
University Hospital of Martinique
Hatem Kallel
UMR-9017, French Guiana
Dabor Resiere
Dabor.resiere@chu-martinique.fr

University Hospital of Martinique

Research Article

Keywords: Snake envenomation, Imaging, Diagnosis, Bothrops lanceolatus, Caribbean

Posted Date: September 14th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10490712/v1

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Additional Declarations: No competing interests reported.

Medical imaging in *Bothrops lanceolatus* envenomation: a retrospective series from Martinique

Jonathan Florentin[1-3], Rishika Banydeen[1,2], Marie-Daniela Dubois[1,2], Florian Negrello[2,3], Astrid Monfort[2, 4], Papa Gueye[2,3], Guy-Albert Rufin-Duhamel[5], Karim Fard[6] , Christina Iosif[6], Rémi Neviere[1,2] , Hatem Kallel[7,8] and Dabor Resiere[1-3*]

[1]Department of Clinical and Environmental Toxicology, University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France
[2]Cardiovascular Research Team (UR5_3 PC2E), University of the French West Indies (Université des Antilles), 97200 Fort de France, France.
[3]Department of Emergency Medicine and Critical Care, University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France
[4]Department of Cardiology. University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France
[5]Regional Health Agency of Martinique. 97200 Fort de France, France
[6]Department of Medical Imaging. University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France
[7]Tropical Biome and Immunopathology CNRS UMR-9017, Inserm U 1019, Université de Guyane, French Guiana. 97300 Cayenne, France.
[8]Intensive Care Unit, University Hospital, of French Guiana. 97300 Cayenne, France.

*Correspondence:
Dabor Resiere
Dabor.resiere@chu-martinique.fr

ABSTRACT

Background:
Bothrops lanceolatus (Bl), a pit viper endemic to Martinique, is responsible for 40–50 envenomations annually. These are characterized by systemic thrombotic complications, that can lead to cerebral, myocardial, or pulmonary infarction. The introduction of the specific antivenom Bothrofav has substantially improved patient prognosis and management. Although severity grading remains primarily clinical, the specific role of medical imaging in this setting is underexplored. We aimed to delineate the contribution of imaging to the management of *B. lanceolatus* envenomation.

Methods:
We conducted a single-center retrospective observational study at the University Hospital of Martinique from January 2011 to August 2024. All patients with documented *B. lanceolatus* envenomation were included. We collected data in imaging use, clinical severity grade, and complications. Bivariate analyses were performed to examine associations between clinical status and imaging use.

Results:
A total of 389 patients were included (median age 48 years [IQR 35–59]; 128 [33%] women). Seventy-nine patients (20%) underwent at least one imaging examination, for a total of 127 studies. Imaging was infrequently used in mild envenomation (Grades 1–2) but significantly more frequent in severe cases (Grades 3–4, $p < 0.01$) and then complications were present, including compartment syndrome, shock, coma, infection, or the need for surgery. Eleven thrombotic events were confirmed in six pa three cerebral infarctions, three myocardial infarctions, two pulmonary embolisms, and three deep vein thromboses. Thoracic computed tomography (CT) and Doppler ultrasound were central to the diagnosis of pulmonary embolism and peripheral thrombosis, respectively.

Conclusions:
Although the management of snakebite envenomation remains primarily clinical, judicious

use of medical imaging, specifically CT, MRI, and Doppler ultrasound, serves as a valuable adjunct. Imaging enhances severity grading and is essential for confirming thrombotic complications, thereby supporting the development of standardized, imaging-based management protocols for *B. lanceolatus* envenomation.

Keywords: Snake envenomation, Imaging, Diagnosis, *Bothrops lanceolatus*, Caribbean

INTRODUCTION

Bothrops lanceolatus is a pit viper endemic to the island of Martinique, a French territory in the Caribbean. This species is responsible for 30–40 envenomation cases per year [1,2]. Envenomation produces a syndrome characterized by local effects—including pain, oedema, and necrosis, as well as systemic involvement such as hemodynamic disturbances and, in severe cases, hematological abnormalities [1–4]. Most of these features resemble those seen in envenomations caused by other *Bothrops* species [5–7]. However, unlike the typical hemostatic disturbances induced by other *Bothrops* venoms, which are characterized by consumption coagulopathy and defibrinogenation [6,8], untreated *B. lanceolatus* envenomation leads to severe thrombotic complications in up to 30% of cases. These may manifest as cerebral, myocardial, or pulmonary infarction, myocarditis, or diffuse thrombotic microangiopathy [1,9–11]. Whereas some envenomations require ultrasound for early severity assessment [12,13] or to locate foreign bodies such as fangs [14], the severity of *B. lanceolatus* envenomation is assessed primarily using a clinical scale. This scale comprises four grades (Figures 1 and 2), determined by the extent of oedema and pain together with the presence of systemic signs suggesting organ failure or thrombosis. These clinical grades have been correlated with venom concentrations measured in blood [1,3,11].



Figure 1 *Bothrops lanceolatus*



Figure *2* Clinical grades of severity of *B. lanceolatus* envenomation: A: Grade 1, B: Grade 2, C :grade 3, D :Grade 4

Management of *B. lanceolatus* envenomation relies on the early administration of a monovalent antivenom, Bothrofav®2. Since its introduction in 2011, it has greatly reduced the incidence of severe envenomation and thrombotic complications [15]. However, the role and indications for medical imaging in this context remain poorly described in the literature [15,16]. We therefore analyzed our *B. lanceolatus* dataset to assess the contribution of medical imaging to the management of these patients in Martinique over a 14-year period. Our primary objective was to evaluate the use of imaging techniques in initial diagnosis, early

severity assessment, differential diagnosis, and the targeted administration of antivenom therapy.

METHODS

Study Design

We conducted a monocentric retrospective observational study at the University Hospital of Martinique, covering the period from January 1, 2011, to August 10, 2025.

Study Population

The study population included all patients admitted to the University Hospital of Martinique with a confirmed diagnosis of *Bothrops lanceolatus* snakebite envenomation during the specified period. Patients of all ages, including both children and adults, were eligible for inclusion, provided that the diagnosis of *Bothrops* envenomation was established by the attending clinician based on clinical presentation and epidemiological context. Patients were excluded from the study if their medical records were unavailable for review or if an alternative diagnosis—most commonly a centipede bite (e.g., *Scolopendra* spp.)—was identified. This methodology ensured the inclusion of all confirmed cases while minimizing the risk of diagnostic misclassification.

Ethical considerations

The present study was conducted in accordance with the amended Declaration of Helsinki (https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki//) and Good Clinical Practice guidelines (GCP European Directive 2005/28/EC). It was approved by the Institutional Review Board (IRB) of the University Hospital of Martinique. All patients were informed about the study, and their consent was systematically obtained.

Study Data

Data collection was performed using the snake envenomation clinical database of the Center for Occupational and Environmental Diseases at the Department of Clinical and Environmental Toxicology, University Hospital of Martinique. Clinical and biological data were supplemented with information from medical records and the following software tools: DxCare®, Résurgences®, X-plore®, and Cyberlab®. All imaging results were retrieved from the X-plore® server and stored securely.

We collected demographic data (age, gender, medical history, and comorbidities), clinical signs indicative of *Bothrops lanceolatus* envenomation (such as edema, pain, digestive

symptoms, and shock), the date of onset, management details, and imaging reports and images.

The severity of envenomation was categorized into four grades: Grade 1 (no severity), Grade 2 (moderate severity requiring outpatient treatment), Grade 3 (severe severity requiring hospitalization), and Grade 4 (major severity requiring critical care hospitalization).

Statistical analysis

Data were compiled using Microsoft Excel®. Statistical analyses were performed with the SPSS Statistics® software. In the descriptive phase, continuous variables were expressed as mean ± standard deviation or median and interquartile range (IQR), depending on data distribution. Categorical variables were expressed as counts and percentages.

In the analytical phase, bivariate analysis was performed using the Student or Wilcoxon/Mann–Whitney U test for continuous variables, and Chi-square or Fisher's exact test for categorical variables, depending on applicability.

RESULTS

A total of 389 patients with *Bothrops lanceolatus* envenomation were included (261 men, 128 women; median age 48 years, IQR 35–59). Imaging was conducted in 79 patients (20.3%), involving 127 total examinations. These consisted of Doppler ultrasound (n=68), brain MRI (n=32), thoracic CT (n=11), brain CT (n=6), echocardiography (n=6), and cardiac MRI (n=4). The distribution of imaging modalities is illustrated in the flow chart (Figure 3).

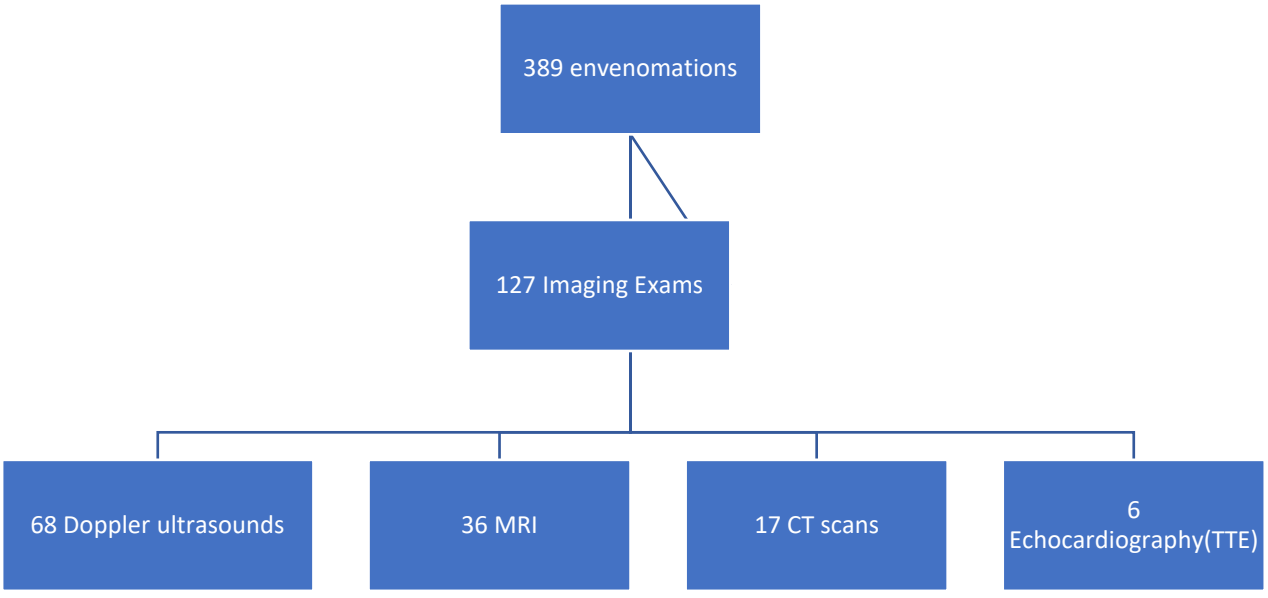


Figure 3 Study flowchart

Univariate analysis using Fisher's exact test demonstrated a significant association between the use of imaging and the severity grade of viperid envenomation. Patients with grade 4 envenomation were significantly more likely to undergo imaging ($p < 0.0001$), as were those with grade 3 envenomation ($p = 0.0014$). Conversely, imaging was performed less frequently among grade 2 patients ($p < 0.0001$) and grade 1 patients ($p = 0.0061$).

Imaging use was also significantly associated with the occurrence of severe complications, including compartment syndrome ($p < 0.0001$), shock ($p = 0.0078$), coma ($p = 0.0015$), and the need for surgical intervention ($p < 0.0001$). Additionally, imaging was strongly associated with infectious complications, such as infection ($p < 0.0001$), cellulitis ($p < 0.0001$), and necrosis ($p = 0.0043$). No significant association was identified with cardiac disorders ($p = 0.36$) or necrotizing fasciitis ($p = 0.36$). Finally, the use of imaging was significantly associated with hospital admission ($p < 0.0001$) and with admission to the ICU or intermediate care unit ($p < 0.0001$). The clinical characteristics of the overall study population are presented in Table 1.

Table 1 Characteristics of the study population

Characteristics	All patients (N=389)	Imaging performed (N=79)	No imaging performed (N=310)	p-value*
Clinical severity				
Grade 4	23 (5.9)	20 (25.3)	3 (1.0)	<0.001
Grade 3	58 (14.9)	26 (32.9)	33 (10.6)	0.001
Grade 2	275 (70.7)	32 (40.5)	242 (78.1)	<0.001
Grade 1	34 (8.7)	1 (1.3)	33 (10.6)	0.006
Compartment syndrome	6 (1.5)	6 (7.6)	0 (0.0)	<0.001
Shock	3 (0.8)	3 (3.8)	0 (0.0)	0.008
Surgical intervention	14 (3.6)	10 (12.7)	4 (1.3)	<0.001
Cardiac disorders	2 (0.5)	1 (1.3)	1 (0.3)	0.361
Coma	4 (1.0)	4 (5.1)	0 (0.0)	0.002
Infection	43 (11.0)	30 (38)	13 (4.2)	<0.001
Cellulitis	27 (6.9)	21 (26.6)	6 (1.9)	<0.001
Necrosis	7 (1.8)	5 (6.3)	2 (0.6)	0.004
Necrotizing fasciitis	2 (0.5)	1 (1.3)	1 (0.3)	0.361
Hospitalisation	209 (53.7)	60 (75.9)	149 (48.1)	<0.001
Intensive/Critical care	38 (9.7)	15 (19)	23 (7.4)	<0.001
Supplementary dose of Antivenom	48 (12.3)	32 (40.5)	16 (5.2)	<0.001
Death	0	0	0	

* statistical significance set at $p<0.05$

A total of 11 thrombotic complications were documented in 6 patients during the study period. These complications included three acute cerebral infarctions, all confirmed by brain MRI, which consistently revealed recent ischemic lesions. Three cases of acute myocarditis were identified based on characteristic findings in cardiac MRI, including myocardial edema and late

gadolinium enhancement. Two pulmonary embolisms were diagnosed through contrast-enhanced thoracic CT angiography, which demonstrated segmental or bilateral thromboembolic involvement. Additionally, three deep vein thromboses were detected using Doppler ultrasond, affecting peripheral venous territories. All cases of compartment syndrome were confirmed via Doppler ultrasonography, with five of these patients receiving an additional dose of antivenom. The detailed imaging characteristics of each thrombotic event are presented in Table 2.

Table 2 Thrombotic complications reported after Bothrops lanceolatus envenomation during the study period. University Hospital of Martinique

Patient	Type of imaging	Result
1	Cardiac MRI	Multiple punctate areas of late gadolinium enhancement in the lateral wall and apex, from mid-myocardial to transmural, consistent with myocarditis. Recent onset suggested by lateral myocardial edema on T2-weighted imaging.
1	Brain MRI	Bilateral cerebellar junctional lesions.
2	Thoracic CT	Thrombus in the lumen of the ascending aorta (5 mm diameter) and in the aortic arch at the origin of the brachiocephalic trunk (6 mm). Left segmental pulmonary embolism.
2	Doppler Ultrasound	Isolated thrombosis of the left soleal and fibular veins.
2	Cardiac MRI	T2 hyperintense area and transmural late gadolinium enhancement in the basal lateral wall, consistent with a recent microvascular event.

2	Brain MRI	Multiple established ischemic foci in both supratentorial and infratentorial regions.
3	Brain MRI	Recent established ischemic lesions in the left posterior cerebral artery territory.
3	Cardiac MRI	Multiple focal areas of late gadolinium enhancement, ranging from subendocardial to transmural (inferior, inferoseptal, and apicolateral regions).
4	Thoracic CT	Bilateral pulmonary embolism.
5	Doppler ultrasound	Upper limb deep vein thrombosis.
6	Doppler ultrasound	Thrombosis of a branch of the right internal jugular vein; occlusive (11 mm on compression), in direct contact with the internal jugular vein but without extension into the main vessel.

172 *Abbreviations: MRI: Magnetic Resonance Imaging; CT: computerized tomography*

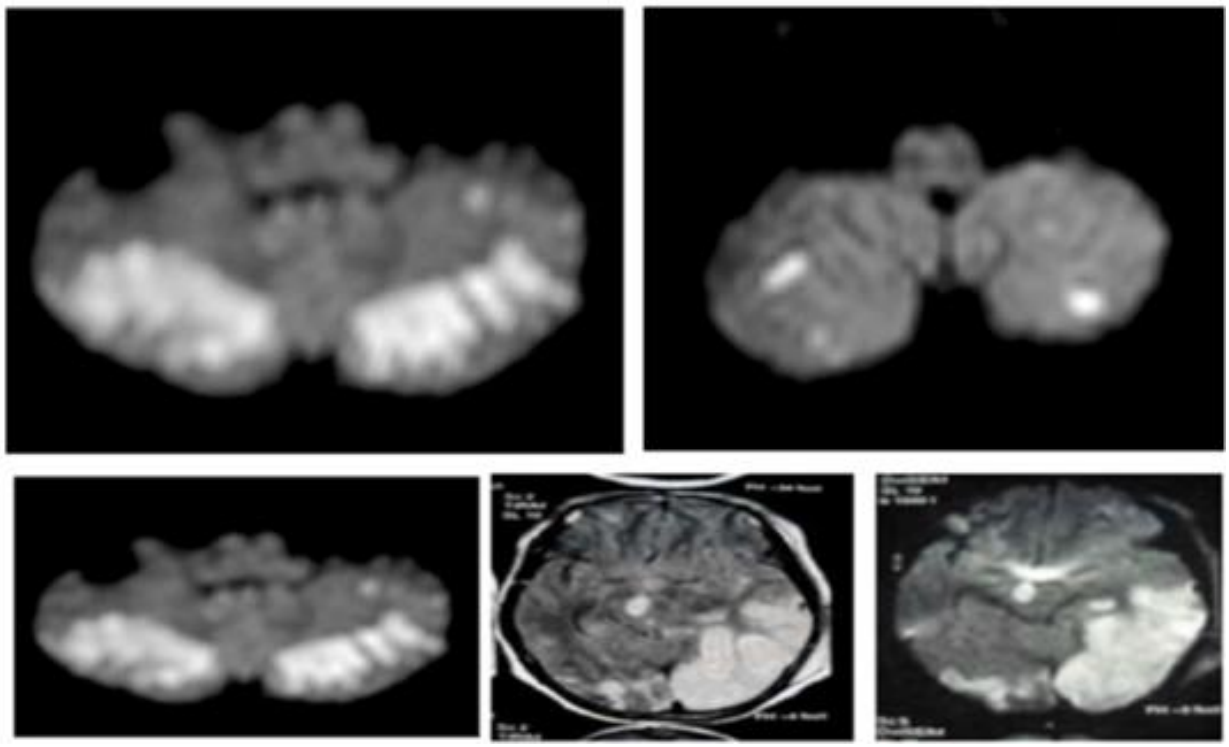


Figure 4. *Characteristic MRI pattern, constantly showing a junctional stroke predominating in the region of posterior cerebral arteries (PICA) in Bl bite-related strokes*

DISCUSSION

The genus *Bothrops* comprises more than 48 species distributed across the Neotropics, with ten species identified within the Caribbean Basin [17]. These snakes are highly venomous and are responsible for the majority of snakebite-related morbidity and mortality in the Americas, accounting for over 90% of all envenomations in the Caribbean. Notably, two of the three species responsible for the highest global incidence of snakebites belong to this genus [17]. In Martinique, *Bothrops lanceolatus* is the sole venomous species and is responsible for approximately 40 envenomation's annually. Although modern clinical management has been highly effective, with no recorded fatalities over the past 20 years, systemic thrombotic complications remain a critical concern [15]. These complications are particularly prevalent in untreated cases or when antivenom therapy is delayed beyond the therapeutic window of six hours. For diagnosis, brain magnetic resonance imaging (MRI) remains the gold standard for

identifying ischemic lesions, particularly within the posterior inferior cerebellar artery (PICA) territory, which is frequently involved in *B. lanceolatus* envenomation. There is also an increasing role for specialized modalities such as cardiac MRI, used to screen for myocarditis and other cardiovascular complications.

Our experience suggests that imaging plays a complementary role to clinical examination in assessing the severity of *B. lanceolatus* envenomation and may influence decisions regarding antivenom therapy in a substantial proportion of cases. These findings indicate that clinical severity assessment can be enhanced through integrated imaging. In particular, point-of-care ultrasonography (POCUS) may assist in the early evaluation of envenomation severity, provided that emergency physicians receive dedicated training in these techniques [12,14,18–21].

Other modalities, such as computed tomography (CT) or MRI, appear to have limited utility in clinically mild cases; their role is primarily restricted to confirming thrombotic complications in severe envenomation. This is consistent with the existing literature: snakebite envenomation primarily affects rural, socioeconomically disadvantaged populations in tropical regions, where most patients are treated in primary healthcare settings [22]. Consequently, advanced modalities such as brain MRI or thoracic CT are generally reserved for severe cases, to help guide targeted antivenom administration [23–28].

These findings confirm that effective clinical management is achievable even in resource-limited settings. Early assessment using soft-tissue ultrasound can improve severity stratification, guide the timely indication of antivenom therapy, and assist in the surgical management of compartment syndrome, as observed in envenomation by Crotalidae species or *Bothrops jararaca* [13,29,30]. Conventional ultrasonography can also be used to localize and characterize soft-tissue oedema. As a non-invasive and well-tolerated modality, it supports clinical evaluation of the affected limb and allows longitudinal monitoring of swelling [21,31].

In cases of severe envenomation or antivenom failure where a differential diagnosis is required, transfer to an advanced care center for MRI or CT may be necessary. These modalities help confirm the diagnosis and guide continuation of therapy, particularly in neurological complications [24,28,32–35]. Although CT is highly reliable for identifying deep infectious lesions, it is most critical for diagnosing pulmonary embolism (PE) and thoracic thrombosis, which are rare but life-threatening complications of viperid envenomation. In both our study and previous reports, CT pulmonary angiography (CTPA) consistently emerged as the gold-standard modality for these events [4,36–38].

Thoracic thromboses are reported more frequently following viperid envenomation in Europe and North Africa. They may develop several days after the initial bite and often appear unresponsive to prophylactic heparin therapy [27,37,39]. Although less common in *Bothrops* envenomation, they should be suspected in severe cases with compatible clinical features. Notably, these PEs are typically not associated with deep vein thrombosis (DVT) of the limbs, suggesting a localized mechanism of endothelial injury mediated by venom components, specifically metalloproteinases, phospholipases, C-type lectins, and thrombin-like enzymes, that affect the medium and large thoracic vessels [40].

The diagnosis of snakebite relies on identifying the snake, the circumstances of the bite, and clinical signs such as bleeding, swelling, and pain [1]. Coagulation tests (platelet count, prothrombin time, activated partial thromboplastin time, fibrinogen) help identify thrombocytopenia or disseminated intravascular coagulation, and a clinical scoring system can assess envenomation severity. Although identification of the snake is helpful, it is not always possible. Routine imaging is not typically required in snakebite envenomation. However, it can be valuable in specific situations: neuroimaging (CT or MRI) is necessary to investigate intracranial bleeding or other neurological complications in patients with altered mental status or neurological deficits [24,28,33]. Finally, thermography offers a promising

avenue for the diagnosis, initial assessment, and follow-up of *Bothrops* envenomation [41–43]. This low-cost, sensitive technique may eventually become a routine tool in managing *B. lanceolatus* cases. Recent studies also suggest a potential role for artificial intelligence (AI) in facilitating snake species identification and improving the precision of imaging analysis [44].

Study Limitations

This study has several limitations. Its retrospective, single-center design may have introduced selection and information biases, and clinical documentation was occasionally incomplete. Imaging was performed on the basis of clinical judgement rather than a standardized protocol, which may have led to under-diagnosis of asymptomatic or mild thrombotic events, particularly where MRI was not obtained. The small number of confirmed thrombotic complications limits statistical power and precludes more detailed subgroup analyses. Finally, as the study was conducted in a referral center with access to advanced imaging, the findings may not be fully generalizable to primary care or low-resource settings, where the majority of snakebites occur.

Despite these limitations, this study provides the most extensive imaging-based assessment of *Bothrops lanceolatus* envenomation to date and offers valuable insights to guide clinical management and future research.

CONCLUSION

Our study shows that the management of snakebite envenomation relies primarily on clinical assessment, but it also highlights the value of targeted imaging, providing a foundation for initial recommendations. Imaging can assist in diagnosis, assess initial severity, monitor ongoing severity, help adjust antivenom therapy, and enable early identification of adverse outcomes and disease progression. Medical imaging is therefore a valuable adjunct in the early evaluation and management of severe snakebite envenomation, especially among rural

and socioeconomically disadvantaged populations in tropical regions, where access to imaging is often limited.

Ultrasonography can serve as an effective indicator of severity and aid diagnosis, particularly in assessing the extent of soft-tissue oedema; training healthcare teams in bedside ultrasound could therefore be beneficial. In non-severe cases managed in resource-limited settings, contrast-enhanced CT may be considered when available, alongside ultrasonographic findings. Although diagnosis remains primarily clinical, a differential diagnosis is necessary in selected cases; in such instances ultrasonography is a valuable diagnostic tool, whereas the role of MRI , though validated, particularly in severe cases, remains more limited in this context.

Authors' contributions

Conception and design of the research: Jonathan Florentin & Dabor Resiere. Acquisition of data: Jonathan Florentin, Rishika Banydeen, & Marie-Daniela Dubois. Analysis and interpretation of data: Jonathan Florentin, Rishika Banydeen, Marie-Daniela Dubois & Dabor Resiere. Writing of the manuscript: Jonathan Florentin & Dabor Resiere. Critical revision of the manuscript for intellectual content: Jonathan Florentin, Rishika Banydeen, Florian Negrello, Astrid Monfort, Papa Gueye, Guy-Albert Rufin-Duhamel, Karim Fard, Rémi Neviere, Christina Iosif,

Hatem Kallel & Dabor Resiere. All the authors read and approved the final draft.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

Data are available upon reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate

The present study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice (GCP) guidelines. The study was approved by the

Institutional Review Board (IRB) of the University Hospital of Martinique. All patients were informed about the study, and their consent was systematically obtained.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]*Department of Clinical and Environmental Toxicology, University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France*
[2]*Cardiovascular Research Team (UR5_3 PC2E), University of the French West Indies (Université des Antilles), 97200 Fort de France, France.*
[3]*Department of Emergency Medicine and Critical Care, University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France*
[4]*Department of Cardiology. University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France*
[5]*Regional Health Agency of Martinique. 97200 Fort de France, France*
[6]*Department of Medical Imaging. University Hospital of Martinique (CHU Martinique), 97261 Fort-de-France, France*
[7]*Tropical Biome and Immunopathology CNRS UMR-9017, Inserm U 1019, Université de Guyane, French Guiana. 97300 Cayenne, France.*
[8]*Intensive Care Unit, University Hospital, of French Guiana. 97300 Cayenne, France.*

REFERENCES

1. Resiere D, Mégarbane B, Valentino R, Mehdaoui H, Thomas L. Bothrops lanceolatus bites: guidelines for severity assessment and emergent management. Toxins. 2010;2:163–73. https://doi.org/10.3390/toxins2010163

2. Thomas L, Tyburn B, Lang J, Ketterle J. Early infusion of a purified monospecific F(ab')2 antivenom serum for Bothrops Ianceolatus bites in Martinique. The Lancet. 1996;347:406. https://doi.org/10.1016/S0140-6736(96)90590-5

3. Bucher B, Canonge D, Thomas L, Tyburn B, Robbe-Vincent A, Choumet V, et al. Clinical indicators of envenoming and serum levels of venom antigens in patients bitten by Bothrops lanceolatus in Martinique. Trans R Soc Trop Med Hyg. 1997;91:186–90. https://doi.org/10.1016/S0035-9203(97)90219-4

4. Thomas L, Tyburn B, Bucher B, Pecout F, Ketterle J, Rieux D, et al. Prevention of thromboses in human patients with Bothrops lanceolatus envenoming in Martinique: failure of anticoagulants and efficacy of a monospecific antivenom. Research Group on Snake Bites in Martinique. Am J Trop Med Hyg. 1995;52:419–26.

5. Malaque C, Gutiérrez J. Snakebite envenomation in Central and South America. In: Critical Care Medicine (Brendt et al., Eds.), Springer International, Switzerland, pp. 1-22. 2016. p. 1–22. https://doi.org/10.1007/978-3-319-20790-2_146-1

6. Monteiro WM, Contreras-Bernal JC, Bisneto PF, Sachett J, Mendonça da Silva I, Lacerda M, et al. Bothrops atrox, the most important snake involved in human envenomings in the amazon: How venomics contributes to the knowledge of snake biology and clinical toxinology. Toxicon X. 2020;6:100037. https://doi.org/10.1016/j.toxcx.2020.100037

7. Otero-Patiño R. Epidemiological, clinical and therapeutic aspects of *Bothrops asper* bites. Toxicon. 2009;54:998–1011. https://doi.org/10.1016/j.toxicon.2009.07.001

8. Houcke S, Pujo JM, Vauquelin S, Ngoula GRL, Matheus S, NkontCho F, et al. Effect of the time to antivenom administration on recovery from snakebite envenoming-related coagulopathy in French Guiana. PLoS Negl Trop Dis. Public Library of Science; 2023;17:e0011242. https://doi.org/10.1371/journal.pntd.0011242

9. Florentin J, Farid K, Kallel H, Neviere R, Resiere D. Case Report: Acute myocarditis and cerebral infarction following Bothrops lanceolatus envenomation in Martinique: a case series. Front Cardiovasc Med. 2024;11:1421911. https://doi.org/10.3389/fcvm.2024.1421911

10. Malbranque S, Piercecchi-Marti MD, Thomas L, Barbey C, Courcier D, Bucher B, et al. Fatal diffuse thrombotic microangiopathy after a bite by the "Fer-de-Lance" pit viper (Bothrops lanceolatus) of Martinique. Am J Trop Med Hyg. 2008;78:856–61.

11. Thomas L, Tyburn B, Ketterlé J, Biao T, Mehdaoui H, Moravie V, et al. Prognostic significance of clinical grading of patients envenomed by Bothrops lanceolatus in Martinique. Trans R Soc Trop Med Hyg. 1998;92:542–5. https://doi.org/10.1016/S0035-9203(98)90907-5

12. Cavalcante JS, Arruda SST, Riciopo PM, Pucca M, Ferreira Junior RS. Diagnosis of human envenoming by terrestrial venomous animals: Routine, advances, and perspectives. Toxicon X. 2024;24:100211. https://doi.org/10.1016/j.toxcx.2024.100211

13. Vohra R, Rangan C, Bengiamin R. Sonographic signs of snakebite. Clin Toxicol Phila Pa. 2014;52:948–51. https://doi.org/10.3109/15563650.2014.958613

14. Rushton WF, Vakkalanka JP, Moak JH, Charlton NP. Negative predictive value of excluding an embedded snake foreign body by ultrasonography. Wilderness Environ Med. 2015;26:227–31. https://doi.org/10.1016/j.wem.2014.12.015

15. Resiere D, Florentin J, Mehdaoui H, Kallel H, Legris-Allusson V, Gueye P, et al. Bothrops lanceolatus Envenoming in Martinique: A Historical Perspective of the Clinical Effectiveness of Bothrofav Antivenom Treatment. Toxins. 2024;16:146. https://doi.org/10.3390/toxins16030146

16. Thomas L, Chausson N, Uzan J, Kaidomar S, Vignes R, Plumelle Y, et al. Thrombotic stroke following snake bites by the "Fer-de-Lance"Bothrops lanceolatus in Martinique despite antivenom treatment: a report of three recent cases. Toxicon Off J Int Soc Toxinology. 2006;48:23–8. https://doi.org/10.1016/j.toxicon.2006.04.007

17. Gutiérrez JM. Snakebite Envenomation in Central America: Epidemiology, Pathophysiology and Treatment. Handb Venoms Toxins Reptil. 2nd ed. CRC Press; 2021.

18. Kirwadi A, Pakala VB, Kumar DS, Evans PA. Tooth remnant in non-venomous snake bite on the face: a rare occurrence. Emerg Med J EMJ. 2008;25:782. https://doi.org/10.1136/emj.2008.057893

19. Ockerse P, Mallin M. Point of care ultrasound strikes again. Clin Toxicol Phila Pa. 2014;52:909–10. https://doi.org/10.3109/15563650.2014.961069

20. Wood D, Sartorius B, Hift R. Ultrasound findings in 42 patients with cytotoxic tissue damage following bites by South African snakes. Emerg Med J EMJ. 2016;33:477–81. https://doi.org/10.1136/emermed-2015-205279

21. Xu S, Liu Y, Zhu L, Hu Y, Xuan J. Value of multimodal ultrasound in the assessment of snakebite. BMC Med Imaging. 2025;25:376. https://doi.org/10.1186/s12880-025-01908-6

22. Gutiérrez JM, Calvete JJ, Habib AG, Harrison RA, Williams DJ, Warrell DA. Snakebite envenoming. Nat Rev Dis Primer. Nature Publishing Group; 2017;3:17063. https://doi.org/10.1038/nrdp.2017.63

23. Chara K, Baccouche N, Turki O, Regaig K, Chaari A, Bahloul M, et al. A rare complication of viper envenomation: cardiac failure. A case report. Med Sante Trop. 2017;27:52–5. https://doi.org/10.1684/mst.2016.0636

24. Ghosh R, León-Ruiz M, Roy D, Naga D, Sardar SS, Benito-León J. Cerebral venous sinus thrombosis following Russell's viper (Daboia russelii) envenomation: A case report and review of the literature. Toxicon Off J Int Soc Toxinology. 2022;218:8–12. https://doi.org/10.1016/j.toxicon.2022.08.014

25. Gutiérrez JM, R Casewell N, Laustsen AH. Progress and Challenges in the Field of Snakebite Envenoming Therapeutics. Annu Rev Pharmacol Toxicol. 2025;65:465–85. https://doi.org/10.1146/annurev-pharmtox-022024-033544

406 26. Numeric P, Moravie V, Didier M, Chatot-Henry D, Cirille S, Bucher B, et al. Multiple
407 cerebral infarctions following a snakebite by Bothrops caribbaeus. Am J Trop Med Hyg.
408 2002;67:287–8.

409 27. Senthilkumaran S, Sampath S, Almeida JR, Williams J, Williams HF, Patel K, et al.
410 Pulmonary Thromboembolism following Russell's Viper Bites. Toxins. 2024;16:222.
411 https://doi.org/10.3390/toxins16050222

412 28. Upadhyay U. Neurotoxic Snakebite Cases with Role of Imaging. J Evid Based Med
413 Healthc [Internet]. [cited 2025 Dec 25]; https://doi.org/10.18410/JEBMH/2017/1084

414 29. Bucaretchi F, De Capitani EM, Hyslop S, Mello SM, Fernandes CB, Bergo F, et al.
415 Compartment syndrome after South American rattlesnake (Crotalus durissus terrificus)
416 envenomation. Clin Toxicol Phila Pa. 2014;52:639–41.
417 https://doi.org/10.3109/15563650.2014.913177

418 30. Bucaretchi F, de Capitani EM, Hyslop S, Mello SM, Madureira PR, Zanardi V, et al.
419 Compartment syndrome after Bothrops jararaca snakebite: monitoring, treatment, and
420 outcome. Clin Toxicol Phila Pa. 2010;48:57–60. https://doi.org/10.3109/15563650903356201

421 31. Wood D, Sartorius B, Hift R. Ultrasound findings in 42 patients with cytotoxic tissue
422 damage following bites by South African snakes. Emerg Med J EMJ. 2016;33:477–81.
423 https://doi.org/10.1136/emermed-2015-205279

424 32. Guidelines for the management of snakebites, 2nd edition [Internet]. [cited 2025 Dec 25].
425 https://www.who.int/publications/i/item/9789290225300. Accessed 25 Dec 2025

426 33. Senthilkumaran S, Williams J, Almeida JR, Williams HF, Patel K,
427 Thirumalaikolundusubramanian P, et al. Snakebite-induced reversible cerebral
428 vasoconstriction syndrome: Report of three cases. Toxicon Off J Int Soc Toxinology.
429 2024;251:108161. https://doi.org/10.1016/j.toxicon.2024.108161

430 34. Srinath KM, Sethi M, Madhu B, Prasad MC, Sangappa SB. Serpent strikes, sapien sways:
431 A rare case of bilateral cerebellar infarct following viper bite. Ann Afr Med. 2024;23:104–6.
432 https://doi.org/10.4103/aam.aam_44_23

433 35. Zeng X, Hu J, Liang X, Wu Y, Yan M, Zhu M, et al. Acute cerebral infarction following a
434 Trimeresurus stejnegeri snakebite: A case report. Medicine (Baltimore). 2019;98:e15684.
435 https://doi.org/10.1097/MD.0000000000015684

436 36. Bhagat R, Sharma K, Sarode R, Shen Y-M. Delayed massive pulmonary thromboembolic
437 phenomenon following envenomation by Mojave rattlesnake (Crotalus scutulatus). Thromb
438 Haemost. 2010;104:186–8. https://doi.org/10.1160/TH09-12-0874

439 37. Chani M, Abouzahir A, Larréché S, Mion G. [Pulmonary embolism in the context of
440 severe envenomation by a Moroccan viper]. Bull Soc Pathol Exot 1990. 2012;105:162–5.
441 https://doi.org/10.1007/s13149-012-0248-7

442 38. Halkin A, Jaffe R, Mevorach D, Bursztyn M. Thoracic complications following snake
443 envenomization. Am J Med. 1997;102:585–7. https://doi.org/10.1016/s0002-9343(97)89438-
444 7

445 39. Makis A, Kattamis A, Grammeniatis V, Sihlimiri P, Kotsonis H, Iliadis A, et al.
446 Pulmonary embolism after snake bite in a child with Diamond-Blackfan anemia. J Pediatr
447 Hematol Oncol. 2011;33:68–70. https://doi.org/10.1097/MPH.0b013e3181e88677

448 40. Estrade G, Garnier D, Bernasconi F, Donatien Y. [Pulmonary embolism and disseminated
449 intravascular coagulation after being bitten by a Bothrops lanceolatus snake. Apropos of a
450 case]. Arch Mal Coeur Vaiss. 1989;82:1903–5.

451 41. Medeiros CR de, Souza SN de, Lara AN, Grego KF. Use of infrared thermography in a
452 case of systemic envenomation by the coral snake Micrurus frontalis (Duméril et al., 1854) in
453 Sao Paulo, Brazil. Toxicon Off J Int Soc Toxinology. 2019;163:70–3.
454 https://doi.org/10.1016/j.toxicon.2019.03.016

455 42. Medeiros CR de, Brioschi ML, Souza SN de, Teixeira MJ. Infrared thermography to
456 diagnose and manage venomous animal bites and stings. Rev Soc Bras Med Trop.
457 2017;50:260–4. https://doi.org/10.1590/0037-8682-0390-2016

458 43. Sabitha P, Ramadoss R, Bammigatti C, Kadhiravan T. Serial evaluation of local changes
459 in snakebite envenomation using infrared thermal imaging. Trans R Soc Trop Med Hyg.
460 2025;119:175–81. https://doi.org/10.1093/trstmh/trae056

461 44. Zhang J, Chen X, Song A, Li X. Artificial intelligence-based snakebite identification
462 using snake images, snakebite wound images, and other modalities of information: A
463 systematic review. Int J Med Inf. 2023;173:105024.
464 https://doi.org/10.1016/j.ijmedinf.2023.105024

465