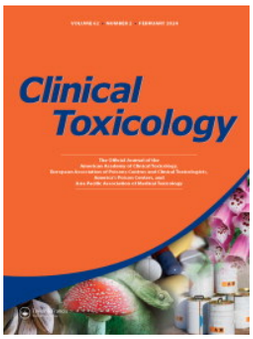

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CLINICAL RESEARCH

Use of point-of-care ultrasound to assess the severity of scorpion stings in hospitalized patients

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ABSTRACT

Introduction: Scorpionism is a public health problem, especially in tropical regions. In Brazil, the prevalence of envenomation by scorpions is high, and the average national lethality is around 0.16 percent. The *Tityus serrulatus* scorpion is the primary species of medical importance. However, objective tools to predict and define the severity of these envenomations are lacking.

Materials and methods: This was an observational study conducted among patients aged 0–19 years with scorpionism. Patients were admitted to a reference hospital between December 2020 and May 2022. Point-of-care ultrasound was performed within 24 hours of the scorpion sting.

Results: Forty-nine patients were included, with a median age of 3.6 (interquartile range 2.3–5.3) years and a predominance of females (51 percent). Fifteen patients (30.6 percent) presented major life-threatening signs, 32 (65.3 percent) minor systemic manifestations, and two (4.1 percent) only local manifestations. Left ventricular dysfunction was identified in 13 patients (26.5 percent). Ten patients (20.4 percent) presented pattern B (visualization of three or more B lines in the evaluated quadrant) in at least one lung window. The sensitivity and specificity of cardiac and pulmonary ultrasound to identify the most severely ill patients were 86 percent and 94 percent, respectively.

Discussion: The changes found on point-of-care ultrasound were associated with life-threatening signs. All patients with class III envenomation were referred to the intensive care unit, showing the importance of early identification of this subgroup. The main limitations were the small sample size and the fact that admission to intensive care was not based on systematic criteria.

Conclusions: Point-of-care ultrasound is able to identify early signs of pulmonary congestion and heart failure in scorpionism. It can be useful for the objective selection of patients who are at a higher risk of complications and death and who require intensive support; it may also be valuable for periodic reassessments. Point-of-care ultrasound is a valuable tool for identifying and monitoring severe cases of scorpionism.

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KEYWORDS
Scorpion sting; *Tityus serrulatus*; echocardiography; bedside ultrasound; heart failure; myocarditis

Introduction

Around 1.2 million scorpion stings are recorded annually worldwide, resulting in more than 3,000 deaths [1]. In Brazil, the prevalence of envenomation by scorpions is high, and the average national lethality is around 0.16%, which corresponds to around 150 deaths per year [2]. The *Tityus serrulatus* scorpion is the primary species of medical importance in the country [3]. The main harmful effects of scorpion venom occur in the cardiovascular system, which can lead to myocarditis, cardiac dysrhythmias, cardiogenic shock, and acute pulmonary edema, among other organ failures [1–5].

According to the severity classification proposed by the 2010 International Consensus [6], scorpion stings can be divided into class I (local manifestations), class II (minor manifestations, which are non-life threatening), and class III (severe manifestations, which are life-threatening) (Table 1). The classification most commonly used in Brazil was proposed by the Brazilian Ministry of Health and divides envenomations into mild, moderate, or severe, as well as based on clinical presentation [7].

Both classifications lack objectivity and require experience from the medical team, which is not always available outside major urban centers. The use of more objective and reproducible tools to classify the severity of scorpionism could help guide clinical management and signal the risk of complications, including the decision to transfer from low-resource environments to toxicology reference centers or the intensive care units (ICU). Moreover, a tool that could help better classify the severity of scorpion envenomation can help stratify inclusion criteria in clinical studies. Among the potential

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Table 1. Classification of scorpion envenomation according to the 2010 International Consensus (only signs and symptoms with total agreement are included).

Class I: local manifestations	Class II: minor manifestations (non-life-threatening)		Class III: severe manifestations (life-threatening). The presence of at least one of the following signs
Bullous eruption	Abdominal distension	Nausea	Cardiogenic failure
Burning sensation	Agitation/restlessness/excitement	Odynophagia	Cyanosis
Ecchymosis	Arthralgia	Pallor	Dyspnea
Erythema	Confusion	Pancreatitis	Glasgow Coma Scale <6
Hyperesthesia	Convulsion	Paresthesia	Hypotension
Itching	Diarrhea	Priapism	Neurological failure
Necrosis	Dry mouth	Ptosis	Paralysis
Paresthesia	Dystonia	Rhinorrhea	Pulmonary edema
Pain	Fasciculation	Salivation	Respiratory failure
Purpura/petechia	Gastrointestinal hemorrhage	Somnolence/lethargy/drowsiness	Ventricular dysrhythmia
Swelling	Hematuria	Stridor	
Tingling	Headache	Sweating	
	Hypertension	Tachycardia	
	Hyperthermia	Thirst	
	Hypothermia	Urinary retention	
	Lacrimation	Vomiting	
	Local muscular cramps	Wheezing	
	Miosis		
	Mydriasis		

Modified from Khattabi et al. [6].

tools, the point-of-care ultrasound appears to be an excellent low-cost alternative that is widely available [8].

This study aimed to evaluate the role of cardiac and pulmonary point-of-care ultrasound as a tool to identify signs of severity in patients stung by scorpions.

Materials and methods

Study design and population

This was an observational study carried out at Hospital João XXIII, Belo Horizonte, Brazil. This hospital is a reference center for patients with poisoning through the Centro de Informação e Assistência toxicológica de Minas Gerais (Center for Information and Toxicological Assistance of Minas Gerais) and manages approximately 1,500 scorpion stings per year.

Patients who were victims of scorpionism and received medical care at the Centro de Informação e Assistência toxicológica de Minas Gerais between December 2020 and May 2022, were classified upon admission as moderate or severe cases, according to the Brazilian classification, and aged 0–19 years, were consecutively included in the study. Patients admitted more than 24 h after the envenomation and patients who did not undergo point-of-care ultrasound within the first 24 h after admission were excluded from the survey.

This research was submitted to the ethics committees of the two institutions involved and approved by Plataforma Brasil under CAAE number 40930820.8.0000.5149.

Data collection

Data were collected using a questionnaire designed for this study based on the Research Electronic Data Capture platform (REDCAP 12.4.0, Vanderbilt University, Nashville, TN). Epidemiological and demographic variables (gender, date of birth, date of admission, and place of birth), as well as data related to the envenomation and clinical manifestations, were obtained from all patients included in the study. These variables included the following information: the site of the sting, the time elapsed between stings and the onset of symptoms, as well as between the sting and the first visit and the hospital admission and the application of the antivenom serum. Reaction to the serum and symptoms presented (pain, vomiting, sweating, tachycardia, bradycardia, hypertension, hypotension, agitation, lethargy, seizure, dysrhythmias, tachypnea, acute pulmonary edema, shock, and others) were also recorded.

The definition of severity was initially made by the care team, following the classification of the Brazilian Ministry of Health [7], with no participation of the researchers. The same occurred with the indication of transfer to the ICU. The research team was contacted by the toxicology assistants through a text message sent to a group created for this purpose as soon as cases of moderate/severe scorpionism were admitted to the hospital. Patients were then reclassified by the main researcher (JSA) according to the International Consensus [6] into class I, class II, or class III for purposes of comparative analyses in this study (Table 1).

All participants underwent 12-lead electrocardiography and chest radiography, as well as general hematological and biochemical tests, during the first hour after admission. Additional tests were performed according to the needs defined by the medical team. All participants received treatment with antivenom serum therapy and supportive measures, following the local care protocol. All the decisions regarding the patient's management were led by the medical team.

Point-of-care ultrasound assessment

The point-of-care ultrasound assessments were performed either by the main investigator (JSA), who is certified by the World Interactive Network Focused On Critical UltraSound (WINFOCUS) and who has more than six years of experience

in this technique or by a team of five residents from the point-of-care ultrasound Emergency Medicine Resident Program, Hospital das Clínicas, Universidade Federal de Minas Gerais, who received two years of training and certification during residency. When performed by residents, the ultrasound was remotely supervised in real-time by the main researcher, who had access to images from all examinations. Additionally, the ultrasounds were recorded and validated by two echocardiographers blinded to the patient's clinical condition (severity classification) and not part of the research team. All examinations were performed using a TOSHIBA Nemio MX device (SSA-590A).

The presence of left ventricular dysfunction was qualitatively defined, initially as present or absent, and in positive cases, it was classified as mild, moderate, or severe. Three quadrants of each hemithorax were evaluated, with a search for the presence of pattern A, pattern B (visualization of three or more B lines in the evaluated quadrant), consolidation, and pleural effusion, according to the Bedside Lung Ultrasound in Emergency protocol [9]. Thirty-one patients were randomly submitted to two-dimensional Doppler echocardiography, performed by the institution's cardiology team. This test was later compared to focused echocardiography as a validation strategy for cardiac point-of-care ultrasound.

Statistical analysis

First, a descriptive analysis of the data was performed, with an evaluation of central tendency and dispersion for continuous variables and proportions for categorical/binary variables. Median and interquartile ranges were used to evaluate the central tendency and dispersion due to the non-parametric distribution. For the evaluation of normality, the Kolmogorov–Smirnov test was used. Comparative analyses were performed using the Chi-square or Fisher's test for proportions or the Mann–Whitney test for continuous variables. A comparative analysis was performed between the groups according to the need for ICU admission. For this, a univariate logistic regression test was used to determine the odds ratio (OR) for the following variables: pulmonary ultrasonography, focused echocardiogram, and the association of pulmonary and/or cardiac ultrasound changes. Cohen's Kappa test was performed to assess the agreement between the point-of-care ultrasound and the echocardiogram performed by an echocardiographer. *P*-values of less than 0.05 were considered statistically significant. The IBM SPSS Statistics package for Windows, Version 27.0 (IBM Corp., 2020, Armonk, NY) was used for all necessary analyses.

Results

Over the 18 months of the study, 1,117 patients stung by scorpions were admitted to the Centro de Informação e Assistência toxicológica de Minas Gerais. Fifty-six were evaluated for eligibility, as they had moderate or severe forms of scorpionism, according to the criteria of the Brazilian Ministry of Health. Of these, seven patients (12.5%) were excluded from the study for the following reasons: age greater than 19 years (two patients), not having point-of-care ultrasound performed within the first 24 h after hospital admission (two patients), or having been admitted 24 h after the scorpion sting (three patients). This study showed a predominance of females (51%), with a median age of 3.6 interquartile range (IQR) 2.3–5.3 years.

Approximately, 98% of the stings occurred at home, and three patients (5%) reported more than one sting. The median time between the sting and the initial medical care was 60 (IQR 30–90) min. Twenty-nine patients (56%) had abnormal electrocardiograms, predominantly sinus tachycardia (27%) and ST-segment depression (21%). Abnormal laboratory results were more frequent among patients with class III envenomation, as depicted in Table 2.

Two patients were classified as class I (4.1%), 32 as class II (65.3%), and 15 as class III (30.6%) envenomations. A total of 28 patients (53%) were transferred to the ICU by the attending team, including the 15 class III envenomation patients cited above. All ICU transfers occurred within the first 24 hours of hospital admission. The main clinical manifestations that led to transfers to the ICU were hypotension, shock, dyspnea, and some degree of respiratory failure (Table 2).

All participants received antivenom serum within an average of 30 (IQR 10.0–62.5) min after admission, and in 51% of the cases, the serum therapy was administered in the hospital where this study was carried out. Six patients (11.8%) had a hypersensitivity reaction associated with antivenom therapy, all of which were mild and described as skin rash or papules. The time interval between the sting and hospital admission, as well as the interval between the sting and administration of antivenom therapy, correlated with the presence of life-threatening signs (class III envenomation) ($P = 0.028$ and $P = 0.017$, respectively). One (2.4%) patient died during hospitalization.

Point-of-care ultrasound assessment

The median time between hospital admission and the completion of the point-of-care ultrasound was 240 (IQR 105–408) min. Left ventricular dysfunction was identified in 13 patients (26.5%), proving to be severe in seven cases (53%). Left ventricular dysfunction was found in 80% of patients with class III envenomation, compared to 2.9% among class I or II envenomation (OR 132; 95% confidence interval [CI]: 12.5–1394; $P < 0.001$). One patient with a class II envenomation had a change in point-of-care ultrasound and was referred to the ICU. The sensitivity of cardiac point-of-care ultrasound to identify patients with class III envenomation was 92%, specificity 97%, positive predictive value 92%, negative predictive value 97%, likelihood ratio for a positive test result 30, and likelihood ratio for a negative test result 0.07.

Regarding pulmonary point-of-care ultrasound, the presence of a B pattern (more than three B lines) in at least one evaluated window was verified in 10 (20.4%) patients. This finding was also significantly more common in patients classified as class III envenomation (60%) when compared to the other two classes (2.9%) (OR 49.5; (95%CI: 5.2–465; $P < 0.001$). The presence of the B pattern in at least one

Table 2. Demographic characteristics, clinical symptoms and laboratory results of patients with scorpion envenomation.

	Total ($N = 49$)	Class III ($n = 15$)	Class I/II ($n = 34$)	*P*-value
Characteristics/symptoms				
Sex male (*n*, %)	24 (49)	9 (60)	15 (44)	0.305
Age (years), median [IQR][a]	3.7 [IQR 2.3–5.3]	4.1 [IQR 2.3–6.9]	3.2 [IQR 1.6–4.9]	0.374
Weight (kg) median [IQR][a]	16 (IQR 12–24)	16 [IQR 12–25]	14.2 [IQR 11.7–22]	0.789
Pain (*n*, %)	31 (63.3)	7 (46.7)	24 (70.6)	0.025
Sialorrhea (*n*, %)	9 (18.4)	2 (13.3)	7 (20.6)	0.702
Sweating (*n*, %)	31 (63.3)	13 (86.7)	18 (52.9)	0.024
Vomiting (*n*, %)	44 (89.8)	12 (80)	32 (94.1)	0.16
Abdominal pain (*n*, %)	3 (6.1)	0	3 (8.8)	0.543
Tachycardia (*n*, %)	22 (44.9)	9 (60)	13 (38.2)	0.158
Bradycardia (*n*, %)	18 (36.7)	6 (40)	12 (35.3)	0.753
Dysrhythmia (*n*, %)	1 (2)	1 (6.7)	0	0.306
Hypotension (*n*, %)	11 (22.4)	11 (73.3)	0	<0.001
Shock (*n*, %)	13 (26.5)	13 (86.7)	0	<0.001
Dyspnea (*n*, %)	14 (28.6)	10 (66.7)	4 (11.8)	<0.001
Tachypnea (*n*, %)	36 (73.5)	14 (93.3)	22 (64.7)	0.043
Pulmonary edema (*n*, %)	3 (6.1)	3 (20)	0	0.025
Neurological signs (*n*, %)	29 (59.2)	11 (73.3)	18 (52.9)	0.181
Seizures (*n*, %)	2 (4.1)	1 (6.7)	1 (2.9)	0.523
Oxygen saturation <93% (*n*, %)	7 (14.3)	7 (46.7)	0	<0.001
Laboratory results				
Leukocyte count ($\times 10^9$/L), median [IQR]	17.6 [12.1–22.5]	19.0 [12.2–22.9]	17.3 [11.3–22.4]	0.558
Blood glucose concentration (mg/dL), median [IQR]	132 [102–230]	126 [111–203]	134 [100–237]	0.828
Blood glucose concentration (mmol/L), median [IQR]	7.33 [5.6–12.7]	7 [6.1–11.2]	7.4 [5.5–13.1]	
Creatine kinase activity (U/L), median [IQR]	253 [149–486]	517 [400–832]	170 [132–324]	<0.001
Amylase activity (U/L), median [IQR]	100 [62.5–201]	179 [100–270]	82 [59.5–178]	0.045
Potassium concentration (mmol/L), median [IQR]	3.6 [3.1–4.0]	3.6 [3.1–4]	3.6 [3–4]	0.400
Lactate concentration (mmol/L), median [IQR]	3.3 [1.7–5.8]	2.8 [1.9–4.1]	3.5 [1.7–6]	1.000
Bicarbonate concentration (mEq/L), median [IQR]	18.5 [16.2–21.2]	16.4 [14.9–19]	19.4 [16.9–21.5]	0.857
Troponin concentration (ng/L), median [IQR]	36.9 [2.2–832.8]	2695 [425–3658]	14.6 [0–44]	<0.001
Creatinine concentration (mg/dL), median [IQR]	0.38 [0.28–0.49]	0.43 [0.31–0.56]	0.37 [0.26–0.49]	0.182
Creatinine concentration (μmol/L), median [IQR]	33.5 [24.7–43.3]	38 [27–49.5]	32.7 [22.9–43.3]	

[a]IQR: interquartile range.

pulmonary window has the following accuracy in identifying patients with class III envenomation: sensitivity of 60%, specificity of 97%, positive predictive value of 90%, negative predictive value of 84.6%, the likelihood ratio for a positive test result 20, and likelihood ratio for a negative test result 0.41.

When evaluated together, left ventricular dysfunction and/or pattern B in any lung window were observed in 86.7% of the patients with class III envenomation and 5.9% of the patients with class I/II envenomation (OR 104; 95% CI: 13.2–818; $P < 0.001$), with better accuracy than the tests evaluated separately: sensitivity of 86%, specificity of 94%, positive predictive value of 86%, negative predictive value of 94%, likelihood ratio for a positive test result of 14.3, and likelihood ratio for a negative test result of 0.14.

Cohen's Kappa test to assess the agreement between point-of-care ultrasound and the echocardiogram performed by an echocardiographer showed strong reliability between the tests ($k = 0.931$; $P < 0.001$; 96.5% agreement). It is important to mention that all patients with changes in cardiac function detected on point-of-care ultrasound had complete recovery in the examination performed before hospital discharge.

Discussion

In this study of 49 patients with scorpion stings, changes in left ventricular function and B patterns in at least one lung field in a point-of-care ultrasound were significantly associated with the presence of life-threatening signs (class III envenomation). All patients with class III envenomations were referred to the ICU, showing the importance of the early identification of this subgroup.

The definition of severity in scorpion envenomations is currently based on clinical criteria that lack objectivity [6,7], which is only obvious in patients with overt organ dysfunction – shock, respiratory failure, coma, or severe dysrhythmias. There is a need for accurate and objective tools that allow for the early identification of patients with the greatest potential for aggravation or, conversely, in whom the risk of this complication is quite low. Victims of scorpionism may present rapid deterioration, requiring an immediate administration of antivenom serum therapy, the main therapeutic measure available [5,10–15]. Thus, the use of predictive tools would be of great help in these cases.

Several authors have sought to develop scores to determine the severity of scorpion envenomations in Brazil and worldwide, but most of these tools are based exclusively on clinical criteria [14–17]. Furthermore, the clinical manifestations differ among the various species of scorpions involved in envenomations around the world, which makes the generalization of the criteria more challenging [16–18]. Pediatric mortality scores in critically ill patients, such as the pediatric risk of mortality score and the pediatric index of mortality, show that physiological instability is a key factor in predicting outcomes in critically ill patients [19]. These prediction tools are essential in establishing the severity of critical illness in general and assessing the quality of services [20]. However, the use of these scores in scorpionism has rarely

been investigated and has limitations, especially those referring to the subgroup of patients with no clear signs of severity upon hospital admission but who may present a rapid deterioration of the clinical picture.

In this study, point-of-care ultrasound alterations present in either cardiac or pulmonary assessment were associated with life-threatening signs. Point-of-care ultrasound is relatively easy to perform after a relatively short period of training and is able to identify early signs of pulmonary congestion and heart failure [20–22]. Overall, the median time interval between patient admission and the performance of the point-of-care ultrasound was approximately four times shorter (240 min) than the time taken to perform the echocardiogram by the institution's staff echocardiographer. In the subgroup of patients with class III evenomation, the median interval was 120 (range 60–600) min for point-of-care ultrasound compared to a median time of 780 (480–1,200) min for echocardiography, demonstrating the greater agility of the bedside examination.

Heart and lung ultrasounds of some patients evaluated in the study are available in supplementary material (Supplementary videos 1–4).

A study conducted by Bouaziz et al. [23] investigated factors associated with pulmonary edema in 428 patients stung by scorpions. The diagnosis of pulmonary congestion was based on chest radiography associated with signs and symptoms. However, even with crackles upon auscultation, 85 patients were excluded from the analysis because they had normal chest radiographs [23], which suggests a low sensitivity of radiographs in this diagnosis. Some studies [24,25] have shown that chest radiography may not identify a moderate increase in extravascular pulmonary fluid since radiological signs of pulmonary edema are usually evident only when it increases by at least 35% [24,25]. Ultrasound enables earlier identification of this alteration by identifying the B pattern [26]. In cardiogenic or inflammatory pulmonary edema, the distribution of B lines is usually bilateral and symmetrical, predominating in the dependent zones in the first case [26]. These characteristics may not be repeated in patients stung by a scorpion since unilateral and asymmetric acute pulmonary edema has been described in the literature in the context of envenomation due to an animal sting [4,27]. In this study, of the 10 patients with changes in pulmonary point-of-care ultrasound, five had unilateral B lines, predominantly in the right hemithorax (three patients), and one patient (10%) had asymmetrical bilateral B lines. Thus, point-of-care ultrasound may play an important role in the assessment of pulmonary edema, considering the low sensitivity of chest radiographs to investigate pulmonary congestion.

Cardiac evaluation with point-of-care ultrasound (focused echocardiogram) fills a gap between the physical examination and the transthoracic echocardiogram performed by the echocardiography service, allowing faster clinical decision-making and reducing the demand or postponing the need to call the specialized service [20,28,29]. In general, the usefulness of point-of-care ultrasound has proven to identify the level of care required for patients admitted to emergency services, predicting the need for mechanical ventilation and vasopressors, as well as mortality [20,28–30].

Unlike pulmonary point-of-care ultrasound, experience with cardiac point-of-care ultrasound in pediatrics is more recent, and studies in the area are still scarce. In part, this is explained by the rarity of acute cardiac involvement in children [31,32]. One study published in 2021 by Hamad et al. [31], which included 10 children with acute heart failure, showed that the time to start therapeutic management with vasoactive agents or diuretics was significantly reduced when point-of-care ultrasound was used in the emergency department, compared to the use of this tool only in the ICU. In our study, point-of-care ultrasound was performed in the emergency department in 13 of the 15 patients with cardiac involvement and helped in the decision to administer sympathomimetic amines and inotropes for these patients, which demonstrates the agility and consequent benefit of the tool in decisions related to referrals and therapeutic management.

This study has several limitations, some of which deserve mention. First, the number of patients included was small, even though it corresponded to almost all cases of scorpionism in the eligible age group treated at the study site during the recruiting period. Second, the ultrasound assessment was performed by more than one examiner, with potential heterogeneity in the interpretation of the findings. This problem was partially resolved with the review of the images in real-time by one of the researchers with experience in point-of-care ultrasound, and the fact that in more than half of the patients (63.2%), the cardiac findings of left ventricular dysfunction were validated in examinations performed by echocardiographers. Finally, the reasons for ICU admission were at the discretion of the admitting physicians, based on their clinical judgment, without systematic criteria defined by the researchers.

Conclusions

Point-of-care ultrasound is able to identify early signs of pulmonary congestion and heart failure in patients with scorpion envenomation. It can be useful in the objective selection of patients at a higher risk of complications and death and require intensive support; it may also be valuable for periodic reassessments. Point-of-care ultrasound is a valuable tool for identifying and monitoring severe cases of scorpionism and can help to optimize treatment and improve outcomes in scorpionism.

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Author contributions

Juliana Sartorelo Almeida: conception and design of the study, analysis and interpretation of data, acquisition of data. Vandack Nobre:

conception and design of the study, drafting the article, final approval of the version to be submitted; Cecilia Gomez Ravetti: conception and design of the study, analysis and interpretation of data, final approval of the version to be submitted; Marcus Vinícius de Melo Andrade: analysis and interpretation of data, final approval of the version to be submitted; Paula Frizera Vassallo: analysis and interpretation of data, final approval of the version to be submitted; Adebal de Andrade Filho: conception and design of the study, final approval of the version to be submitted; Rafael Silva e Castro: analysis and interpretation of data, acquisition of data; Pedro Pires Costa Pimenta: acquisition of data.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

Access to data collected in the research through the Research Electronic Data Capture platform can be obtained upon request to the authors.

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