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Kinetic changes in high-sensitivity cardiac troponin for risk stratification of emergency department chest pain patients

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ABSTRACT

Objective: Kinetic patterns of high-sensitivity cardiac troponin I (hs-cTnI) levels may provide prognostic value in chest pain patients. This study aimed to evaluate the association between these patterns and 30-day major adverse cardiac events (MACE).

Methods: A retrospective observational study was conducted, involving Emergency Department (ED) chest pain patients with at least two serial hs-cTnI measurements during their ED stay. Patients were categorized into three groups based on their hs-cTnI kinetic patterns: no change (delta hs-cTnI ≤15 ng/L), rising pattern (RP, delta hs-cTnI>15 ng/L), and falling pattern (FP, delta hs-cTnI>15 ng/L). Thirty-day MACE outcomes were compared across these groups. A stepwise multivariable logistic regression was utilized to evaluate the association of hs-cTnI patterns with 30-day MACE.

Results: This study included 4243 patients. No changes in hs-cTnI were observed in 3777 patients, with 136 (3.6 %) experiencing 30-day MACE. RP was identified in 294 patients, of whom 101 (34.4 %) experienced 30-day MACE, while FP was observed in 172 patients, with 25 (14.5 %) experiencing 30-day MACE. After adjusting for potential confounders, the adjusted odds ratio (AOR) for RP associated with 30-day MACE was 7.68 (95 % CI 5.34–11.05, $p < 0.001$) and the AOR for FP associated with 30-day MACE was 1.99 (95 % CI 1.14–3.48, $p = 0.016$).

Conclusions: Serial hs-cTnI measurements are valuable for identifying patients at risk for 30-day MACE, as both a RP and a FP in hs-cTnI levels are associated with a significantly increased risk of 30-day MACE.

1. Introduction

Chest pain is one of the most common clinical complaints that prompt patients to seek emergency care [1]. In recent years, high-sensitivity cardiac troponin (hs-cTn) testing has become a cornerstone in the risk stratification of patients presenting with cardiac chest pain in the Emergency Department (ED) [2]. While a single hs-cTn measurement is often used, prior studies have shown that it may miss certain cases of acute coronary syndrome (ACS), particularly in patients whose symptoms are intermittent or whose hs-cTn testing occurs within three hours of symptom onset [3,4]. Consequently, serial hs-cTn testing is recommended in such cases to enhance diagnostic accuracy [5].

Serial hs-cTn measurements can reveal kinetic changes in troponin levels over time, which can be further categorized into rising, falling, and unchanged patterns. While rising and falling troponin patterns may reflect myocardial injury at different stages, the same diagnostic approach is often applied to rule out ACS [6]. A previous study reported that a rising troponin pattern (RP) was more commonly associated with ACS, whereas a falling troponin pattern (FP) was more frequently observed in non-ACS conditions [7]. More recently, a European study analyzing data from two prospective clinical trials found that the positive predictive value for acute myocardial infarction (AMI) was significantly lower in patients with FP compared to those with RP [8]. Another study, which investigated patients hospitalized for non-ST-segment elevation myocardial infarction (NSTEMI), found that individuals with FP were more likely to be Black, female, and had higher 28-day mortality rates compared to those with RP [9]. These findings highlight critical gaps in our current understanding of serial hs-cTn testing and underscore the need for the development of tailored management strategies for ED patients presenting with decreasing troponin levels.

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Thirty-day major adverse cardiac events (MACE) are widely used as a clinical endpoint to guide risk stratification in patients presenting with cardiac chest pain [10,11]. The HEART score (history, electrocardiogram, age, risk factors, and troponin), a validated tool for predicting 30-day MACE, incorporates the initial troponin level in its calculation [10,12]. However, the potential prognostic value of kinetic changes in serial troponin measurements, such as RP, FP, or unchanged levels, remains unclear in the prediction of 30-day MACE outcomes.

A better understanding of the role of serial troponin changes in 30-day MACE prediction could significantly enhance risk stratification of ED chest pain patients. Patients categorized by HEART score as low risk may have better evidence to be safely discharged from the ED, reducing hospital admissions and associated healthcare costs. Conversely, high-risk patients would have more supportive data to be hospitalized for additional cardiac testing [13]. Despite these implications, the comparative prognostic value of RP and FP in this context has not been evaluated.

We hypothesize that patients with RP in hs-cTn levels may exhibit similar or even inferior 30-day MACE outcomes compared to those with FP in hs-cTn levels. To address this, our study aims to: 1) evaluate the role of serial hs-cTn changes, with a particular focus on patients with FP, in predicting 30-day MACE outcomes; and 2) determine whether the kinetic change patterns of hs-cTn levels can serve as independent predictors of 30-day MACE outcomes.

2. Methods

2.1. Study design and setting

This single-center retrospective observational study was conducted at an urban tertiary referral and chest pain center. The hospital's ED has approximately 120,000 to 130,000 patient visits annually and is home to an Accreditation Council for Graduate Medical Education (ACGME) accredited Emergency Medicine residency program. The study received approval from the regional institutional review board with a waiver of informed consent (IRB No. 1541042–4).

2.2. Study participants

Our study included patients who met the following criteria: 1) presented to the ED between January 1, 2019, and December 31, 2023, with chest pain or equivalent symptoms (e.g., jaw pain, facial pain, upper arm pain, or shortness of breath) suggestive of acute coronary syndrome (ACS) as assessed by clinicians; 2) had HEAR (History, Electrocardiogram, Age, and Risk factors) scores calculated during their evaluation; and 3) had at least two hs-cTnI measurements obtained during their ED visit. Patients were excluded if: 1) only one hs-cTnI measurement was available during their initial ED visit; and 2) the interval between serial hs-cTnI measurements was less than 1 h (0/1 interval to rule-in /rule-out AMI) or exceeded 12 h (less applicable for ED usage) [14-17]. If patients had multiple ED visits during the study period, each ED visit was viewed as a separate encounter since patients' conditions may change with each ED presentation. Patients who were under 18 years old, incarcerated, pregnant, or presented with chest pain attributable to non-cardiac etiologies (e.g., pneumonia, pulmonary embolism, or musculoskeletal pain) were excluded.

2.3. High-sensitivity cardiac troponin I (hs-cTnI)

This study utilized the Siemens hs-cTnI assay (Siemens, Germany) in our ED laboratory. The 99th percentile upper reference limit (URL) for hs-cTnI was gender-specific, with a cutoff of 78 ng/L for males and 53 ng/L for females, and a coefficient of variation (CV) of <10 %, ensuring high precision. For patients with more than two hs-cTnI measurements during their ED stay, only the first two hs-cTnI measurements were analyzed. A “no change” delta was defined as a difference of ≤15 ng/L between the first and second measurements. A RP was defined as the second hs-cTnI measurement exceeding the first by >15 ng/L, while a FP was defined as the first hs-cTnI measurement exceeding the second by >15 ng/L.

2.4. Outcome measurements

The primary outcome was the occurrence of 30-day MACE after the indexed ED visit. MACE was defined as acute myocardial infarction (AMI), coronary revascularization (including percutaneous coronary intervention [PCI] and coronary artery bypass graft surgery [CABG]), or all-cause mortality.

2.5. Sociodemographic variables

Our study's sociodemographic variables included patient age, sex, race and ethnicity, marital status, preferred language, mode of arrival to the ED, and insurance status.

2.6. Data analysis

Patients were categorized into three groups based on serial hs-cTnI trends: no change, RP, and FP. Thirty-day MACE outcomes were compared among these groups using Pearson's Chi-square test. Stepwise multivariable logistic regressions were conducted to assess the association between the three kinetic hs-cTnI groups and 30-day MACE outcomes. Three models were analyzed including model 1 (no adjustment), model 2 (adjusted for HEAR scores), and model 3 (fully adjusted, incorporating HEAR scores and other sociodemographic variables). Unadjusted and adjusted odds ratios (AORs) with their corresponding 95 % confidence intervals (CIs) were reported. All analyses were performed using STATA software version 14.2 (College Station, TX, USA). A p-value of <0.05 was considered statistically significant.

3. Results

Between January 1, 2019, and December 31, 2023, a total of 10,495 ED visits included at least one hs-cTnI measurement. We excluded 5800 visits where only a single hs-cTnI measurement was performed and 452 visits where serial hs-cTnI measurements were obtained less than 1 h apart or more than 12 h apart. This resulted in 4243 ED visits included in the final analysis (Fig. 1). When examining serial hs-cTnI kinetic changes, no change (≤15 ng/L) in hs-cTnI was observed in 3777 patients, of whom 136 (3.6 %) experienced a positive 30-day MACE outcome. RP was identified in 294 patients, with 101 (34.4 %) experiencing a 30-day MACE outcome. FP was observed in 172 patients, with 25 (14.5 %) experiencing a 30-day MACE outcome (Fig. 1).

Table 1 presents the general characteristics of patients stratified into three groups based on their kinetic hs-cTnI changes (i.e., no change, RP, and FP). Patients in the RP group had the highest

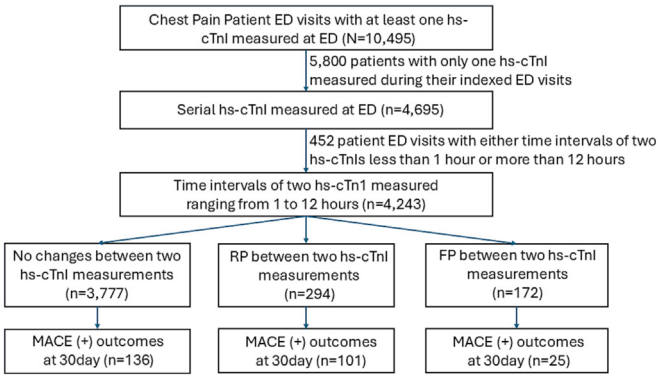

Fig. 1. Study flow diagram.

Table 1
General characteristics of the study population.

	Kinetic hs-cTnI (No Changes) (Second-First ≤15 ng/L)	Kinetic hs-cTnI (RP) (Second – First >15 ng/L)	Kinetic hs-cTnI (FP) (First – Second >15 ng/L)	p
Number of patients –n	3777	294	172	
30-day MACE – n (%)				<0.001
Yes	136 (3.6)	101 (34.4)	25 (14.5)	
No	3641 (96.4)	193 (65.6)	147 (85.5)	
Age – years				<0.001
Mean (SD)	56 (12)	59 (12)	56 (12)	
Median (IQR)	57 (49–64)	60 (53–67)	56 (49–64)	
Sex – n (%)				0.001
Male	2023 (53.56)	170 (57.82)	116 (67.44)	
Female	1754 (46.44)	124 (42.18)	56 (32.56)	
Race and ethnicity – n (%)				0.043
NHW	1020 (27.01)	86 (29.25)	54 (31.40)	
NHB	1462 (38.71)	95 (32.31)	76 (44.19)	
Hispanic	1110 (29.39)	98 (33.33)	38 (22.09)	
Others	185 (4.90)	15 (5.10)	4 (2.33)	
Marital status – n (%)				0.034
Single	1494 (39.56)	102 (34.69)	76 (44.19)	
Married	1054 (27.91)	102 (34.69)	37 (21.51)	
Others	1229 (32.54)	90 (30.61)	59 (34.30)	
Languages --- n %)				0.160
English	3055 (80.88)	232 (78.91)	149 (86.63)	
Spanish	589 (15.59)	55 (18.71)	19 (11.05)	
Other languages	133 (3.52)	7 (2.38)	4 (2.33)	
Insurance --- n (%)				0.621
No	761 (20.15)	54 (18.37)	31 (18.02)	
Yes	3016 (79.85)	240 (81.63)	141 (81.98)	
Mode of arrival --- n (%)				<0.001
Ambulatory	429 (11.36)	16 (5.44)	17 (9.88)	
Ambulance	1387 (36.72)	157 (53.40)	72 (41.86)	
Private Car	1555 (41.17)	89 (30.27)	67 (38.95)	
Others	406 (10.75)	32 (10.88)	16 (9.30)	

A total of 4243 patients were included. Patient general characteristics were compared among three groups (kinetic hs-cTnI no change vs. RP vs. FP). Abbreviations: hs-cTnI, high-sensitivity cardiac troponin I; RP, rising pattern; FP, falling pattern; n, number; SD, standard deviation; IQ, interquartile range; NHW, non-Hispanic White; NHB, non-Hispanic Black.

proportion of 30-day MACE outcomes (34.4 %), followed by the FP group (14.5 %) and the no-change group (3.6 %, $p < 0.001$, Table 1). Elderly patients were more frequently observed in the RP group compared to the no-change or FP groups ($p < 0.001$, Table 1). A greater proportion of patients in the RP group arrived at the ED via ambulance compared to those in the no-change or FP groups ($p < 0.001$, Table 1). In contrast, no statistically significant differences were observed among the three groups regarding insurance coverage or preferred language ($p > 0.05$, Table 1).

Our study further evaluated the association between kinetic hs-cTnI changes and 30-day MACE outcomes. Among 3505 patients with serial hs-cTnI levels below the 99th URL, 98.32 % (3446/3505) exhibited no serial hs-cTnI changes, 1.26 % (44/3505) had RP hs-cTnI changes, and 0.43 % (15/3505) had FP hs-cTnI changes. Notably, 30-day MACE occurred more frequently in patients with RP hs-cTnI changes compared to those with no serial hs-cTnI changes (13.64 % vs. 3.25 %; $p < 0.001$, Table 2).

For patients with discrepancies in serial hs-cTnI measurements (i.e., one hs-cTnI level below the 99 % URL and the other equal to or above the 99 % URL), 30-day MACE occurred more often in patients with RP compared to those with FP or no-change (33.33 % vs. 8.33 % vs. 6.98 %; $p = 0.002$, Table 2).

Among 608 patients with serial hs-cTnI levels equal to or above the 99 % URL, the 30-day MACE rate was 7.29 % (21/288) in patients with no-change, 40 % (70/175) in those with RP changes, and 16.55 % (24/145) in those with FP changes ($p < 0.001$, Table 2).

Stepwise multivariable logistic regression analyses were conducted to evaluate the association between kinetic hs-cTnI changes and 30-day MACE outcomes. Compared to patients with no changes in kinetic hs-cTnI, the AOR for patients with RP changes was 9.40 (95 % CI: 6.66–13.27, $p < 0.001$), while the AOR for FP changes was 2.40 (95 % CI: 1.41–4.09, $p = 0.001$; Table 3). After further adjustment for other components of the HEAR score (i.e., history, electrocardiogram, age,

Table 2
Kinetic hs-cTnI measurements associated with 30-day MACE outcomes.

	Both hs-cTnIs negative			Discrepancy hs-cTnIs			Both hs-cTnIs positive		
	MACE (−)	MACE (+)	p	MACE (−)	MACE (+)	p	MACE (−)	MACE (+)	p
			<0.001			0.002			<0.001
Delta hs-cTnI – n (%)	3334	112		40	3		267	21	
No changes	(96.75)	(3.25)		(93.02)	(6.98)		(92.71)	(7.29)	
Delta hs-cTnI – n (%)	38	6		50	25		105	70	
RP	(86.36)	(13.64)		(66.67)	(33.33)		(60.00)	(40.00)	
Delta hs-cTnI –n (%)	15	0		11	1		121	24	
FP	(100.00)	(0)		(91.67)	(8.33)		(83.45)	(16.55)	

A total of 4243 patients were included in the analysis. Delta hs-cTnI no change: First-second hs-cTnI≤15 ng/L, RP: second-first hs-cTnI>15 ng/L, and FP: first-second hs-cTnI >15 ng/L. hs-cTnI negative: hs-cTnI level less than 99 % upper reference limit (i.e., male<78 ng/L and female<53 ng/L), hs-cTnI positive: hs-cTnI level equal or above 99 % upper reference limit (i.e., male≥78 ng/L and female≥53 ng/L), MACE refers to 30 day MACE outcomes. Discrepancy defines as either the initial hs-cTnI level was positive and the second hs-cTnI level was negative, or the initial hs-cTnI level was negative and the second hs-cTnI level was positive. Abbreviations: hs-cTnI, high sensitivity cardiac troponin I; MACE, major adverse cardiac event; RP, rising pattern; FP, falling pattern.

Table 3
Risks associated with 30-day MACE outcomes among ED chest pain patients by stepwise multivariable logistic regressions.

	Adjusted Odds Ratios	95 % Confidence Interval	p
Model-1			
hs-cTnI			
less than 99 % URL (ref)			
equal or above 99 % URL	2.19	1.55–3.08	<0.001
Delta hs-cTnI			
No changes (ref)			
RP	9.40	6.66–13.27	<0.001
FP	2.40	1.41–4.09	0.001
Model-2			
hs-cTnI			
less than 99 % URL (ref)			
equal or above 99 % URL	1.99	1.39–2.83	<0.001
Delta hs-cTnI			
No changes (ref)			
RP	7.79	5.46–11.12	<0.001
FP	2.02	1.17–3.50	0.012
History score			
0 (ref)			
1	2.33	1.58–3.45	<0.001
2	4.98	3.29–7.56	<0.001
EKG score			
0 (ref)			
1	1.49	1.06–2.09	0.022
2	2.83	1.66–4.81	<0.001
Age-score			
0 (ref)			
1	1.60	0.98–2.61	0.062
2	1.65	0.96–2.83	0.068
Risk factor score			
0 (ref)			
1	1.86	0.68–5.07	0.227
2	3.03	1.12–8.15	0.028
Model-3			
hs-cTnI			
less than 99 % URL (ref)			
equal or above 99 % URL	2.13	1.48–3.05	<0.001
Delta hs-cTnI			
No changes (ref)			
RP	7.68	5.34–11.05	<0.001
FP	1.99	1.14–3.48	0.016
History score			
0 (ref)			
1	2.27	1.53–3.38	<0.001
2	4.69	3.08–7.14	<0.001
EKG score			
0 (ref)			
1	1.51	1.08–2.13	0.018
2	2.85	1.66–4.87	<0.001
Age-score			
0 (ref)			
1	1.58	0.96–2.60	0.073
2	1.58	0.90–2.76	0.111
Risk factor score			
0 (ref)			
1	1.84	0.67–5.05	0.234
2	2.97	1.10–8.06	0.032
Sex			
Male (ref)			
Female	0.82	0.61–1.10	0.179
Race and ethnicity			
NHW (ref)			
NHB	0.56	0.39–0.79	0.001
Hispanic	0.73	0.46–1.16	0.183
Other	0.87	0.42–1.79	0.701
Marital Status			
Single (ref)			
Married	1.24	0.87–1.76	0.236
Others	0.68	0.47–0.97	0.034
Language speaking			
English (ref)			
Spanish	1.15	0.68–1.93	0.599
Others	1.14	0.47–2.77	0.772
Insurance			
No (ref)			

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Table 3 (*continued*)

	Adjusted Odds Ratios	95 % Confidence Interval	p
Yes	1.46	0.96–2.23	0.074
Mode of arrival at ED			
Ambulatory (ref)			
Ambulance	1.14	0.66–1.99	0.635
Private Car	1.33	0.77–2.29	0.313
Others	1.45	0.59–2.23	0.683

Multivariable logistic regressions were performed to determine factors associated with 30-day MACE outcome. This analysis was performed based on 4243 patients. Model-1 only analyzed the initial positive hs-cTnI level and kinetic hs-cTnI changes associated with 30-day MACE outcome. Model-2 was performed with the additional HEAR scores. A final Model-3 was performed with hs-cTnI level, kinetic hs-cTnI changes, HEAR scores, and other socio-demographic factors (sex, race and ethnicity, marital status, language speaking, mode of arrival, and insurance). Abbreviations: MACE, major adverse cardiac event; ED, emergency department; hs-cTnI, high sensitivity cardiac troponin-I; RP, rising pattern; FP, falling pattern; URL, upper reference limit; ECG, electrocardiogram; NHW, non-Hispanic White; NHB, no-Hispanic Black.

and risk factors), the AOR for RP was 7.79 (95 % CI: 5.46–11.12, $p < 0.001$), and the AOR for FP was 2.02 (95 % CI: 1.17–3.50, $p = 0.012$). In the fully adjusted model, which accounted for the initial hs-cTnI value, kinetic hs-cTnI changes, HEAR, and collected socio-demographic variables, the AOR for RP was 7.68 (95 % CI: 5.34–11.05, $p < 0.001$), and the AOR for FP was 1.99 (95 % CI: 1.14–3.48, $p = 0.016$; Table 3).

4. Discussion

Serial troponin measurements have been an accepted method for risk stratifying chest pain patients in the ED [3,14]. Negative serial troponin measurements have demonstrated high sensitivity and specificity in ruling out patients at risk for cardiac ischemia, while positive serial troponin levels require further cardiac evaluation [18]. However, few studies have investigated the prognostic role of serial troponin kinetic changes, especially using high-sensitivity cardiac troponin. In this study, we assessed the role of kinetic hs-cTnI changes in risk stratifying chest pain patients in the ED. Our findings revealed that the occurrence of 30-day MACE was significantly higher in patients with both RP and FP changes compared to those with no hs-cTnI changes. Patients with RP changes had over seven times higher odds of experiencing 30-day MACE, even after adjusting for demographic and other factors included in the HEAR score.

Our study emphasizes the importance of recognizing the risks of 30-day MACE associated with: 1) rising hs-cTnI pattern changes, especially when serial hs-cTnI measurements remain below the 99 % URL; and 2) falling hs-cTnI pattern changes, even if the second hs-cTnI measurement falls within the 99 % URL. Our findings support previous studies indicating a higher positive predictive value of RP changes for identifying AMI and also confirm the prognostic value of kinetic hs-cTnI changes in relation to short-term MACE outcomes [8]. Our findings contribute evidence to the literature, suggesting that attention should be given to both RP and FP changes. Based on these findings, urgent referral of patients with HP or FP findings to a cardiologist for advanced cardiology testing may help identify types of acute cardiac ischemia, possibly reducing the incidence of 30-day MACE.

Patients with serial hs-cTnI measurements taken within one hour were excluded from our study due to evidence from prior studies supporting the use of a one-hour interval to rule in or rule out AMI [14,15]. Additionally, this study excluded patients with serial hs-cTnI measurements taken beyond 12 h in alignment with a typical ED setting, where the average length of stay is expected to be less than four to six hours [16,17]. Prolonged intervals for troponin measurement could delay ED discharge, increase healthcare costs, and provide limited additional diagnostic value, since the median elimination half-life of hs-cTnI ranges from 12.4 to 17.3 h [19]. Furthermore, previous studies have reported that the average observation time for chest pain patients in the ED was less than 12 h [20,21]. For these reasons, patients with serial hs-cTnI measurements taken within one hour or beyond 12 h were excluded in this study.

The 99 % URL was employed as the cutoff value for positive hs-cTnI measurements, consistent with previous studies [22,23]. Given the increased sensitivity and specificity of the HEART score for predicting MACE outcomes, as reported in those studies, we highly recommend incorporating the HEART score for risk stratification of chest pain patients in the ED [22,23]. However, when serial troponin measurements are performed, a key question arises regarding which troponin value should be used for the HEART score calculation: the initial or any subsequent troponin values. Currently, there is no consensus in the literature. Considering the risks associated with RP and FP hs-cTnI changes and their association with 30-day MACE outcomes, our results suggest that both the HEART score and kinetic troponin changes be considered simultaneously for ED providers when stratifying chest pain patients.

Our study has several strengths. It includes a relatively large sample size with over 4200 patients in the final analysis. We explicitly examined the role of kinetic hs-cTnI changes in relation to short-term MACE outcomes, a topic rarely explored in previous research. Additionally, a comprehensive analysis was performed using stepwise multivariable logistic regression, incorporating hs-cTnI, HEAR scores, and other sociodemographic factors to assess their associations with 30-day MACE outcomes. Our findings support the importance of RP and FP hs-cTnI changes in predicting 30-day MACE which can provide valuable clinical guidance for interpreting serial troponin measurements when managing acute chest pain patients in the ED.

Our study also has several limitations. First, as a single-center retrospective observational study, potential issues such as missing or incorrect data, patient lost to follow-up, and missing key variables (e.g., the time interval between chest pain onset and hs-cTnI measurement), could introduce bias. However, a prior sensitivity analysis revealed that missing follow-up information did not affect 30-day MACE outcomes in this cohort [24]. Next, our study only included ED patients with serial hs-cTnI measurements. In general, a single hs-cTnI measurement is usually sufficient for risk stratifying chest pain patients in the ED if symptom onset occurred more than 3 h before arrival. Therefore, serial hs-cTnI measurements may only be necessary for patients whose symptoms onset is within 3 h of ED arrival [25]. However, this study could not determine the exact time interval between symptom onset and initial hs-cTnI measurement. Additionally, we did not perform sub-cohort analyses on patients with chronic renal diseases, as hs-cTnI levels can be influenced by renal function, and the pattern of serial hs-cTnI changes may differ from patients with normal renal function. Moreover, our study included serial hs-cTnI measurements taken within the first 12 h of the ED stay, this timeframe may need to be adjusted according to the specific chest pain protocol implemented in different EDs. These limitations may restrict the generalizability of our findings. Finally, while our study focused on comparing 30-day MACE based on kinetic hs-cTnI changes, previous studies have demonstrated the superior performance of the HEART score compared to hs-cTnI measurements alone for MACE prediction. [24,26] Future prospective studies should address the optimal time intervals between symptom onset and hs-cTnI measurements and compare the predictive value of kinetic

hs-cTnI changes with the HEART score for risk stratifying chest pain patients in the ED.

5. Conclusion

Serial hs-cTnI measurements may play a significant role in predicting patients at risk for 30-day MACE, particularly among patients with rising pattern hs-cTnI changes. Patients with a falling pattern hs-cTnI changes can also be associated with a higher incidence of 30-day MACE compared to patients without serial hs-cTnI changes.

CRediT authorship contribution statement

Charles Huggins: Writing – review & editing, Validation, Investigation, Conceptualization. **Nicholas Saltarelli:** Writing – review & editing, Validation, Investigation, Conceptualization. **Thomas K. Swoboda:** Writing – review & editing, Validation, Methodology. **Kaitlyn Lizardo:** Writing – review & editing, Validation, Investigation, Data curation. **Radhika Cheeti:** Writing – review & editing, Validation, Data curation. **Timothy Muirheid:** Writing – review & editing, Validation, Data curation. **Hao Wang:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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