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Original Contribution

Improving risk stratification in patients with chest pain: the Erlanger HEARTS$_3$ score

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Abstract

Background: The HEART score uses elements from patient *H*istory, *E*lectrocardiogram, *A*ge, *R*isk Factors, and *T*roponin to obtain a risk score on a 0- to 10-point scale for predicting acute coronary syndromes (ACS). This investigation seeks to improve on the HEART score by proposing the HEARTS$_3$ score, which uses likelihood ratio analysis to give appropriate weight to the individual elements of the HEART score as well as incorporating 3 additional "S" variables: *S*ex, *S*erial 2-hour electrocardiogram, and *S*erial 2-hour delta troponin during the initial emergency department valuation.

Methods: This is a retrospective analysis of a prospectively acquired database consisting of 2148 consecutive patients with non–ST-segment elevation chest pain. Interval analysis of likelihood ratios was performed to determine appropriate weighting of the individual elements of the HEART$_3$ score. Primary outcomes were 30-day ACS and myocardial infarction.

Results: There were 315 patients with 30-day ACS and 1833 patients without ACS. Likelihood ratio analysis revealed significant discrepancies in weight of the 5 individual elements shared by the HEART and HEARTS$_3$ score. The HEARTS$_3$ score outperformed the HEART score as determined by comparison of areas under the receiver operating characteristic curve for myocardial infarction (0.958 vs 0.825; 95% confidence interval difference in areas, 0.105-0.161) and for 30-day ACS (0.901 vs 0.813; 95% confidence interval difference in areas, 0.064-0.110).

Conclusion: The HEARTS$_3$ score reliably risk stratifies patients with chest pain for 30-day ACS. Prospective studies need to be performed to determine if implementation of this score as a decision support tool can guide treatment and disposition decisions in the management of patients with chest pain.

1. Introduction

The HEART score was developed at a community hospital in the Netherlands in a patient population of 122 emergency department (ED) patients with chest pain to assist in the triage of patients with non–ST-segment elevation chest pain [1]. It uses elements from patient *H*istory,

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*E*lectrocardiogram (ECG), *A*ge, *R*isk factors for coronary artery disease (CAD), and *T*roponin levels. The 5 components were given a score of 0, 1, or 2, with little rationale given for the weighting of the score other than stating that the scores were "based on clinical experience and current medical literature." The primary end point of the study was a composite of acute myocardial infarction (AMI), coronary revascularization, and death. The rates of composite end point in patients with scores of 0 to 3, 4 to 6, and 7 to 10 were 2.5%, 20.3%, and 72.7%, respectively. A subsequent prospective study in 880 patients with chest pain at 4 hospitals in the Netherlands found similar rates for the composite end point (measured at 6 weeks) of 1.0%, 11.6%, and 65.2%, respectively, in the 3 subgroups of patients [2]. Although the authors do not specifically state that patients with a HEART score of 3 or lower can be safely discharged home without further evaluation, they do state that the HEART score can be used in "triage" of patients with chest pain because it is a "reliable predictor of outcome."

A drawback to the HEART score is that the individual variables were selected "based on clinical experience and current medical literature," and weighting of the score was arbitrarily assigned without taking into account the likelihood of predicting adverse cardiac events. For example, 3 risk factors or age greater than 65 years has the same score (2 points) as having acute ischemia on the initial ECG or markedly elevated troponin, although these latter 2 findings are virtually diagnostic of acute coronary syndrome (ACS) in a patient with chest pain. Due to this lack of appropriate weighting, the HEART score has decreased discriminatory power, especially in patients with midrange scores. Another limitation of the HEART score is that it does not take into account the sex of the patient, although it is has been well established that there are significant age-related sex differences in determining the risk of CAD [3-6]. Finally, the HEART score does not take advantage of the incremental information obtained when one obtains serial ECG and repeat cardiac marker measurements during the initial ED evaluation [7,8].

This investigation seeks to improve on the HEART score by using likelihood ratio (LR) analysis to give appropriate weight to the individual elements of the HEART score, to create a HEART (weighted) score in risk stratifying patients with chest pain for 30-day ACS. This investigation also presents the $HEARTS_3$ score that incorporates 3 additional "S" variables into the HEART (weighted) score: *S*ex, *S*erial 2-hour ECG, and *S*erial 2-hour delta troponin testing during the initial ED evaluation.

2. Methods

2.1. Study design

This is a retrospective analysis of a prospectively acquired database of 2206 consecutive patients with chest pain presenting to the ED. This study was performed with approval of the institutional review committee.

2.2. Setting

This study was performed at an urban county hospital with an adult ED volume of approximately 45 000. The hospital has full cardiac capability with both interventional cardiologists and cardiothoracic surgery available 24 hours a day.

2.3. Study population

The study population consists of consecutive patients with chest pain 18 years or older having suspected ACS presenting to Erlanger Medical Center during a 13-month period in whom data were prospectively collected. Results in this patient population have been previously described [8,9]. Exclusion criteria included patients presenting with chest pain in the presence of a tachyarrhythmia (ventricular tachycardia, supraventricular tachycardia, or rapid atrial fibrillation), patients with pulmonary edema on presentation requiring mechanical ventilation, patients with chest pain not deemed by the physician to warrant cardiac workup (obvious nonischemic chest pain and absence of risk factors or preexisting disease that would prompt screening examination), and patients with suspected ACS who did not present with chest pain.

2.4. Measurements

All patients not undergoing emergent arteriogram for suspected acute ST-segment elevation myocardial infarction (MI) were risk stratified by the evaluating physician into 3 chest pain categories based on history and physical examination: category 2, probable ACS chest pain; category 3, possible ACS chest pain; and category 4, probable noncardiac chest pain, but the presence of preexisting disease or significant cardiac risk factors warrant screening examination. Patients then underwent a standardized accelerated evaluation protocol consisting of 2-hour delta cardiac marker testing and automated serial ECG monitoring, which has been demonstrated to reliably identify and exclude AMI [7-9]. At the completion of this accelerated chest pain evaluation protocol, patients were again classified into 3 groups based on the physician's estimate of likelihood of ACS: category 2, probable ACS (clinical diagnosis of ACS, and/or positive serum marker measurements, and/or diagnostic abnormalities on serial ECG); category 3, possible ACS; and category 4, non-ACS chest pain. Category 2 patients were admitted for presumed ACS, category 3 patients underwent immediate nuclear stress testing, and category 4 patients were directly discharged from the ED, unless another serious non-ACS medical condition was thought to exist. Comprehensive details of this protocol have been previously published [8,9].

For the assessment of HEART score, the 3 HEART history categories "highly suspicious," "moderately suspicious," and "slightly suspicious" were deemed to correspond to the 3 Erlanger baseline category 2, 3, and 4 patients, respectively. For the assessment of ECG, the 3 HEART ECG categories "significant ST-depression," "non-specific repolarization disturbance," and "normal" were deemed to correspond to the 3 Erlanger ECG categories: "acute ischemia"; "infarction, BBB, or hypertrophy"; and "non-diagnostic for injury, ischemia, infarction, BBB, or hypertrophy."

Definition of risk factors used in this study for determination of the HEART risk score was as follows: diabetes was diagnosed if the patient had history of diabetes diagnosed and treated with diet and/or medications, or ED blood glucose of 150 or higher; hypertension was diagnosed if the patient had history of hypertension diagnosed and treated with lifestyle modification and/or medication; in the absence of prior diagnosis, hypertension was diagnosed if the patient demonstrated left ventricular hypertrophy on the initial ECG and either of the 2 following findings: (1) diastolic blood pressure greater than 100 mm Hg on 2 ED measurements at least 30 minutes apart or longer or (2) systolic blood pressure greater than 140 mm Hg and diastolic blood pressure greater than 90 mm Hg on 2 ED measurements at least 30 minutes apart or longer; cigarette use was considered positive if the patient was a current or recent (<1 year) cigarette smoker; dyslipidemia was diagnosed if the patient had history of dyslipidemia diagnosed and treated with diet and/or medications, or total cholesterol greater than 200 mg/dl with low-density lipoprotein greater than 130 mg/dl or high-density lipoprotein less than 35 mg/dl; *family history of CAD* was defined as any first-degree relative 60 years or younger who had any 1 of the following: MI, percutaneous coronary intervention (PCI), coronary artery bypass grafting (CABG), or sudden death of cardiac or unknown cause; *obesity* was defined as having a body mass index greater than 27 kg/m^2 [6].

Table 1 Demographic characteristics of 315 patients with 30-day ACS and the 1833 patients without 30-day ACS

Population demographics	30-day ACS (n = 315), n (%)	Non-ACS (n = 1833), n (%)
Age (y), mean ± SD	59.2 ± 13.0	53.6 ± 14.2
Race		
White	257 (81.6)	1320 (72.0)
Black	55 (17.5)	494 (27.0)
Other	3 (1.0)	19 (1.0)
Male sex	201 (63.8)	906 (49.4)
Diabetes	97 (30.8)	358 (19.5)
Hypertension	207 (65.7)	1018 (55.5)
Cigarette use	131 (41.6)	727 (39.7)
Hyperlipidemia	182 (57.8)	839 (45.8)
Family history of CAD	116 (36.8)	542 (29.6)
Obesity	112 (35.6)	743 (40.5)
History of MI	141 (44.8)	539 (29.4)
History of CABG/PCI	132 (41.9)	415 (22.6)
History of CAD (MI ± CABG/PCI)	161 (51.1)	608 (33.2)

Table 2 Thirty-day adverse outcome in the 315 patients with 30-day ACS

30-d outcome	n (%)
24-h AMI	169 (53.7)
24-h recent MI [a]	33 (10.5)
30-d PCI	141 (44.9)
30-d CABG	69 (22.0)
30-d stenosis [b]	43 (13.7)
30-d life-threatening complication [c]	25 (8.0)
30-d death	10 (3.2)

[a] Recent MI represents patients with MI who presented on the falling curve of troponin.

[b] Stenosis of 70% or greater on coronary arteriogram not amenable to PCI/CABG.

[c] Life-threatening complications were defined as ventricular fibrillation, sustained ventricular tachycardia, third-degree atrioventricular block, bradycardic or asystolic arrest, post-ED presentation MI, cardiogenic shock, or electromechanical dissociation.

For HEART troponin assessment, the cutoff for an *abnormal cardiac troponin* was defined as the lowest cutoff value above the 99th percentile in which the assay imprecision is 10% or less.[10,11] This value for the Troponin I Axsym Fluorometric Enzyme Immunoassay (Abbott Laboratories, Abbott Park, IL) used in this study is 0.8 ng/mL [11]. The definition of the 3 additional S components of the HEARTS$_3$ score were as follows: sex equals sex of patient, serial troponin was defined as the difference between the 2-hour and the baseline troponin (ie, 2-hour delta troponin), and serial ECG was categorized as "new injury or evolving ischemia," "non-diagnostic changes," or "no changes" during the initial 2 hour of continuous 12-lead ECG monitoring. Calculation of the LRs for the delta troponin excluded patients with recent MI because these patients, by definition, presented on the falling curve of cardiac marker measurements (see later).

Interval LR analyses of the individual elements of the HEART score and the 3 additional S elements sex, serial ECG, and serial troponin for predicting 30-day ACS were performed to determine appropriate weighting of each variable. Weighting of the score was LR dependent: +LR less than 1: 0 points; 1 to 2.5: 1 point; more than 2.5 to 5: 2 points; more than 5 to 10: 3 points; more than 10 to 20: 4 points; and more than 20: 5 points. The HEART (weighted) score was calculated by summing the weighted scores for the individual elements of the HEART score. The HEARTS$_3$ score was calculated by adding the scores for sex, serial ECG, and serial troponin to the HEART (weighted) score.

2.5. Main outcomes

Myocardial infarction was defined according to the current American College of Cardiology and European Society of Cardiology criteria using troponin as the criterion standard [10]. Because the initial studies from this database used

Table 3 Positive LRs and associated score for 30-day ACS for each individual element of the HEART score, the HEART(weighted) score, and the 3 additional S elements of the $HEARTS_3$ score

Variable	+LR (95% CI)	HEART score	HEART (weighted) score	$HEARTS_3$ score
History				
Probable noncardiac CP	0.21 (0.14-0.31)	0	0	0
Possible ischemic CP	1.03 (0.95-1.12)	1	1	1
Probable ischemic CP	13.26 (9.18-19.15)	2	4	4
ECG (baseline)				
Absence of below ECG findings	0.71 (0.63-0.80)	0	0	0
Infarct/BBB/Hypertrophy	1.47 (1.28-1.69)	1	1	1
Ischemic ST depressions	6.79 (3.66-12.60)	2	3	3
Age (y)				
<45	0.35 (0.25-0.48)	0	0	0
45-65	1.22 (1.10-1.35)	1	1	1
>65	1.39 (1.15-1.69)	2	1	1
Risk factors				
No. of risk factors: no hx CAD				
0	0.25 (0.08 to 0.77)	0	0	0
1-2	0.83 (0.70-1.0)	1	0	0
3-6	1.40 (1.19-1.66)	2	1	1
No. of risk factors: hx CAD				
0	0.67 (0.27-1.72)	2	0	0
1-2	0.93 (0.76-1.13)	2	0	0
3-6	1.10 (0.93-1.29)	2	1	1
Troponin (baseline)				
Less than the cutoff (0.8 ng/mL)	0.66 (0.60-0.71)	0	0	0
1-3× cutoff (0.8-2.4 ng/mL) [a]	4.68 (3.01 to 7.29)	1	2	2
>3× cutoff (2.4 ng/mL) [a]	58.92 (28.78-120.62)	2	5	5
Serial (sex, serial ECG, serial troponin)				
Sex				
Female	0.72 (0.61-0.83)	NI [b]	NI [b]	0
Male	1.29 (1.17-1.42)	NI	NI	1
Serial ECG				
No change	0.82 (0.78-0.87)	NI	NI	0
Non-Dx changes	3.00 (2.02-4.46)	NI	NI	2
Dx changes	23.28 (10.83-50.04)	NI	NI	5
Serial troponin (2-h delta) [c]				
<+0.1 ng/mL	0.59 (0.53-0.65	NI	NI	0
+0.1-+0.3 ng/mL	3.31 (2.05-5.32)	NI	NI	2
>+0.3 ng/mL	25.07 (116.64-37.76)	NI	NI	5

Abbreviations: BBB, bundle-branch block; CP, chest pain; Dx, diagnostic; hx, history; NI, not included.

[a] Likelihood ratio determination for the 2-hour delta troponin excluded patients with recent MI.

[b] Calculator for $HEART_3$ score can be found at: http://107.22.120.83/hearts3/.

[c] The pilot HEART study used 1 to 2× cutoff as equal to 1 point. Two follow-up studies used 1 to 3× cutoff value as equal to 1 point.

modified World Health Organization criteria for MI that was in affect at the time of data collection [12], the current American College of Cardiology/European Society of Cardiology criteria were retrospectively applied to the entire patient population [10]. Patients with MI were subdivided into AMI (patients on rising curve of troponin with at least 1 value above the 99th percentile during the first 24 hours after presentation) and recent MI (patients presenting on the falling curve of troponin). *Thirty-day ACS* was defined as MI on presentation, PCI, CABG, arteriogram revealing stenosis in major coronary vessel (or bypass graft if native vessel totally occluded) 70% or greater not amenable to CABG or PCI, life-threatening complications, or death from cardiac or unknown cause occurring within 30 days of presentation. *Life-threatening complications* were defined as ventricular fibrillation, sustained ventricular tachycardia, third-degree atrioventricular block, bradycardic or asystolic arrest, post-ED presentation MI, cardiogenic shock, or electromechanical dissociation.

2.6. Data analysis

Calculation of scores for the HEART, HEART (weighted), and $HEARTS_3$ score, as well as calculation of basic demographic analysis, was performed using SYSTAT 13.0 (SPSS, Inc, Chicago, IL). Interval LR analyses for determination of appropriate scoring for each individual

element of the HEART score and the 3 additional S elements (sex, serial ECG, and serial troponin) of the $HEARTS_3$ were performed using MedCalc 11.6.1 (MedCalc Software, Mariakerke, Belgium). Comparisons of areas under the receiver operating characteristic (ROC) curves for each scoring system as well as 95% confidence intervals (CIs) for difference in areas also were performed using MedCalc.

3. Results

3.1. Characteristics of study subjects

The study population was derived from a total of 2206 consecutive patients with chest pain presenting to our ED for evaluation. Fifty-eight patients with injury on the initial ECG were excluded, leaving a total patient population of 2148 patients. Table 1 provides the demographic characteristics in patients with and without 30-day ACS. Patients without 30-day ACS tended to be younger, be less likely to be white or male sex, and have lower rates of coronary risk factors and history of preexisting CAD. Table 2 provides the breakdown of 30-day outcome in patients with ACS. Overall, a total of 202 (9.4%) patients had MI and 315 (14.7%) patients had 30-day ACS.

3.2. Interval LR analysis

Table 3 demonstrates positive LR interval measurements for the individual elements of the HEART score and the 3 additional S elements of the $HEARTS_3$. The HEART score overestimates the significance of older age, number of risk factors, and presence or absence of CAD. The HEART score also underestimates the significance of a history of probable ischemic chest pain, diagnostic ECG, and elevated troponin. There also are increased LR values for 30-day ACS associated with male sex, changes on serial ECG monitoring, and increasing values of 2-hour delta troponin testing.

3.3. Receiver operating characteristic curve analysis

Fig. 1 represents the ROC curve for MI and 30-day ACS of the HEART score, HEART (weighted) score, and $HEARTS_3$ score. Table 4 provides areas under the ROC curves for the 3 scoring systems as well as pairwise comparison between the HEART and the HEART (weighted) score and comparison between the HEART (weighted) score and the $HEARTS_3$ score. The HEART (weighted) score and $HEARTS_3$ score provide incremental improvement in discrimination for 30-day ACS. Comparing the $HEARTS_3$ score with the HEART, there are significant differences in areas under the ROC curve for MI (0.958 vs 0.825; 95% CI difference in areas, 0.105-0.161) and 30-day ACS (0.901 vs 0.813; 95% CI difference in areas, 0.064-0.110).

3.4. Risk score comparison

Fig. 2 represents the incidence of 30-day ACS and MI according to $HEARTS_3$ score, and Table 5 reveals the number of individuals with MI and 30-day ACS according to the score as ascertained by HEART, HEART (weighted), and $HEARTS_3$ score. A $HEARTS_3$ score of less than or equal to 1 identified 304 (14.2%) patients without a single case of 30-day ACS as compared with 177 (8.2%) patients without a single case of 30-day ACS with a HEART score of less than or equal to 1. A $HEARTS_3$ score of 2 identified 400 (18.6 %)

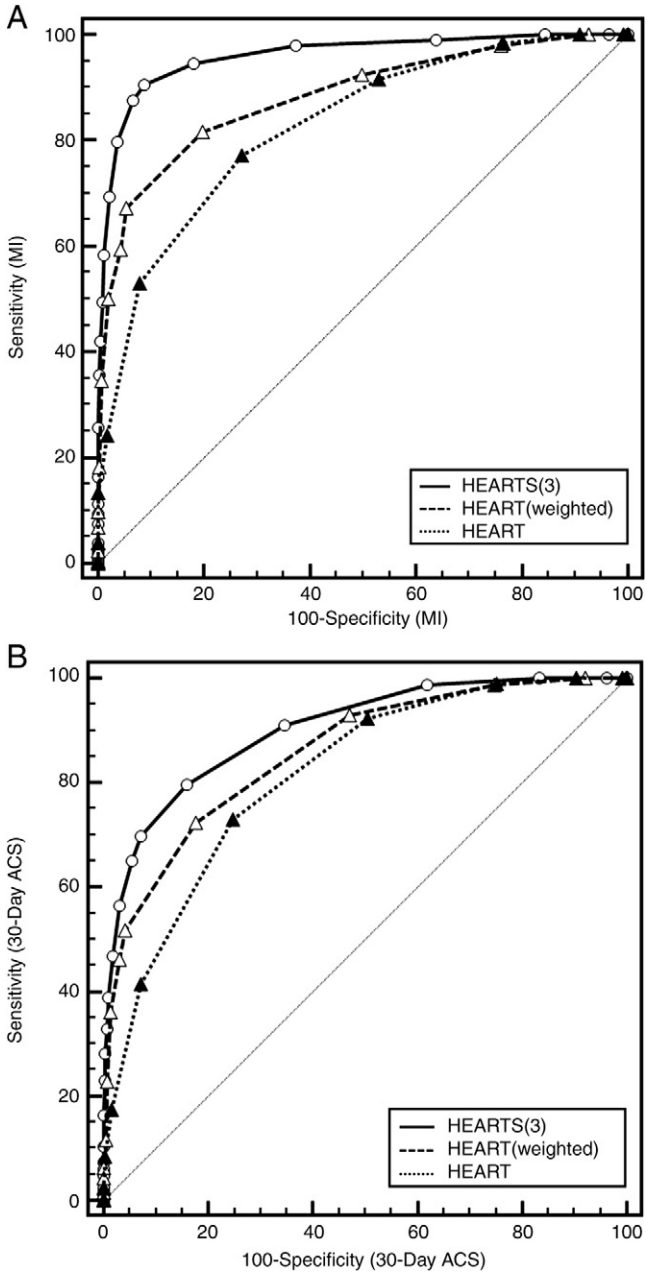

Fig. 1 Receiver operating characteristic curves for MI (A) and 30-day ACS (B) of the HEART, HEART (weighted), and $HEARTS_3$ scores.

Table 4 ROC curve areas for MI and 30-day ACS for the HEART, HEART (weighted), and $HEARTS_3$ scores (difference in areas: pairwise 95% CI for difference in areas of ROC curves between the HEART and the HEART (weighted) scores and between the HEART (weighted) and the $HEARTS_3$ scores

	MI (95% CI)	Difference in areas	30-day ACS (95% CI)	Difference in areas
HEART	0.827 (0.811-0.843)	0.038-0.073	0.816 (0.799-0.832)	0.028-0.058
HEART (weighted)	0.883 (0.868-0.896)	0.054-0.099	0.859 (0.843-0.873)	0.026-0.061
$HEARTS_3$	0.959 (0.950-0.967)		0.902 (0.889-0.914)	

patients with 1.0% incidence of 30-day ACS as compared with a 1.1% incidence of ACS in 281 (13.1%) patients with a HEART score of 2. Overall, a $HEARTS_3$ score of 2 or lower identified 704 (32.8%) patients with a 0.6% incidence of 30-day ACS as compared with a HEART score of 2 or lower that identified only 458 (21.3%) patients with a 0.7% incidence of 30-day ACS.

4. Discussion

Various risk assessment scores and clinical prediction rules have been developed to assist the clinician in determining which patients are at higher risk for significant CAD and ACS [3-6,13-23]. The Framingham score was developed in a large population cohort to predict the 5- and 10-year risk of developing CAD [3]. The Hubbard-Ho and Morise score were developed to predict risk of CAD in patients referred for stress testing [4-6]. The Thrombolysis In Myocardial Infarction (TIMI) score [14], Platelet Glycoprotein IIb/IIIa in Unstable Angina: Receptor Suppression Using Integrilin Therapy (PURSUIT) score [15], and Global Registry of Acute Coronary Events (GRACE) score [16] were developed in patients with diagnosed as having ACS to predict the risk of death and recurrent MI. The GRACE and TIMI scores have been applied with some success to ED patients with chest pain, although these scores were developed specifically to predict outcome in patients with diagnosed ACS and not to the undifferentiated ED patients with chest pain [20-23]. The Sanchis score [17] and the Vancouver rule [13] were developed specifically for ED patients with chest pain. Of interest, the Vancouver rule actually was developed in Canada with the intent of allowing up to a 2% miss rate [13]. It is doubtful that the same threshold would be true among American ED physicians as compared with their Canadian counterparts. However, experts agree that it is very difficult to get the risk of missed ACS below 1%, and, pending malpractice reform, most emergency physicians in the United States are unwilling to accept even a 1% miss rate [24]. Despite showing a correlation with the risk of ACS and adverse outcome, none of these risk stratification systems have gained widespread acceptance in clinical practice [25].

Preliminary results of a prospective validation of the HEART score were reported at the 2010 Congress of the European Society of Cardiology [26]. The investigators reported that the HEART score outperformed the GRACE and TIMI score for identification of a 6-week composite outcome of AMI, PCI, CABG, and death as measured by the area under the ROC curve in 2150 consecutive patients with chest pain presenting to 1 of 10 hospitals during a 6-month period (area under the ROC curve, 0.83, 0.73, and 0.66, respectively) [26]. Because the GRACE and TIMI scores were developed in patients with diagnosed ACS, it is not surprising that the HEART score outperformed these 2 methods when applied to a population with undifferentiated chest pain.

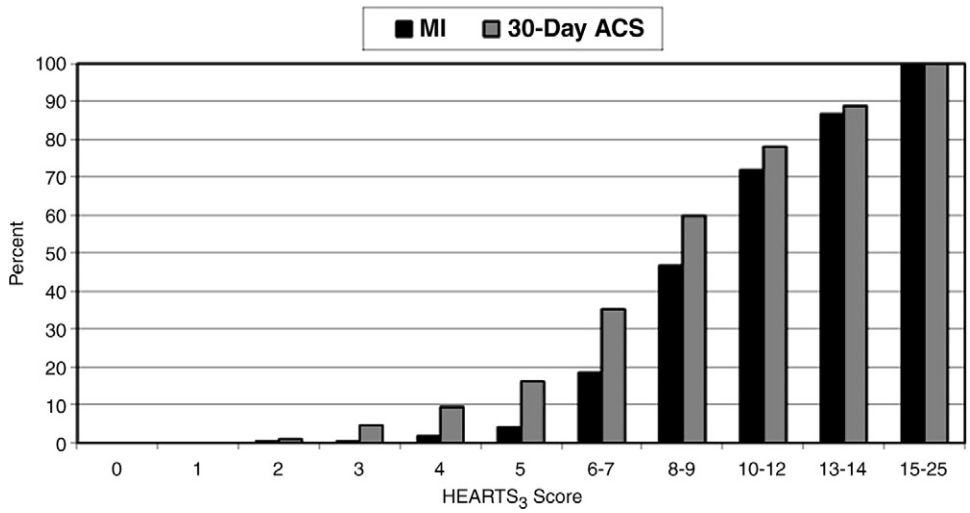

Fig. 2 Incidence of MI and 30-day ACS in 2148 study patients according to $HEARTS_3$ score.

A recent retrospective study applied the HEART score to 1070 low-risk patients with chest pain admitted to an observation unit [27]. Patients with a clinical assessment of "not low risk" or TIMI score less than 1 were excluded from the observation unit protocol. Although not stated in the methodology, presumably patients with a history of preexisting CAD were excluded because none of the study patients had CAD. Also, there were no patients with an abnormal troponin or ischemia on initial ECG because these patients undoubtedly would be considered not low risk. The investigators followed up patients for a composite end point of AMI, coronary revascularization, or death within 30 days of presentation. The composite end point was reached in 0.6% (5/904) of patients with a HEART score of 0 to 3 and 4.2% (7/166) of patients with a HEART score higher than 3. The addition of a 4- to 6-hour troponin greater than 0.065 ng/mL identified all 5 low-risk patients with a HEART score of 0 to 3 who had an adverse cardiac event. Because all patients in this observation unit underwent mandatory stress testing, the investigators conclude that a HEART score of 0 to 3 with a negative 6-hour troponin potentially could reduce stress testing by 82%. The findings of this study are severely limited because it, actually, is not a true HEART score but a "HAR" score because there were no patients with ischemia on the initial ECG or elevated troponin at baseline in the study population. The study also is limited by the fact that only 12 (1.1%) patients had ACS, indicating that their chest pain observation unit consists of extremely low-risk patients. A final limitation is that retrospective medical record review was used to assign individual patients to 1 of the 3 HEART history categories.

As our data demonstrate, interval LR analyses for each of the elements of the HEART score indicate significant disparities in scores "based on clinical experience and current medical literature" vs weighted scores based on LR values. In regard to increasing age, greater number of risk factors, and presence or absence of preexisting CAD, physicians probably are more conservative in evaluating patients with atypical chest pain. This conservative approach probably accounts for the decrease weighting of score in the HEART (weighted) and $HEARTS_3$ score as compared with the HEART score. In regard to a history suggestive of ACS, ischemic ECG, and abnormal troponin, it is not surprising that the score based on LR analyses is much greater than the score used by the HEART scheme because history, ECG, and troponin are the most reliable predictors of the presence or absence of ACS. The use of adding serial ECG and serial troponin to the $HEARTS_3$ score supports the practice of delaying final disposition until MI has been reliably ruled out with an accelerated protocol [7,8].

5. Limitations

The primary limitation of our study is the retrospective design, although we feel that this limitation is offset by the fact that the data collection was prospectively performed in consecutive patients with chest pain undergoing a standardized chest pain evaluation protocol. Another major limitation is that the study used an older-generation troponin. Undoubtedly, newer-generation, high-sensitivity troponin assays would have resulted in more patients with diagnosis of MI as well as altering the LR scores obtained for the baseline troponin. We have minimized this bias by calculating LRs for 30-day ACS and not MI. An additional limitation is that 2-hour delta troponin testing for the serial troponin component of the $HEARTS_3$ score is not a component of the chest pain evaluation protocol at many institutions. However, we believe that accelerated protocols that use a 6- to 8-hour chest pain strategy will have even greater sensitivity for detecting rising values in troponin. Also, the serial ECG component of the $HEARTS_3$ score

Table 5 Rates of MI and 30-day ACS according to HEART, HEART (weighted), and $HEARTS_3$ scores

	No. of patients	MI, n (%)	30-d ACS, n (%)
HEART score			
0	15	0 (0)	0 (0)
1	162	0 (0)	0 (0)
2	281	3 (1.1)	3 (1.1)
3	473	14 (3.0)	21 (4.4)
4	533	29 (5.4)	61 (11.4)
5	422	49 (11.6)	99 (23.5)
6	179	58 (32.4)	76 (42.5)
7	52	22 (42.3)	28 (53.9)
8	23	19 (82.6)	19 (82.6)
9-10	8	8 (100)	8 (100)
HEART (weighted) score			
0	142	0 (0)	0 (0)
1	326	4 (1.2)	4 (1.2)
2	523	11 (2.1)	18 (3.4)
3	605	22 (3.6)	65 (10.7)
4	311	29 (9.3)	65 (20.9)
5	36	16 (44.4)	17 (47.2)
6	65	19 (29.2)	32 (49.3)
7	55	31 (56.4)	42(76.4)
8	40	33 (82.5)	35 (87.5)
9	25	17 (68.0)	17 (68.0)
10-15	20	20 (100%)	20 (100%)
$HEARTS_3$ score			
0	69	0 (0)	0 (0)
1	235	0 (0)	0 (0)
2	400	2 (0.5)	4 (1.0)
3	520	2 (0.4)	24 (4.6)
4	380	7 (1.8)	36 (9.5)
5	191	8 (4.2)	31 (16.2)
6-7	119	22 (18.5)	42 (35.3)
8-9	92	43 (46.7)	55 (59.8)
10-12	64	46 (71.9)	50 (78.1)
13-14	45	39 (86.7)	40 (88.9)
15-25	33	33 (100.0)	33 (100.0)

was performed using continuous serial ECG monitoring. It is unknown how this affects the $HEARTS_3$ score when one uses serial static ECGs in the ED and chest pain observation setting. Because our institution no longer has the capability for continuous 12-lead ECG monitoring, our current practice is to obtain a repeat static ECG at 2 hours in all patients and more frequent ECGs in patients with ongoing or worsening symptoms at the discretion of the evaluating physician. Despite the limitations of the troponin and ECG component of the HEART (weighted) score and $HEARTS_3$ score, our study still highlights the importance of the use of LR analyses or other statistical techniques to give appropriate weighting to variables used in any scoring system.

A final limitation is that the $HEARTS_3$ score is not easily memorized due to the complexity of scoring as compared with the HEART score. However, we elected to assign 0 points to LR values less than 1 so as to prevent one from having to subtract numbers. We also have created a user-friendly pocket-sized Web-based Adobe Acrobat PDF file of the HEART (weighted) and $HEARTS_3$ score that may be printed out as well as a Web-based decision support tool that one may use to enter data directly on a computer or smart phone (http://107.22.120.83/hearts3/).

6. Conclusion

The HEART (weighted) and $HEARTS_3$ score outperform the HEART score in risk stratification of ED patients with chest pain. Future studies are needed to determine appropriate weighting of the troponin component of the $HEARTS_3$ score using high-sensitivity troponin assays as well as validating the weighting of the other individual elements used in the $HEARTS_3$ score. In addition, prospective studies investigating whether or not this score can be used as a decision support tool to assist ED physicians in patient management and disposition are warranted.

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