

Characteristics of hemodynamics and fluid management in severe amlodipine poisoning with shock: a retrospective case series

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Abstract

Background: Shock is a risk factor for mortality in amlodipine poisoning, yet comprehensive hemodynamic characterization including direct invasive assessment remains rare. We characterized the hemodynamic profile and fluid-management patterns in patients with shock due to severe amlodipine poisoning.

Methods: This single-center retrospective case series enrolled consecutively admitted adults with amlodipine poisoning from 2019 to 2025. Demographic, ingestion, clinical, hemodynamic, treatment, and outcome data were collected. The primary outcome was hemodynamic profile in shock patients with amlodipine poisoning.

Results: Twelve patients (median age 54 years, IQR 47–67; 75% female) ingested 140–1120 mg amlodipine. Five with mild-to-moderate shock required norepinephrine alone (0.1–0.8 µg/kg/min); seven with severe shock required multiple vasopressors (norepinephrine 0.55–2.0 µg/kg/min, terlipressin, and epinephrine in three). Initial CVP was elevated (15–28 mmHg) in 9/11 patients. The predominant findings on complete echocardiography in 11 patients were hyperdynamic left ventricular function, inferior vena cava dilation, and right-heart enlargement. Invasive monitoring in ten patients showed increased or normal cardiac index (3.43–5.66 L/min/m²) and decreased SVRI (621–1647 dyn·s·cm⁻⁵·m²). Initial CVP correlated positively with length of stay (LOS; $r = 0.636$, 95% CI 0.06–0.89, $P = 0.035$). Early negative single-day fluid balance within 3 days was associated with shorter vasopressor duration (4 vs 10 days; $r = 0.641$, 95% CI 0.02–0.91, $P = 0.046$).

Conclusions: Amlodipine poisoning induces severe vasoplegia with hyperdynamic (preserved) left ventricular function, frequently accompanied by elevated CVP and right-heart enlargement. Higher initial CVP predicts longer LOS, whereas early negative fluid balance may accelerate vasopressor weaning.

Background

Calcium channel blockers (CCBs) are among the most commonly prescribed cardiovascular medications worldwide. Amlodipine, a dihydropyridine CCB widely used for hypertension and angina, is also the most common CCB implicated in overdose-associated mortality [1, 2]. A recent analysis of 236 CCB overdoses found that amlodipine accounted for 62% of cases, with hypotension occurring in one-third of cases and vasopressor support required in 20% of cases [3]. Additionally, a national study of 1,856 patients treated with high-dose insulin identified amlodipine as the most frequently implicated cardiotoxicant (61% of CCB cases); these patients more commonly received methylene blue (16% vs. 2% for verapamil/diltiazem), suggesting that refractory vasoplegia is a distinctive feature of severe amlodipine overdose [4]. However, in-depth investigations into the hemodynamic characteristics of amlodipine-poisoning-induced shock remain particularly scarce. This study aimed to characterize the hemodynamic profile in 12 patients with shock due to severe amlodipine poisoning.

Methods

Study design and ethics approval

This was a single-center observational case series registered at the Chinese Clinical Trial Registry on April 30, 2024 (chictr.org, ChiCTR 2400083687). The study was conducted in an urban, tertiary-care university hospital in China from January 2019 to December 2025. The protocol was approved by the hospital's Institutional Ethics Committee (No. 2024 KY073) and conformed to the Declaration of Helsinki and applicable medical research ethics standards. As this was a retrospective study involving anonymized data collection and analysis, the requirement for informed consent was waived.

Selection of participants

Inclusion criteria were as follows: (1) age ≥ 18 years; (2) clear history of recent amlodipine overdose, or confirmed amlodipine overdose by toxicological testing (serum amlodipine concentration); and (3) clinical manifestations consistent with CCB poisoning, accompanied by shock requiring vasopressor support to maintain blood pressure. When the ingestion history was unclear or the reported dose was unreliable, serum toxicological screening was performed to confirm the presence of amlodipine and rule out co-ingestion of other cardioactive substances. Shock was defined as the requirement for vasopressor support to maintain mean arterial pressure (MAP) ≥ 65 mmHg, consistent with prior literature on CCB poisoning [5]. Severe shock was additionally defined by the requirement for multiple vasopressors (norepinephrine > 0.5 µg/kg/min with terlipressin and/or epinephrine), or presence of multi-organ failure.

Exclusion criteria included: (1) overdose involving CCBs other than amlodipine; and (2) unavailable outcome data.

Patients were identified through a systematic query of the hospital's electronic medical record system. The search strategy included: (1) ICD-10 codes T46.1X1A - T46.1X2A (poisoning by CCBs); and (2) a keyword search combining "amlodipine" AND ("overdose" OR "poisoning" OR "intoxication" OR "toxicity").

Data collection

Data were collected from the hospital's electronic medical record system by two independent investigators, with discrepancies resolved by a third senior investigator. The following variables were extracted:

(1) Demographics and ingestion details: gender, age, comorbidities, time of ingestion, time of presentation to hospital, estimated ingested dose (based on patient or family report, pill counts, or prescription records), reason for ingestion (intentional vs. accidental), and co-ingestants.

(2) Diagnostic and treatment data: presenting symptoms; vital signs (heart rate, blood pressure, respiratory rate, oxygen saturation); respiratory support (mode of oxygen delivery and need for endotracheal intubation and invasive mechanical ventilation); other organ-support measures (blood purification modality, extracorporeal membrane oxygenation [ECMO]); vasopressor use and duration; arterial blood gas results; fluid balance; and hemodynamic parameters. The latter comprised central venous pressure (CVP), echocardiographic findings, and invasive hemodynamic monitoring. Invasive hemodynamic monitoring using either the Pulse index Continuous Cardiac Output (PiCCO) system (Getinge, Gothenburg, Sweden) or the Pressure Recording Analytical Method (PRAM) with the MostCareUp monitor (Vygon, Padua, Italy) was performed at the discretion of the treating physicians. PiCCO was established via a femoral arterial catheter in patients with the most severe shock, whereas PRAM-derived data were obtained predominantly via a radial arterial catheter. Bedside echocardiography was performed by attending physicians with formal training in critical care echocardiography, and the acquired images were reviewed by a senior sonographer. Left ventricular function, left ventricular outflow tract (LVOT) velocity-time integral (VTI), inferior vena cava (IVC) diameter, and right-heart size were assessed.

(3) Poisoning-specific treatments: gastric lavage, blood purification, and administration of calcium, lipid emulsion, and high-dose insulin euglycemia therapy (HIET).

(4) Laboratory tests during hospitalization: troponin I, N-terminal pro-B-type natriuretic peptide (NT-proBNP), blood urea nitrogen, serum creatinine, bilirubin, alanine aminotransferase (ALT), and aspartate aminotransferase (AST).

(5) Outcomes: length of hospital stay (LOS) and survival status at hospital discharge.

Outcomes

The primary outcome of this study was to characterize the hemodynamic profile (cardiac index [CI], systemic vascular resistance index [SVRI], central venous pressure [CVP], and echocardiographic findings) of patients with shock due to severe amlodipine poisoning. The secondary outcome was to describe CVP and fluid balance patterns and their association with the duration of vasopressor support and with clinical outcomes.

Statistical analyses

Continuous variables are described as median (interquartile range) [M (Q1, Q3)] because some of the data were not normally distributed. Categorical variables are presented as frequencies (n) and percentages (%). Comparisons between groups were not performed due to the small sample size and descriptive nature of this case series.

To explore relationships among initial CVP, timing of negative fluid balance, vasopressor duration, and LOS, we performed Pearson and Spearman correlation analyses using the maximum number of observations available for each comparison (ranging from 10 to 11, depending on missing data). Simple linear regression was used to quantify the association between initial CVP and LOS. Sensitivity analyses were performed by excluding individual patients whose clinical course was influenced by non-medical factors (family withdrawal of care) or by comorbidity and complications burden. Pearson correlation coefficients are reported with their 95% confidence intervals (95%CI, derived using Fisher's z-transformation), whereas Spearman's rho is reported as a non-parametric robustness check. Statistical analyses were conducted using SPSS software (version 26.0, IBM, USA) and Python 3.13 (SciPy, Statsmodels). A *P*-value < 0.05 was considered statistically significant.

Results

Patient characteristics, ingestion details, and presenting symptoms

During the study period, 19 patients with amlodipine poisoning were admitted. Of these, 15 presented with hypotension, and 12 patients (initial systolic BP 66–94 mmHg and diastolic BP 30–54 mmHg, initial heart rate 50–112 bpm, Table 1) who required vasopressor support were included in the analysis. The remaining three hypotensive patients responded to fluid alone and did not receive vasopressors.

Table 1
Baseline characteristics of 12 patients with severe amlodipine poisoning.

No.	Sex	Age (y)	Comorbidities	Amlodipine dose (mg)	Time to presentation (h)	Co-ingestants	Heart rate (bpm)	Respiratory rate (/min)	SBP/DBP (mmHg)
1	M	46	HBP, cerebral hemorrhage	140	3	Valsartan, hydrochlorothiazide	112	13	70/42
2	M	66	HBP, cerebral hemorrhage	840	24	None	70	28	70/44
3	F	68	HBP, cerebral hemorrhage	350	5	None	107	12	85/49
4	F	56	HBP, diabetes mellitus, rheumatoid arthritis, hyperthyroidism	300	4	None	112	24	94/54
5	F	46	Cholecystectomy, kidney calculi	140	1.5	Lercanidipine, metoprolol	50	22	67/38
6	F	80	HBP, cerebral infarction, knee replacement	210	7	Aspirin	78	16	80/40
7	F	52	None	450	12	None	90	30	66/30
8	F	49	HBP, cholecystitis	750	24	None	98	34	80/44
9	F	30	Appendectomy	1120	6	Cefdinir	105	16	89/35
10	F	78	HBP, coronary heart disease	NA	48	None	70	23	90/47
11	F	52	HBP, melancholia	280	6	Enalapril	68	15	68/45
12	M	59	HBP, depression	NA	12	Venlafaxine	98	28	82/51
Abbreviation: HBP, hypertension.									
NA indicates amlodipine dose not available. 'None' denotes no co-ingestants or no comorbidities.									

All 12 cases involved intentional ingestion. Patient ages ranged from 30 to 80 years (median 54, IQR 47–67). Nine patients (75%) were female, and nine (75%) had comorbid hypertension. The ingested amlodipine dose ranged from 140 mg to 1120 mg (median 325 mg). The dose was estimated from a clear ingestion history provided by family members and corroborated by empty medication packages brought to the hospital. In two patients (Cases 10 and 12), the exact ingested dose was unavailable and the diagnosis was confirmed by toxicological testing. Quantitative serum amlodipine concentrations were 115 ng/mL in Case 10 (measured on hospital day 4) and 289 ng/mL in Case 12 (measured on hospital day 2), both markedly exceeding the upper limit of the therapeutic range of 18 ng/mL. Six patients had co-ingested other medications (Table 1). The interval from ingestion to hospital presentation ranged from 1.5 to 48 hours (median 6, IQR 4–24).

The most common early clinical symptoms were dizziness and fatigue (6/12), epigastric discomfort with nausea and vomiting (4/12), and confusion (4/12). Notably, initial pulse rate was elevated (> 90 bpm) in 7/12 patients, consistent with reflex tachycardia due to peripheral vasodilation. Nine patients (75%) received gastric lavage within 6 hours of ingestion (Table 2), with the exception of Case 1 who refused to cooperate, Cases 11 and 12 whose poisoning history was initially unavailable.

Table 2
Clinical management and outcomes of 12 patients with severe amlodipine poisoning.

No.	Gastric lavage	Calcium	HDI	ILE	Blood purification	Respiratory support	LOS (d)	Outcome
1	No	No	No	Yes	HP	COT	2	Survived
2	Yes	Yes	Yes	Yes	HP	HFNC	4	Survived
3	Yes	Yes	No	Yes	HP	COT	4	Survived
4	Yes	Yes	Yes	Yes	HP	COT	6	Survived
5	Yes	Yes	No	Yes	HP	HFNC	5	Survived
6	Yes	Yes	Yes	Yes	HP+CRRT + PE	IMV	1	Died
7	Yes	Yes	Yes	Yes	HP+CRRT + PE	IMV	21	Survived
8	Yes	Yes	Yes	Yes	HP	IMV	21	Died
9	Yes	Yes	Yes	Yes	HP+CRRT+ECMO	IMV	30	Survived
10	No	Yes	Yes	Yes	HP+CRRT + PE	IMV	24	Survived
11	Yes	Yes	Yes	Yes	HP+CRRT	HFNC	6	Survived
12	No	Yes	Yes	Yes	HP+CRRT+ECMO	IMV	51	Survived

Abbreviations: HDI, high-dose insulin; ILE, intravenous lipid emulsion; HP, hemoperfusion; CRRT, continuous renal replacement therapy; PE, plasma exchange; ECMO, extracorporeal membrane oxygenation; COT, conventional oxygen therapy; HFNC, high-flow nasal cannula; IMV, invasive mechanical ventilation; LOS, length of hospital stay.

Gastric lavage, calcium, HDI and ILE are recorded as Yes/No.

Hemodynamic findings

Hemodynamic data were collected as part of routine clinical care and were not available for all patients because of the retrospective design and variation in clinical practice. CVP data were available for 11 of the 12 patients. With the exception of Cases 1 and 4, whose initial CVP was ≤ 10 mmHg, the remaining nine patients had elevated initial CVP readings (15–28 mmHg, Table 3). Elevated CVP in the majority of patients with severe amlodipine poisoning is a notable, previously under-reported hemodynamic characteristic.

Table 3
Hemodynamic parameters and echocardiographic findings.

No.	CVP (mmHg)	Echocardiography				ScvO ₂ (%)	Lactate (mmol/L)	Hemodynamic monitoring				Max vasoactive dose
		IVC (cm)	LV function	RV size	LVOT VTI (cm)			CI (L/min/m ²)	GEDV (mL/m ²)	SVRI (dyn·s·cm ⁻⁵ ·m ²)	ELWI (mL/kg)	
1	3	1.67	Normal	Normal	NA	NA	6.8	NA	NA	NA	NA	Norepinephrine 0.1 µg/kg/min
2	22	1.92	Hyperdynamic	Slightly enlarged	NA	NA	4.1	5.25	NA	1240	NA	Norepinephrine 0.25 µg/kg/min
3	NA	NA	NA	NA	NA	74	11.6	NA	NA	NA	NA	Norepinephrine 0.275 µg/kg/min
4	10	1.71	Hyperdynamic	Normal	NA	NA	5.1	4.32	NA	1364	NA	Norepinephrine 0.3 µg/kg/min
5	16	1.82	Hyperdynamic	Slightly enlarged	NA	NA	10.6	5.17	NA	957	NA	Norepinephrine 0.8 µg/kg/min
6	18	2.06	Hyperdynamic	Slightly enlarged	NA	62.8	7.4	4.93	NA	1083	NA	Norepinephrine 1 µg/kg/min + terlipressin 160 U/h
7	20	1.74	Hyperdynamic	Slightly enlarged	24.7	93.3	7.8	5.66	561	621	7	Norepinephrine 0.55 µg/kg/min + terlipressin 160 U/h
8	20	2.05	Hyperdynamic	Enlarged	23.5	56.3	9.2	4.87	NA	1046	NA	Norepinephrine 1.2 µg/kg/min + epinephrine 0.02 µg/kg/min + terlipressin 160 U/h
9	20	1.78	Hyperdynamic	Slightly enlarged	25.1	87.8	7.5	4.92	435	881	14	Norepinephrine 1 µg/kg/min + terlipressin 160 U/h
10	15	2.54	Hyperdynamic	Enlarged	31.8	84.5	4.1	4.65	795	1150	8	Norepinephrine 1.6 µg/kg/min + terlipressin 160 U/h + epinephrine 0.2 µg/kg/min
11	17	2.03	Hyperdynamic	Slightly enlarged	23.0	80.2	1.5	3.43	955	1647	12.7	Norepinephrine 0.6 µg/kg/min + terlipressin 160 U/h
12	28	2.56	Hyperdynamic	Slightly enlarged	20.6	76.3	7.3	5.04	NA	912	NA	Norepinephrine 2.0 µg/kg/min + terlipressin 160 U/h + epinephrine 0.4 µg/kg/min

Abbreviations: CVP, central venous pressure; IVC, inferior vena cava diameter; LV, left ventricular; RV, right ventricular; LVOT VTI, left ventricular outflow tract velocity–time integral; ScvO₂, central venous oxygen saturation; CI, cardiac index; GEDV, global end-diastolic volume index; SVRI, systemic vascular resistance index; ELWI, extravascular lung water index.

Complete bedside echocardiography data were available for 11 of the 12 patients (all except Case 3) (Table 3). The findings consistently showed: (1) hyperdynamic left ventricular function; (2) elevated LVOT VTI, consistent with increased stroke volume and CI; (3) IVC dilation (diameters ≥ 1.7 cm in ten cases and > 2.0 cm in five patients); and (4) right heart enlargement. Table 3 summarizes the echocardiographic findings. The CVP measurements showed good agreement with IVC diameter assessments.

Invasive hemodynamic data were available for all patients except Cases 1 and 3 (Table 3). All ten demonstrated markedly decreased SVRI (621–1647 dyn·s·cm⁻⁵·m²) despite high-dose vasopressor infusions; nine of the ten had an increased CI (4.32–5.66 L/min/m²), whereas Case 11 had a normal CI of 3.43 L/min/m². To our knowledge, this is the first case series to report direct CI and SVRI measurements in amlodipine poisoning.

ScvO₂ data were available in eight patients. Two had an initial ScvO₂ below 70%, whereas the other six showed elevated values (74%–93.3%), consistent with the hemodynamic profile of distributive shock, in which impaired peripheral oxygen extraction leaves venous oxygen saturation elevated.

Classification of shock severity and management

Mild-to-moderate shock group (Cases 1–5)

Patients 1 through 5 presented with relatively less severe conditions and shock. Norepinephrine was the only vasopressor used, at a maximum infusion rate of 0.1–0.8 µg/kg/min, and vasopressor support lasted 2–4 days.

Hemoperfusion (intended for toxin removal) was the only blood purification modality used in this group, and respiratory support was limited to conventional oxygen therapy or high-flow nasal oxygen. Among these five patients, calcium was administered to four patients, high-dose insulin to two, and all five received intravenous lipid emulsion (Table 2). Within this group, all five patients developed mild myocardial injury, four experienced renal dysfunction, and three had mild hepatic impairment (Table 4). All of these organ dysfunctions resolved rapidly during the hospital course.

Table 4
Peak laboratory and organ-function values during hospitalization.

No.	Troponin I (ng/mL)	NT-proBNP (pg/mL)	Total bilirubin (µmol/L)	ALT (U/L)	AST (U/L)	BUN (mmol/L)	Scr (µmol/L)
1	0.012	206	18.4	52	33	6.7	119
2	0.082	2930	18	61	39	11.6	197
3	0.158	4730	19.6	35	29	6.51	112
4	0.012	501	20.5	33	29	4.4	71
5	0.196	1120	32.9	77	123	12.21	183
6	0.013	485	8.4	8	19	8.08	125.5
7	0.299	2080	192.2	3235	3525	28.38	232.6
8	0.139	2020	85.7	29	27	39.28	317.3
9	0.048	770	52.2	282	565	15.83	109.4
10	0.513	23500	31.9	122	128	21.59	433.4
11	< 0.01	108	15.5	127	98	6.68	85.3
12	0.079	16838	62.2	179	210	25.78	312
Values are the worst (peak) recorded for each patient during hospitalization.							
Reference ranges: Troponin I < 0.1 ng/mL; NT-proBNP < 300 pg/mL; total bilirubin 3–22 µmol/L; ALT < 35 U/L; AST 14–36 U/L; BUN 1.7–8.3 mmol/L; Scr 46–92 µmol/L.							
Values exceeding the upper reference limit are shown in bold.							

Severe shock group (Cases 6–12)

Cases 6

to 12 presented with severe shock. The maximum norepinephrine infusion rates ranged from 0.55 to 2.0 µg/kg/min (Table 3). All seven patients received concomitant terlipressin, titrated to the maximum dose of 160 units/h in every case. Adjunctive epinephrine was administered in Cases 8, 10, and 12, while patient 12 also received methylene blue. The duration of vasopressor support in the severe shock cases was 1–19 days; excluding Case 6 (care withdrawn on day 1), it was 3–19 days.

All seven patients in this severe shock group received the combination of calcium, high-dose insulin, and intravenous lipid emulsion as antidotal therapy (Table 2). Regarding blood purification, Case 8 declined continuous renal replacement therapy (CRRT) and received hemoperfusion alone, whereas the other six underwent hemoperfusion combined with CRRT. Indications for CRRT were acute kidney injury (Cases 6, 7, 9, 10, 11 and 12) and persistent elevated CVP with positive fluid balance (Cases 7, 9). Three of the six CRRT recipients (Cases 6, 7, and 10) also received therapeutic plasma exchange.

Two patients (Cases 9 and 12) received ECMO support for severe acute respiratory failure and refractory shock. Regarding respiratory support, Case 11 was managed with high-flow nasal oxygen alone, whereas all others (Cases 6–10 and 12) received endotracheal intubation and invasive mechanical ventilation, with chest radiographs and CT showing significant pulmonary infiltrates. Cases 9 and 12 underwent tracheostomy.

Beyond circulatory and respiratory failure, acute kidney injury, myocardial injury, and hepatic impairment were observed in six patients each within this group of seven. Notably, Case 7 developed liver failure with corresponding imaging abnormalities. The worst organ-function values recorded during the clinical course are presented in Table 4.

Clinical outcomes

Of the 12 patients, 10 ultimately survived, yielding an overall survival rate of 83.3% (Table 2). Cases 1–5, who experienced mild-to-moderate shock, had shorter LOS (2–6 days) and all survived to discharge. Case 6, whose condition was considered potentially survivable, was discharged against medical advice at the family’s request on hospital day 1 and died shortly afterward. Cases 7–10 had considerably longer LOS (21–30 days). Case 8 initially improved, with

resolution of shock and respiratory failure; however, the family ultimately withdrew care, and the patient died of hospital-acquired pneumonia. Case 11 was hospitalized for 6 days, and Case 12 had the longest LOS (51 days).

Statistical analysis of CVP, fluid balance, vasopressor duration and LOS

Among the 11 patients with available CVP data, initial CVP correlated positively with LOS (Pearson $r = +0.636$, 95% CI $+0.06$ to $+0.89$, $P = 0.035$; Spearman $\rho = +0.410$, $P = 0.210$, Fig. 1). Linear regression yielded the equation: $\text{LOS} = -10.6 + 1.5 \times \text{CVP}$ ($R^2 = 0.405$), indicating that each 1 mmHg increase in initial CVP was associated with approximately 1.5 additional days of hospitalization. CVP alone explained 40.5% of the variance in LOS.

Sensitivity analyses confirmed the robustness of the CVP-LOS association. Excluding Case 6 (withdrawal of care on day 1) strengthened the correlation ($r = +0.683$, 95% CI $+0.09$ to $+0.92$, $P = 0.029$), whereas excluding Case 12 (prolonged hospitalization due to acquired complications) attenuated it ($r = +0.402$, 95% CI -0.31 to $+0.82$, $P = 0.250$). When both outliers were excluded, the correlation remained positive and moderate ($r = +0.479$, 95% CI -0.27 to $+0.87$, $P = 0.192$). In the treatment-only cohort (excluding both cases of family-declined care), the CVP-LOS correlation remained strong ($r = +0.680$, 95% CI $+0.03$ to $+0.93$, $P = 0.044$, Fig. 1).

Daily CVP, fluid balance measurements, and vasopressor duration for each patient are presented in Fig. 2. Among the 11 patients with available fluid-balance data, eight (73%) achieved early negative single-day fluid balance within the first 3 hospital days, whereas three (27%) attained negative balance later (on days 4, 4, and 8). Median vasopressor duration was 4.0 (IQR 3.0–4.5) days in the early-balance group and 10.0 (range 7–19) days in the delayed-balance group. In the full cohort, the correlation between negative balance day and vasopressor duration was moderate but did not reach statistical significance ($r = +0.357$, 95% CI -0.31 to $+0.79$, $P = 0.281$, $n = 11$, Fig. 3). However, when the single patient whose negative balance was delayed by family refusal of CRRT (Case 8) was excluded, this relationship became stronger and statistically significant ($r = +0.641$, 95% CI $+0.02$ to $+0.91$, $P = 0.046$, $n = 10$). This finding supports the hypothesis that early achievement of negative fluid balance accelerates vasopressor weaning.

Discussion

This retrospective case series of 12 patients with severe amlodipine poisoning and shock presents several notable findings that expand the existing literature. Our study confirms that the predominant hemodynamic phenotype of severe amlodipine poisoning with shock is a distributive (vasodilatory) shock pattern. Furthermore, elevated CVP and right heart enlargement were observed in the majority of patients, a finding rarely highlighted in previous literature. Initial CVP also emerged as a predictor of LOS, with higher values associated with longer LOS. In patients with elevated CVP, achieving early negative fluid balance may accelerate vasopressor weaning.

Our findings of distributive (vasodilatory) shock are consistent with the larger cohort observations by Cole et al., who reported vasodilation as the predominant hemodynamic pattern in amlodipine versus non-dihydropyridine CCB poisoning [5]. Similarly, Isbister et al. and Chan et al. emphasized that amlodipine poisoning typically presents with vasodilatory shock rather than cardiogenic shock [3, 6]. However, few of these studies provided detailed hemodynamic measurements; instead, vasoplegia was inferred from the vasopressor response during treatment. Therefore, Chan et al. explicitly called for “further serial hemodynamic studies, measuring CI and SVRI alongside echocardiographic assessments” [6], precisely the type of investigation our study undertook. An independent confirmation of the high-output, low-resistance phenotype comes from Brahmi et al., who reported Swan-Ganz catheter data in a single patient with amlodipine-perindopril overdose: CI 6.6 L/min/m² and SVRI 651 dyn·s·cm⁻⁵·m² [7]. With invasive hemodynamic monitoring in 10 patients and bedside echocardiography in 11 patients, our study provides one of the most detailed hemodynamic datasets to date on severe amlodipine poisoning with shock, substantially expanding the evidence base. Our findings support a vasopressor-centric rather than inotrope-centric management approach for this predominantly vasoplegic phenotype. High-dose insulin therapy should be reserved for patients with evidence of left ventricular dysfunction. Even refractory vasoplegic shock complicating severe amlodipine overdose has been reported to respond to high-dose insulin euglycemia when conventional vasopressors fail [8].

Notably, not all amlodipine-poisoned patients present with a hyperdynamic circulation. Isolated case reports had described left ventricular systolic depression [9–11], and Hacker et al. reported a case in which noninvasive cardiac monitoring showed a CI of only 2.1–2.5 L/min/m² with normal biventricular size [12]. This heterogeneity may reflect differences in overdose severity, co-ingestants, or timing of measurement. Amlodipine primarily causes vasodilation and reflex tachycardia, although reduced cardiac contractility may also occur in severe poisoning [13].

In this study, elevated CVP (≥ 15 mmHg) was observed in 9 of 11 patients with available data, and right heart enlargement was consistently found in all severe shock patients who underwent comprehensive echocardiography. To our knowledge, this is the first case series to systematically document right-sided hemodynamic alterations in amlodipine poisoning and to explore their implications for fluid management. We hypothesize that these findings may be explained by the following mechanisms: (1) Amlodipine-induced peripheral vasodilation and arteriovenous shunting significantly increase venous return and pulmonary arterial blood flow. (2) Amlodipine may selectively dilate precapillary pulmonary vessels, with minimal dilation of postcapillary vessels, leading to a paradoxical increase in pulmonary artery pressure [14]. This elevated right ventricle afterload results in significantly increased CVP and right heart enlargement.

These mechanisms may also explain the non-cardiogenic pulmonary edema observed in several of our patients. Under conditions of increased pulmonary blood flow, amlodipine-induced selective dilation of precapillary pulmonary vessels may elevate transcapillary hydrostatic pressure, leading to pulmonary interstitial edema. Fluid overload may serve as an exacerbating factor in this process [15, 16]. Lindeman et al. observed that all cases developing non-cardiogenic pulmonary edema had received significant fluid resuscitation, with a median volume of 6L (range 0.7–7L) of crystalloids within the first 24 hours, and identified fluid overload as a significant contributing factor to pulmonary edema [14]. Our study found that the kidneys, liver, and myocardium are the

most frequently impaired organs in amlodipine poisoning. In addition to hypoperfusion due to severe shock, hepatic congestion and impaired renal venous return resulting from right heart overload and high CVP are likely contributing pathogenic factors.

A particularly noteworthy finding of our study is the impact of CVP and fluid balance on clinical outcomes. Elevated CVP accompanied by right-heart dilatation and IVC congestion indicates that the hemodynamic disturbance extends beyond pure arterial vasoplegia. Mechanistically, a raised CVP can itself sustain shock by restricting venous return and right ventricular output [17, 18]. Viewed in this light, initial CVP serves as both a proxy for overall disease severity and a potentially modifiable determinant of shock persistence [19]. Consistent with this dual role, initial CVP was positively correlated with LOS in our study, indicating that the magnitude of the CVP-elevating pathophysiology parallels the duration of organ support required [20]. This CVP–outcome association is not confined to our cohort: in a cohort of 145 patients with acute poisoning, higher CVP was independently associated with greater in-hospital mortality and a higher need for mechanical ventilation, and survivors showed a greater reduction in CVP after vasopressor support [21].

More directly relevant to management, earlier achievement of negative fluid balance was associated with accelerated weaning from vasopressors after excluding the single patient whose de-resuscitation was delayed by family refusal of CRRT. That the relationship emerged only after removing this outlier highlights that it is when negative balance is reached (rather than whether it is reached) that drives the benefit. We propose that early de-resuscitation lowers CVP and relieves right-heart strain, permitting more rapid vasopressor tapering. These data support a CVP-guided “de-resuscitation” approach (diuresis or early renal replacement aimed at reducing filling pressures once vasodilation is pharmacologically controlled), which aligns with the wider critical-care movement toward fluid stewardship [22, 23].

The main strength of this study is the provision of relatively comprehensive hemodynamic data from a case series of severe amlodipine poisoning, which is rarely reported in the literature. However, several limitations must be acknowledged. First, this was a single-center retrospective analysis with a small sample size. Second, although no patient in this cohort presented with clinically significant left ventricular suppression, such cases may exist with larger sample sizes. Third, owing to the small sample size, the observed correlations between initial CVP and LOS and between early negative fluid balance and vasopressor duration, remain hypothesis-generating and require prospective validation. Fourth, as a retrospective case series, treatment decisions were made by individual clinicians at the bedside. This may introduce variability that limits definitive conclusions about treatment efficacy. Finally, this study primarily focused on amlodipine poisoning, and thus the findings may not be directly applicable to intoxications involving other CCBs [24]. Given the low incidence and critical nature of CCB poisoning, prospective controlled trials are challenging to conduct, making this detailed case series a valuable contribution to the literature on the hemodynamic management of severe amlodipine poisoning.

Conclusions

This retrospective case series of 12 patients confirms that the predominant hemodynamic phenotype of severe amlodipine poisoning with shock is a distributive (vasodilatory) shock pattern, characterized by elevated CVP and right heart enlargement in the majority of patients. Higher initial CVP was associated with longer LOS, whereas achieving early negative fluid balance may accelerate vasopressor weaning.

Abbreviations

ALT
alanine aminotransferase
AST
aspartate aminotransferase
BP
blood pressure
BUN
blood urea nitrogen
CCB
calcium channel blocker
CI
cardiac index
COT
conventional oxygen therapy
CRRT
continuous renal replacement therapy
CVP
central venous pressure
DBP
diastolic blood pressure
ECMO
extracorporeal membrane oxygenation
ELWI
extravascular lung water index
EP
epinephrine

GEDl
global end-diastolic volume index
HDI
high-dose insulin
HFNC
high-flow nasal cannula
HP
hemoperfusion
ICD-10
International Classification of Diseases, 10th Revision
ILE
intravenous lipid emulsion
IMV
invasive mechanical ventilation
IQR
interquartile range
IVC
inferior vena cava
LOS
length of hospital stay
LV
left ventricular
LVOT VTI
left ventricular outflow tract velocity–time integral
NE
norepinephrine
NT-proBNP
N-terminal pro-B-type natriuretic peptide
PiCCO
pulse index continuous cardiac output
PRAM
pressure recording analytical method
RV
right ventricular
SBP
systolic blood pressure
ScvO₂
central venous oxygen saturation
Scr
serum creatinine
SVRI
systemic vascular resistance index.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Ethics Committee of Northern Jiangsu People's Hospital (No. 2024 KY073) and was conducted in accordance with the Declaration of Helsinki. Because this was a retrospective study using anonymized data, the requirement for informed consent was waived by the Institutional Ethics Committee of Northern Jiangsu People's Hospital.

Consent for publication

Not applicable. No individual person's identifiable data, images, or videos are included in this manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Chenlong Wang: Writing - review & editing, Visualization, Methodology. Peng Cao: Writing - review & editing, Software, Investigation. Jiayan Sun: Validation, Investigation, Data curation, Conceptualization. Dingyu Tan: Writing - review & editing, Project administration, Funding acquisition.

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Not applicable.

STROBE statement

This retrospective observational case series was reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement guidelines for observational research where applicable.

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

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Figures

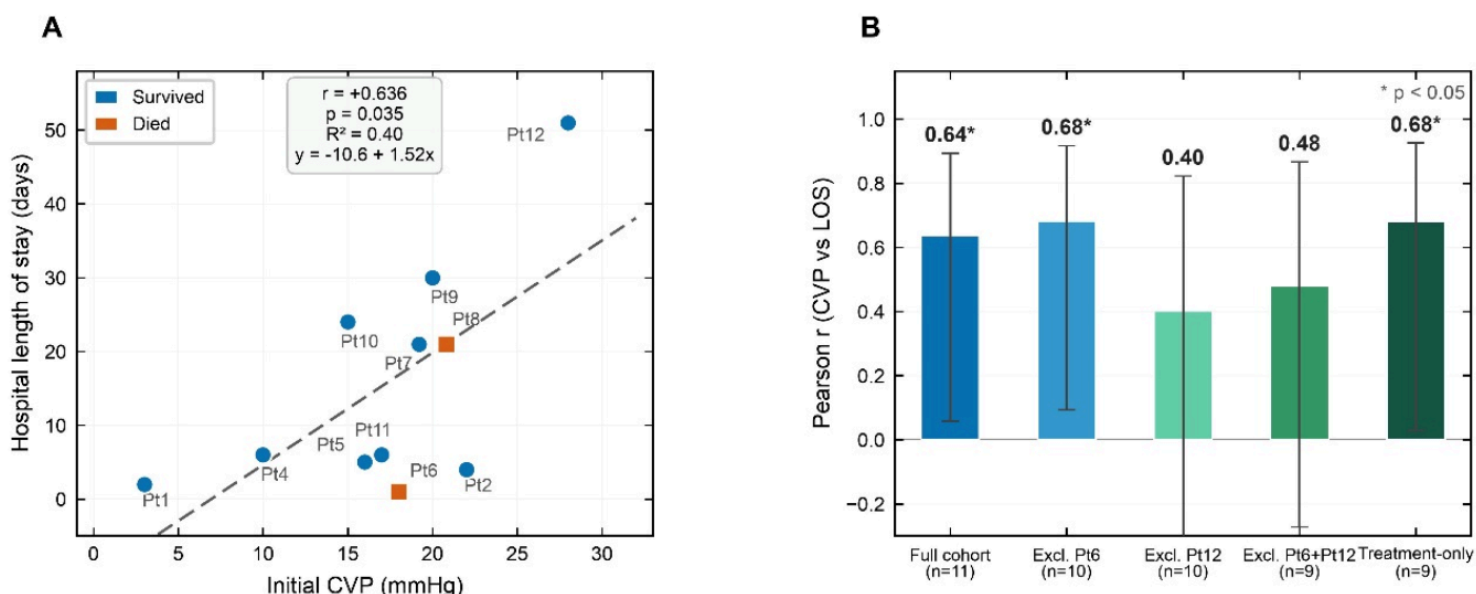


Figure 1

Statistical analysis of the relationship between initial central venous pressure (CVP) and hospital length of stay (LOS).

(A) Scatter plot showing the positive correlation between initial CVP and LOS (n=11, excluding one patient with missing CVP data). The dashed line represents the linear regression fit: $LOS = -10.6 + 1.5 \times CVP$, $R^2 = 0.405$, $p = 0.035$. (B) Sensitivity analysis of the CVP-LOS correlation under different exclusion scenarios. Excluding Case 6 (withdrawal of care on day 1) and the treatment-only cohort (excluding both family-withdrawal cases) strengthened the correlation, whereas excluding Case 12 (prolonged LOS due to comorbidities) attenuated it. Error bars indicate 95% confidence intervals. *p < 0.05.

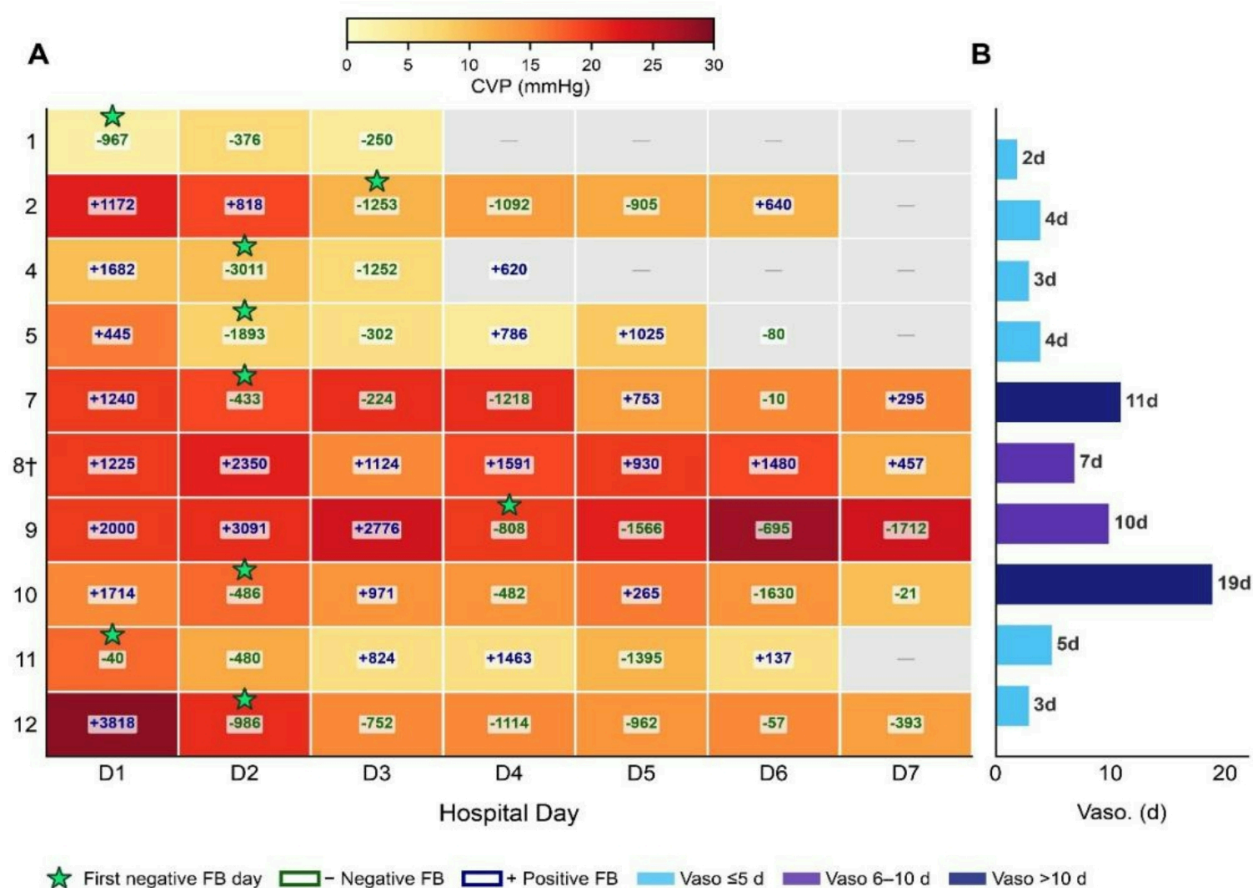


Figure 2

Heatmap visualization of the relationship between central venous pressure (CVP), daily fluid balance, and vasopressor duration during the first week of hospitalization.

(A) Each row represents one patient, ordered by original case number and labeled on the y-axis by patient number. The background color of each cell indicates the CVP value on that hospital day (scale bar at top: yellow = low CVP, dark red = high CVP). The number within each cell indicates the daily fluid balance in milliliters (green text = negative balance, navy blue text = positive balance, "—" = discharged in stable condition). Green stars mark the first day on which negative daily fluid balance was achieved. (B) Horizontal bar chart showing the total duration of vasopressor therapy for each patient, color-coded by duration using a cool blue-purple gradient (light blue: ≤5 days; purple: 6-10 days; dark navy: >10 days).

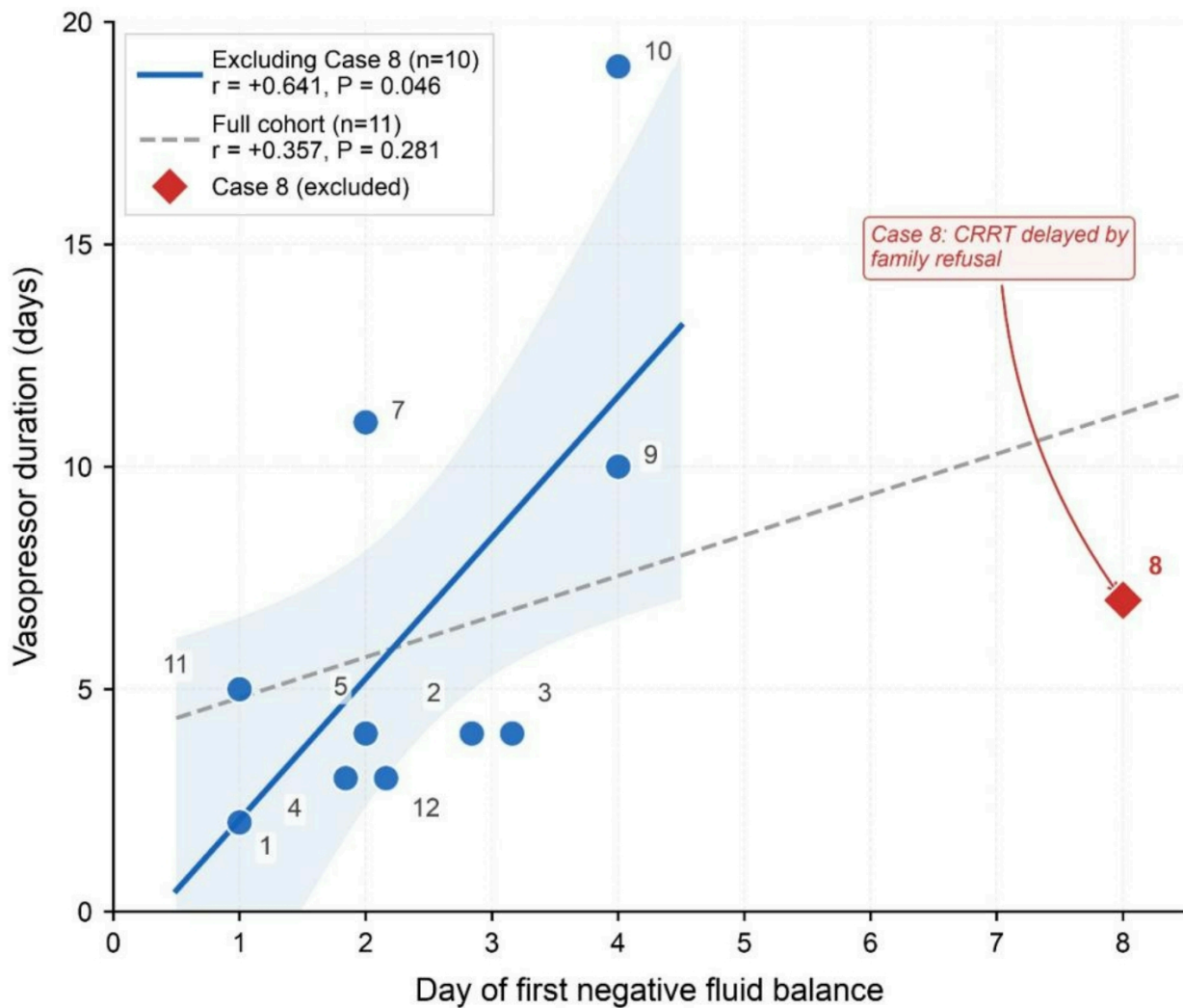


Figure 3

Scatter plot of the relationship between the day of first negative fluid balance and total vasopressor duration.

The dashed gray line shows the least-squares regression for the full cohort ($n = 11$; $r = +0.357$, $P = 0.281$), and the solid blue line shows the regression after excluding Case 8 ($n = 10$; $r = +0.641$, $P = 0.046$), with the shaded area representing the 95% confidence interval. Case 8 is highlighted in red and was excluded from the sensitivity analysis because achievement of negative fluid balance was delayed due to family refusal of continuous renal replacement therapy.