

Diagnosis Patterns and Stress Testing Trends After Implementing High-Sensitivity Troponin Assay

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High-sensitivity troponin testing is increasingly being used internationally as a way to better rule out acute coronary syndrome (ACS). Its utilization has resulted in up to a 33% reduction in emergency department (ED) length of stay¹⁻⁵ and has helped facilitate decision-making in the ED, with decreases in inpatient admissions for chest pain and increased disposition to home.⁶⁻⁸ However, compared with patients who receive conventional troponin I testing, a higher proportion of patients who receive high-sensitivity troponin testing are categorized as positive for ACS, with more than 25% of patients presenting with chest pain found to have an elevated troponin level.⁹ Consequently, international studies evaluating the impact of high-sensitivity troponin testing have demonstrated increased diagnosis of type 2 non-ST-segment elevation myocardial infarctions (NSTEMIs) and increased diagnostic testing to assess for ACS.¹⁰⁻¹⁴

In January 2017, high-sensitivity troponin T (hsTnT) testing was approved for use in the United States.¹⁵ Although robust literature describes the impact of high-sensitivity troponin testing within the international health care community, primary studies highlighting its effects on solely the US health care system are lacking. Additionally, given the implications that a more sensitive test might have on patient care, health care utilization, and cost, it is important to understand its impact on the US health care system and on health care delivery, thus informing future policies, care pathways, and payment models. As such, we sought to understand the impact of hsTnT testing on discharge diagnosis patterns and diagnostic stress testing utilization at a major US medical center.

METHODS

We conducted a retrospective cohort analysis at Michigan Medicine, a large, academic, quaternary care center in Ann Arbor, Michigan, with 1000 licensed beds and more than 100,000 ED visits annually. Our cohort included adult patients (≥ 18 years) presenting with a clinical suspicion of ACS (ie, presenting to the ED with a chief complaint of either “chest pain” or “shortness of breath” per initial triage documentation) who had troponin testing either prior to or

ABSTRACT

OBJECTIVES: High-sensitivity troponin T (hsTnT) testing was approved in the United States to better facilitate diagnosis of acute coronary syndrome (ACS). Although hsTnT has been widely studied internationally, the impact of hsTnT on discharge diagnoses and health care utilization within the United States is less known. We sought to evaluate the effects of implementing hsTnT on diagnosis patterns and stress testing utilization.

STUDY DESIGN: We performed a retrospective cohort analysis consisting of patients with suspected ACS undergoing either conventional troponin I ($n=14,631$) or hsTnT ($n=7237$) testing between January 2016 and February 2019.

METHODS: Log-binomial regression with interrupted time series modeled diagnosis patterns, and logistic regression with segmented time trends modeled stress testing rates. Observed trends were compared with expected trends using average marginal effect (AME).

RESULTS: Rates of acute myocardial infarction-related diagnoses were similar in the post-hsTnT period (AME, -0.6% ; $P=.065$). Post hsTnT introduction, patients were more likely to receive a diagnosis of heart failure (2.1% ; $P<.001$) or atrial fibrillation/flutter (0.9% ; $P<.001$) and less likely to receive a diagnosis of hypertensive heart disease (-10.2% ; $P<.01$) or hypertensive heart disease with chronic kidney disease (-3.7% ; $P<.001$). Likelihood of receiving stress testing increased after hsTnT implementation (2.3% ; $P<.001$).

CONCLUSIONS: Variations in discharge diagnosis patterns and increases in stress test utilization were observed following hsTnT implementation. Hospitals can expect similar changes, which may have long-term implications on health care utilization, cost, and hospital reimbursement.

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TAKEAWAY POINTS

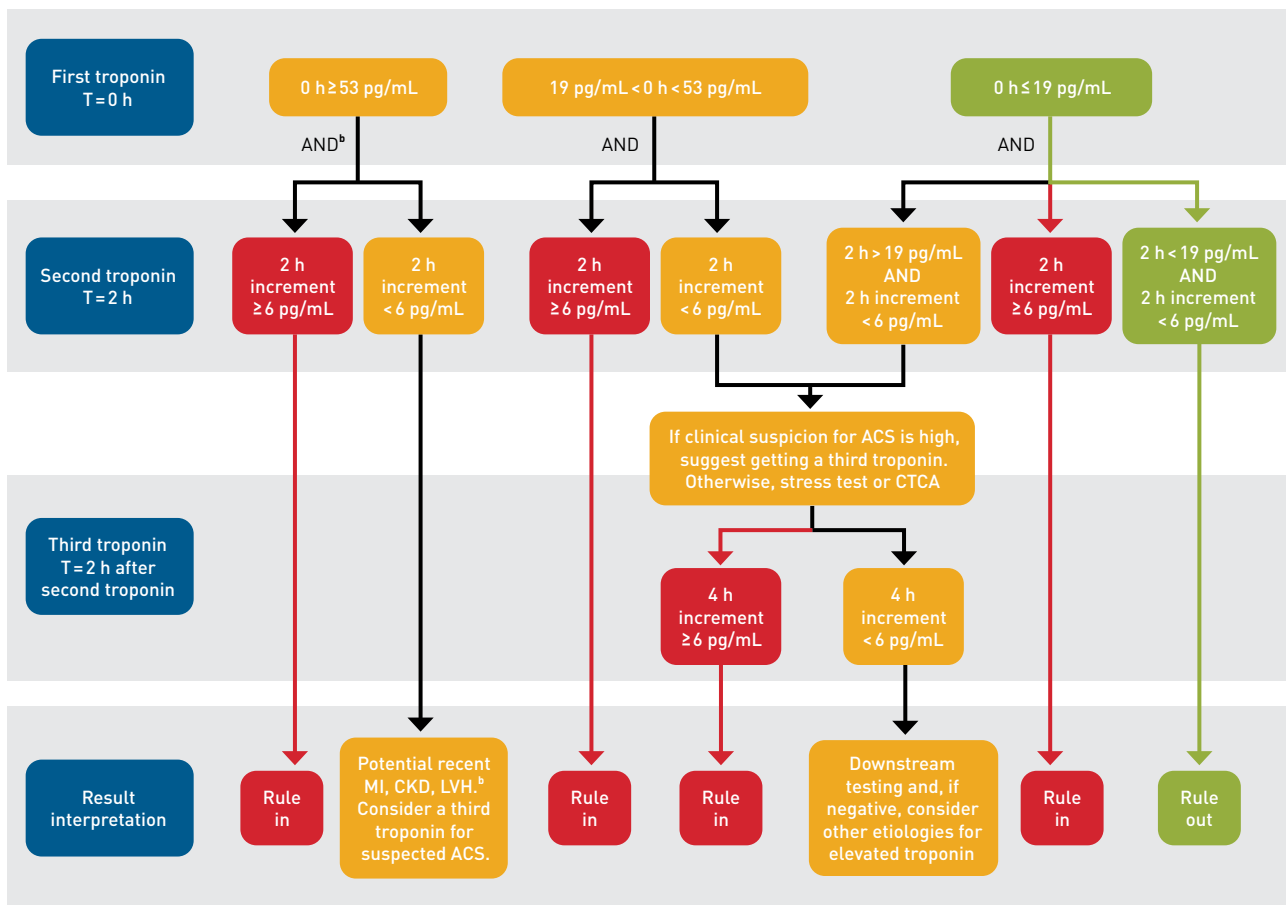
This study demonstrated that switching from a conventional troponin assay to a high-sensitivity troponin assay resulted in changes to diagnosis patterns—specifically, increased rates of heart failure and atrial fibrillation and decreased rates of hypertensive heart disease with and without chronic kidney disease.

- ▶ Switching to a high-sensitivity troponin assay was also associated with increased utilization of electrocardiogram stress testing and echocardiographic stress testing.
- ▶ Changes observed in this study may have an impact on institutions and health care systems by affecting resource utilization, health care cost, and reimbursement models.
- ▶ Furthermore, programs and policies that are tied to specific diagnoses (eg, Hospital Readmissions Reduction Program) may be influenced by such changes seen with switching to a high-sensitivity troponin assay; therefore, further studies are warranted to evaluate the long-term impact of such changes.

after implementation of hsTnT testing (Figure 1). Patients who received conventional troponin I (January 2016–December 2017) or hsTnT (March 2018–February 2019) testing were included for analysis. Data were excluded during our washout period (January 2018–February 2018) to allow providers time to become familiar with the new troponin assay.

Diagnoses were identified using the primary *International Classification of Diseases, Tenth Revision (ICD-10)* coded field in the hospital's electronic health record system. Stress testing (including electrocardiogram stress testing

FIGURE 1. High-Sensitivity Troponin Assay Protocol for Evaluation of Acute Chest Pain^a



ACS, acute coronary syndrome; CAD, coronary artery disease; CKD, chronic kidney disease; CTCA, computed tomography coronary angiography; GFR, glomerular filtration rate; h, hours; LVH, left ventricular hypertrophy; MI, myocardial infarction; T, time.

^aRule in means ruled in for myocardial injury. Clinical content must be taken into consideration to determine if this constitutes MI. If you have a strong suspicion for ACS, then do not delay proper treatment until the high-sensitivity troponin results come back from the lab. Biotin notice: If a patient has taken greater than or equal to 10 mg of biotin in the last 6 hours at time of blood draw, the troponin values may present falsely lower.

^bPatients should be considered for the possibility of known CKD (GFR < 30), congestive heart failure with LVH, or known CAD with LVH. A repeat troponin for these conditions should be demonstrated by a stable follow-up troponin level with a delta of less than 6; however, in some instances this could still be suggestive of a recent MI depending on level of suspicion. If suspicion is high, consider downstream stress or CTCA testing to further assess patient condition, else consider other etiology.

and echocardiographic stress testing) was identified by the ordered procedure name using the electronic health record, and it included any testing performed in the ED or inpatient setting.

To identify changes following implementation of hsTnT, we used log-binomial regression models with an interrupted time series (ITS) design to model the proportion of patients with each final discharge diagnosis in the pre- and post-hsTnT periods. Interaction terms were used to stratify the intercept, level-change, and pre- and post-hsTnT trends by chief complaint in order to assess for differences based on patient presentation. The saturated model under this ITS design allows for distinct intercepts and time trends for each time period and chief complaint as independent variables. We refer to this saturated model as a varying trends model, but we also considered less complex submodels using Akaike's information criterion (AIC) for model selection.¹⁶ Specifically, we considered submodels with only a single constant trend or no trends at all. The constant trend model allows for only a single time trend (per chief complaint) that does not vary between pre- and postintervention periods, whereas the no-trend model omits trends altogether and reduces to a standard adjusted pre-post comparison.

Observed postimplementation percentages were compared with expected percentages extrapolated from prior trends (when present) using average marginal effects (AMEs).¹⁷ The AME represents the patient-level difference between the probability of a given diagnosis predicted by the ITS model less the probability expected under prior trends, averaged over all patients in the post-hsTnT period. The value is converted to percentage scale for easy interpretation. For diagnoses for which models with trends were selected, we further summarized these models by comparing observed postimplementation percentages with the final pre-hsTnT level, referring to this quantity as an "average marginal effect with constant counterfactual," or AME-c. Models also controlled for patient gender, day of the week (grouped empirically as Saturday/Sunday, Monday/Friday, and Tuesday/Wednesday/Thursday) on which an ED visit occurred, and seasonality using a circular smoothing spline basis expansion for day in year. We omitted seasonality, day of the week, and/or interactions between chief complaint and the level-change when justified by AIC. We focused our 12-month postintervention analysis on changes in acute myocardial infarction (AMI)-related diagnosis based on an interim analysis to reduce multiple statistical comparison testing to 16 diagnosis groups.

Stress test utilization was compared using logistic regression with segmented time trends to compare observed rates with expected rates in the post-hsTnT periods, summarized using AME. The stress test model controlled for chief complaint, gender, and age, and it included interactions between chief complaint and all terms except gender.

A nominal *P* value of < .05 was considered statistically significant when describing results. To control the family-wise error rate at 0.05 across all 48 primary comparisons using the Bonferroni method, the reader can consider *P* values of $0.05 / 48 = .001$ significant. There are 48 ($= 16 \times 3$) primary comparisons because we examined changes in 16 diagnosis groups and made 3 comparisons within each

TABLE 1. Patient Characteristics^a

	Pre-hsTnT	Post hsTnT	<i>P</i>
Total, n	14,631	7237	–
Chest pain, n (%)	9023 (61.7%)	4455 (61.6%)	.88
Shortness of breath, n (%)	5608 (38.3%)	2782 (38.4%)	
Age, median (IQR)	59 (47-70)	59 (46-70)	.017
BMI, median (IQR)	29 (25-34)	29 (25-34)	.38
Female, n (%)	7310 (50.0%)	3676 (50.8%)	.25
Hypertension, n (%)	5871 (40.1%)	3089 (42.7%)	<.001
Diabetes, n (%)	2840 (19.4%)	1509 (20.9%)	.013
History of smoking, n (%)	8019 (54.8%)	3793 (52.4%)	<.001

BMI, body mass index; hsTnT, high-sensitivity troponin T; IQR, interquartile range.

^a*P* values for categorical variables are from χ^2 tests; *P* values for continuous variables are calculated using *t* tests.

group—overall and separately for each of 2 chief complaints. Statistical analysis was done in R version 3.6.1 (R Foundation for Statistical Computing) using the *mgcv* package¹⁸ for regression modeling. This analysis was performed as part of a quality improvement project designated as "not regulated" by the University of Michigan Medical School Institutional Review Board (HUM00145002).

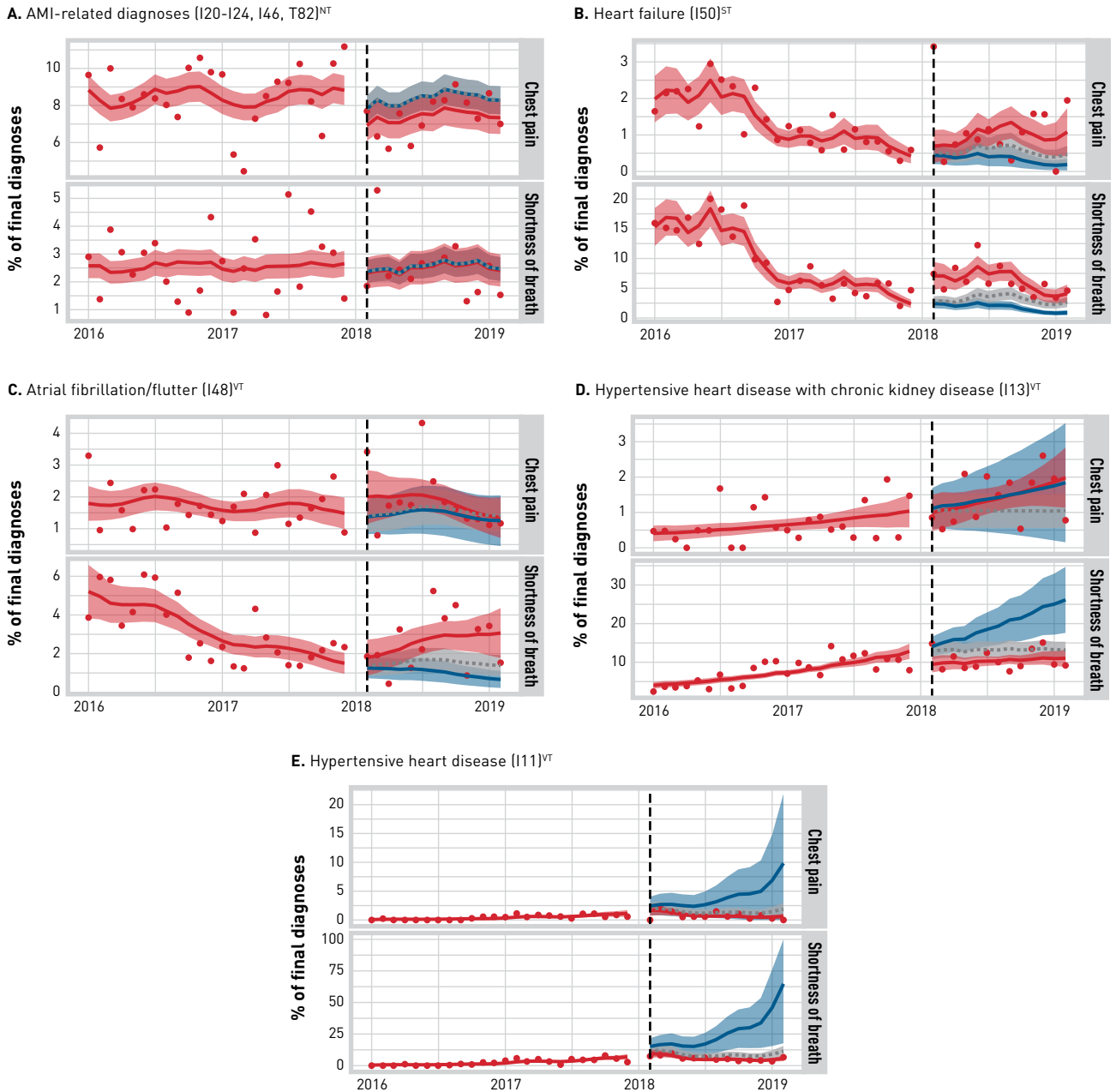
RESULTS

A total of 14,631 and 7237 patients were included in the pre- and postimplementation periods, respectively. Of these, 9023 (61.7%) patients in the pre-hsTnT period and 4455 (61.6%) patients in the post-hsTnT period presented with a chief complaint of chest pain. An additional 5608 (38.3%) patients in the pre-hsTnT period and 2782 (38.4%) patients in the post-hsTnT period presented with a chief complaint of shortness of breath. Each cohort had a median age of 59 years and a median body mass index of 29 kg/m². Other patient characteristics were similar between groups, although there were small increases in frequency of hypertension (42.7% vs 40.1%; *P* < .001) and diabetes (20.9% vs 19.4%; *P* = .013) and a small decrease in smoking history (52.4% vs 54.8%; *P* < .001) when comparing the post-hsTnT cohort with the pre-hsTnT cohort (Table 1).

Following implementation of hsTnT testing, patients who presented with concern for ACS and received troponin testing had similar likelihood of AMI-related diagnoses compared with extrapolated trends from the preimplementation period (AME, -0.6%; 95% CI, -1.3% to 0.04%; *P* = .065) (Figure 2). Rates of AMI-related diagnoses pre- and post hsTnT were comparable if the presenting chief complaint was shortness of breath (-0.1%; 95% CI, -0.8% to 0.7%; *P* = .88). However, AMI-related diagnoses decreased post hsTnT if the presenting chief complaint was chest pain (-1.0%; 95% CI, -1.9% to 0.0%; *P* = .049).

Patients who received hsTnT testing were more likely to receive a final diagnosis of heart failure (2.1%; 95% CI, 1.7%-2.6%; *P* < .001) when compared with expected trends from preceding months. Likelihood of heart failure diagnosis was increased by 0.7% (95% CI, 0.3%-1.0%; *P* < .001) if chief complaint was chest pain and increased by 4.5%

FIGURE 2. Effect on Diagnosis Rates After hsTnT Implementation by Chief Complaint*



AMI, acute myocardial infarction; hsTnT, high-sensitivity troponin T; NT, no trend; ST, single trend; VT, varied trend.

*Points represent the observed monthly percentage of each final diagnosis. Lines represent predicted monthly averages from the interrupted time series models. Red lines represent observed trends, blue lines represent the counterfactuals from extrapolated pre-hsTnT trends, and gray lines represent the constant counterfactuals based on the final pre-hsTnT levels. Shaded areas represent the 95% CIs. Washout period was from January 2018 to February 2018.

(95% CI, 3.4%-5.5%; $P < .001$) if chief complaint was shortness of breath. After hsTnT implementation, patients were also more likely to receive a final diagnosis of atrial fibrillation/flutter (0.9%; 95% CI, 0.3%-1.6%; $P < .001$). When stratified by presenting complaint, patients were more likely to receive a diagnosis of atrial fibrillation/flutter

if the initial chief complaint was shortness of breath (1.6%; 95% CI, 0.9%-2.4%; $P < .001$). However, the increase observed with chest pain (0.4%; 95% CI, -0.4% to 1.2%; $P = .36$) was not statistically significant.

Post hsTnT, patients had a lower-than-expected likelihood of receiving a diagnosis of hypertensive heart disease (-10.2%; 95% CI,

TABLE 2. Effect on Diagnosis Rates Combined and by Condition*

Diagnosis	Chief complaint	Change in % diagnoses, AME [95% CI]	Change in % diagnoses, AME-c [95% CI]	Adjusted risk ratio [95% CI]
Cardiac diagnoses				
AMI (I20-I24, I46, T82) ^{NT,w,y}	Combined	-0.61 [-1.26 to 0.04]	-	0.92 [0.81-1.05]
	Chest pain	-0.96 [-1.91 to -0.00]*	-	0.89 [0.78-1.00]
	Shortness of breath	-0.05 [-0.77 to 0.66]	-	0.98 [0.74-1.30]
Heart failure (I50) ^{ST,w,y}	Combined	2.12 [1.66-2.59]***	1.46 [0.96-1.96]***	-
	Chest pain	0.65 [0.29-1.01]***	0.44 [0.05-0.82]*	-
	Shortness of breath	4.49 [3.43-5.54]***	3.10 [1.95-4.25]***	-
Atrial fibrillation and flutter (I48) ^{VT,y}	Combined	0.86 [0.28-1.55]***	0.60 [0.09-1.10]*	-
	Chest pain	0.38 [-0.43 to 1.18]	0.27 [-0.37 to 0.92]	-
	Shortness of breath	1.64 [0.85-2.43]***	1.12 [0.31-1.93]**	-
Chronic ischemic heart disease (I25) ^{NT,y}	Combined	-0.07 [-0.50 to 0.37]	-	1.01 [0.78-1.30]
	Chest pain	-0.13 [-0.81 to 0.54]	-	0.96 [0.80-1.16]
	Shortness of breath	0.04 [-0.30 to 0.38]	-	1.07 [0.59-1.97]
Hypertensive heart and CKD (I13) ^{VT,w}	Combined	-3.7 [-5.9 to -1.5]***	-0.84 [-1.83 to 0.15]	-
	Chest pain	-0.02 [-1.14 to 1.10]	0.39 [-0.20 to 0.99]	-
	Shortness of breath	-9.7 [-15.1 to -4.3]***	-2.8 [-5.2 to -0.4]**	-
Hypertensive heart disease (I11) ^{VT,y}	Combined	-10.2 [-16.4 to -3.9]**	-1.63 [-2.80 to -0.45]**	-
	Chest pain	-3.2 [-7.1 to 0.7]	-0.62 [-1.42 to 0.19]	-
	Shortness of breath	-21.4 [-35.9 to -6.9]**	-3.3 [-5.9 to -0.6]*	-

(continued)

-16.4% to -3.9%; $P = .001$). Patients presenting with shortness of breath had a 21.4% lower likelihood (95% CI, -35.9% to -6.9%; $P = .004$) of this diagnosis, but the decreased risk was not statistically significant for patients who presented with chest pain (-3.2%; 95% CI, -7.1% to 0.7%; $P = .10$). When observed trends were compared with the final diagnosis rate prior to hsTnT implementation, patients still had an overall lower likelihood of receiving a diagnosis of hypertensive heart disease (-1.6%; 95% CI, -2.8% to -0.5%; $P = .007$), which also held true for patients presenting with a chief complaint of shortness of breath (-3.3%; 95% CI, -5.9% to -0.6%; $P = .017$). However, the decrease was still not statistically significant for patients presenting with chest pain.

Patients were also less likely to receive a diagnosis of hypertensive heart disease with chronic kidney disease (CKD; -3.7%; 95% CI, -5.9% to -1.5%; $P < .001$) after the implementation of hsTnT. The difference in this final diagnosis for patients whose chief complaint was shortness of breath was -9.7% (95% CI, -15.1% to -4.3%; $P < .001$). However, a significant difference was not seen in patients who presented with chest pain (-0.02%; 95% CI, -1.1% to 1.1%; $P = .975$). When comparing observed diagnosis rates with the final pre-hsTnT rate, the decreased likelihood in diagnosis was no longer statistically significant ($P = .096$), except when patients presented with chief complaint of shortness of breath (-2.8%; 95% CI, -5.2% to -0.5%; $P = .021$).

Finally, 2 other ICD-10 diagnoses were noted to have statistically significant changes after the implementation of hsTnT. "Abnormalities in heartbeat" was noted to have increased (0.7%; 95%

CI, 0.3%-1.1%; $P = .001$), with postimplementation change largely driven by patients who presented with chest pain (0.94%; 95% CI, 0.4%-1.5%; $P < .001$) as opposed to shortness of breath (0.2%; 95% CI, -0.3% to 0.7%; $P = .47$). "Other" diagnoses, which represents the aggregate of diagnoses with fewer than 200 occurrences during our study period, exhibited decreased frequency post hsTnT (-1.9%; 95% CI, -3.1% to -0.7%; $P = .002$), which was largely due to decreased diagnosis in patients presenting with shortness of breath (-3.9%; 95% CI, -5.9% to -1.8%; $P < .001$). No other diagnoses within our analysis had statistically significant changes when compared with expected postimplementation trends (Table 2).

Post hsTnT, patients who presented with concern for ACS were more likely to have a diagnostic stress test performed (2.3%; 95% CI, 1.5%-3.1%; $P < .001$). When stratified by chief complaint, stress testing increased by 3.4% (95% CI, 2.2%-4.7%) if patients presented with chest pain, as opposed to no significant change (0.6%; 95% CI, -0.1% to 1.3%) if patients presented with shortness of breath (Figure 3).

DISCUSSION

We describe the impact of switching to a high-sensitivity troponin assay on discharge diagnosis patterns and on frequency of diagnostic stress testing. In patients presenting with concern for ACS, rates of AMI-related diagnoses did not experience a statistically significant change after implementation of hsTnT. However, there was an increased risk of receiving a diagnosis of heart failure or atrial

TABLE 2. (Continued) Effect on Diagnosis Rates Combined and by Condition^a

Diagnosis	Chief complaint	Change in % diagnoses, AME (95% CI)	Change in % diagnoses, AME-c (95% CI)	Adjusted risk ratio (95% CI)
Pulmonary diagnoses				
Respiratory failure, not elsewhere classified (J96) ^{YL}	Combined	0.41 [-0.06 to 0.89]	-	1.19 (0.90-1.57)
	Chest pain	0.14 [-0.26 to 0.53]	-	1.16 (0.75-1.79)
	Shortness of breath	1.12 [-0.07 to 2.32]	-	1.23 (0.99-1.52)
Chronic obstructive pulmonary disease (J44) ^{VT,y}	Combined	0.17 [-0.61 to 0.95]	-0.01 [-0.62 to 0.60]	-
	Chest pain	0.04 [-0.26 to 0.34]	-0.03 [-0.31 to 0.25]	-
	Shortness of breath	0.37 [-1.59 to 2.33]	0.03 [-1.49 to 1.54]	-
Pneumonia, unspecified organism (J18) ^{NT,w,y}	Combined	-0.10 [-0.44 to 0.23]	-	0.96 (0.73-1.27)
	Chest pain	-0.00 [-0.31 to 0.30]	-	0.99 (0.65-1.52)
	Shortness of breath	-0.26 [-1.00 to 0.47]	-	0.91 (0.69-1.19)
Signs and symptoms				
Abnormalities of heartbeat (R00) ^{NT}	Combined	0.65 (0.25-1.05)**	-	1.36 (1.11-1.67)**
	Chest pain	0.94 (0.38-1.50)***	-	1.51 (1.20-1.89)***
	Shortness of breath	0.19 [-0.33 to 0.71]	-	1.16 (0.78-1.71)
Abnormalities of breathing (R06) ^{NT,w,y}	Combined	0.37 [-0.23 to 0.97]	-	0.96 (0.76-1.22)
	Chest pain	-0.12 [-0.46 to 0.22]	-	0.88 (0.61-1.28)
	Shortness of breath	1.16 [-0.30 to 2.62]	-	1.11 (0.98-1.25)
Abdominal and pelvic pain (R10) ^{NT,y}	Combined	0.00 [-0.27 to 0.28]	-	0.84 (0.58-1.22)
	Chest pain	0.14 [-0.28 to 0.55]	-	1.11 (0.82-1.51)
	Shortness of breath	-0.21 [-0.47 to 0.05]	-	0.54 (0.24-1.25)
Pain in throat and chest (R07) ^{NT,w,y}	Combined	-0.19 [-1.36 to 0.99]	-	1.01 (0.94-1.08)
	Chest pain	-0.40 [-2.17 to 1.37]	-	0.99 (0.96-1.03)
	Shortness of breath	0.16 [-0.97 to 1.29]	-	1.03 (0.86-1.22)
Abnormal results of function studies (R94) ^{ST,y}	Combined	-0.30 [-0.96 to 0.36]	-	0.69 (0.46-1.06)
	Chest pain	-0.32 [-1.17 to 0.53]	-	0.76 (0.47-1.22)
	Shortness of breath	-0.27 [-1.23 to 0.70]	-	0.60 (0.29-1.27)
Other diagnoses				
Other sepsis (A41) ^{NT,w}	Combined	-0.10 [-0.46 to 0.25]	-	1.27 (0.89-1.79)
	Chest pain	0.20 [-0.04 to 0.44]	-	1.62 (0.94-2.80)
	Shortness of breath	-0.58 [-1.42 to 0.26]	-	0.85 (0.67-1.08)
Other ^{NT}	Combined	-1.9 [-3.1 to -0.7]**	-	0.93 (0.88-0.98)*
	Chest pain	-0.68 [-2.09 to 0.73]	-	0.96 (0.90-1.04)
	Shortness of breath	-3.9 [-5.9 to -1.8]***	-	0.88 (0.82-0.95)***

AME, average marginal effect; AME-c, AME with constant counterfactual; AMI, acute myocardial infarction; CKD, chronic kidney disease; hsTnT, high-sensitivity troponin T; NT, no trend; ST, single trend; VT, varied trend; w, adjusted for day of week; y, adjusted for day in year; YL, yearly level change.

P* < .05; *P* < .01; ****P* < .001.

^aFor each set of diagnoses, we present the change in % diagnoses as quantified by the AME. For diagnosis groups with significant trends, we also include AME-c, which compares the % use of each diagnosis group with the final pre-hsTnT level rather than the extrapolated pre-hsTnT trend as in the standard AME. For models without significant trends these values are the same (with AME-c omitted). In the NT case, we also present adjusted risk ratios.

fibrillation/flutter and a decreased risk of receiving a diagnosis of hypertensive heart disease with or without CKD. Patients were also found to have an increased likelihood of receiving stress testing during their index encounter, which held true if they presented with chief complaint of chest pain but not if they presented with chief complaint of shortness of breath.

Although no statistically significant change in AMI-related diagnoses occurred for our combined cohort, a statistically significant

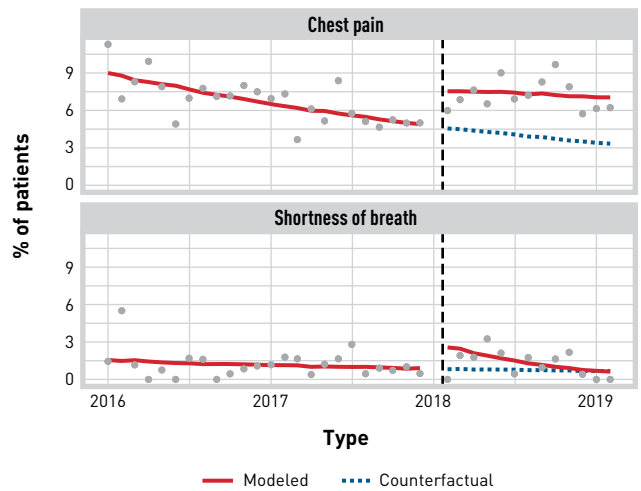
decrease was observed in patients presenting with chest pain (95% CI, -1.9 to 0.0; *P* = .049). Although the combined cohort of AMI-related diagnoses did not reach statistical significance, it is important to note that rates of AMI-related diagnoses did not increase as would have been anticipated with a more sensitive test. This is contrary to international literature noting an increase in AMI-related diagnoses, such as type 2 NSTEMI, after implementing high-sensitivity troponin testing.^{14,19} It is important to note that

these studies utilized a different high-sensitivity troponin assay¹⁴ and had a lower 99th percentile upper reference limit,¹⁹ which may have contributed to their findings. Additionally, the Fourth Universal Definition of Myocardial Infarction was released in August 2018 to accommodate the use of higher-sensitivity troponin testing.²⁰ It introduced the definition of myocardial injury as “detection of an elevated cardiac troponin value above the 99th percentile upper reference limit.” This new emphasis on delineating myocardial infarction from myocardial injury may have mitigated any potential uptick in type 2 NSTEMI diagnoses and any changes in overall rates of AMI-related diagnoses.

Furthermore, implementation of hsTnT was associated with increased likelihood of receiving a diagnosis of heart failure or atrial fibrillation/flutter and a decreased likelihood of receiving a diagnosis of hypertensive heart disease with or without CKD. Changes in frequency of these diagnoses were likely also related to increased sensitivity of the test and recent emphasis on distinguishing myocardial ischemia/infarction from myocardial injury. As no *ICD-10* code specifically identifies myocardial injury, discharge diagnoses are more likely to reflect the underlying causes of the myocardial injury, which include diagnoses such as heart failure, hypertension, or arrhythmias, among others.²¹⁻²⁴ However, we notably saw a decrease in diagnosis of hypertensive heart disease with or without CKD, with changes largely seen in patients presenting with a chief complaint of shortness of breath. It is unclear what led to the decrease in these diagnoses, as it was anticipated that they would increase due to the reasons previously listed. Although it would stand to reason that the decreased diagnosis of hypertensive heart disease with or without CKD may have been counterbalanced by increases in pulmonary-related diagnoses, we did not observe any statistically significant increases within our analysis. In spite of these observed changes, we anticipate that clinical management of patients who receive hsTnT testing for evaluation of ACS will not drastically differ compared with the pre-hsTnT cohort, as management should largely remain focused on addressing underlying comorbidities.

Understanding the systematic impact of hsTnT testing in the United States is vitally important, especially as more health systems begin using it to facilitate ACS rule-out. Postimplementation changes can have significant influence on not only patient care but also hospital reimbursements, particularly as they relate to the Hospital Readmissions Reduction Program.²⁵ CMS has included 4 medical conditions (AMI, chronic obstructive pulmonary disease [COPD], heart failure, and pneumonia) for which 30-day unplanned readmissions are tracked and factored into the reimbursements that acute care hospitals receive. Hospitals that experience increased or decreased diagnosis of these conditions could also see changes in the associated 30-day readmission rates due to changes in the number of at-risk patients. Variations in readmission rates would subsequently affect future reimbursements because they are based upon hospital readmission performance from the preceding 3 years. Additionally, changes in readmission rates could also affect

FIGURE 3. Effect on Stress Testing Rates After hsTnT Implementation, by Chief Complaint*



hsTnT, high-sensitivity troponin T.

*Points represent the observed monthly percentage of patients receiving a stress test. Red lines illustrate predicted trends modeled by the interrupted time series and blue lines represent averages extrapolated from pre-hsTnT trends. Washout period was from January 2018 to February 2018.

reimbursements relating to bundled payments by increasing the expenditure associated with an admission episode. In our analysis, only heart failure diagnoses increased after hsTnT implementation, whereas AMI, COPD, and pneumonia diagnoses did not demonstrate statistically significant changes. Hospitals experiencing increased diagnoses of these conditions selected by CMS should therefore devote additional focus to discharge coordination and follow-up to help mitigate potential risk of increased readmissions. Additionally, as diagnosis patterns change, CMS may need to reevaluate policies and reimbursement models that more accurately reflect and appropriately affect the changing patient population.

In addition to the changes in diagnosis patterns outlined earlier, our analysis also revealed significant changes to diagnostic stress testing rates post hsTnT. We found that patients who presented with concern for ACS and received hsTnT testing had increased likelihood of having inpatient diagnostic stress testing performed. This is consistent with findings of previous international studies, which demonstrated an increase in downstream evaluation techniques such as echocardiography, stress testing, and invasive angiography.¹⁰⁻¹³ However, this increase in stress testing may signify general provider uncertainty with interpreting hsTnT and could represent a transient rise, with subsequent stabilization of stress test ordering, as providers become more familiar with interpreting hsTnT results.

Limitations

Our study has several potential limitations. Although this study was performed at a quaternary care center with a high-volume ED,

it represents the diagnosis and practice patterns at only a single institution. Additionally, our study time frame was limited to the 12 months after implementation of hsTnT, which provides insights into only the immediate postimplementation period without perspective into the long-term implications. Furthermore, because our analysis relied on existing registries and algorithms to collect baseline variables, we are unable to extend our adjusted analyses beyond what we have reported. It is important to note that only ED and inpatient stress test utilization was able to be reliably captured. Therefore, we are unable to comment on the impact of hsTnT implementation on outpatient follow-up test utilization. Finally, although ITS can help evaluate the relationship between specific events and changes in trends, it should not be interpreted as rigorously establishing causal relationships. Despite these limitations, we believe that our study provides valuable insights into how hsTnT testing affects diagnosis patterns and stress test utilization within a large US hospital, particularly in an era in which increased focus is placed on distinguishing myocardial injury from myocardial infarction. Improved understanding of these changes will help hospitals and health systems adapt to shifts in resource utilization and can have significant impact on how future policies and payment structures are designed in relation to the diagnoses assessed.

CONCLUSIONS

Patients who presented with concern for ACS and received hsTnT evaluation had similar likelihood of AMI-related diagnoses compared with prior trends. Post-hsTnT patients were more likely to receive a discharge diagnosis of heart failure or atrial fibrillation and less likely to receive a diagnosis of hypertensive heart disease with or without CKD. Implementation of hsTnT testing was associated with increased downstream utilization of stress testing in both the ED and inpatient settings. As US hospitals consider switching to highly sensitive troponin testing, postimplementation changes may affect long-term health care utilization, cost, and reimbursement. ■

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critical revision of the manuscript for important intellectual content (RYY, HH, JH, KG, ERD, AG, DG, JF, DS, SAF, GDB); statistical analysis (RYY, JH); provision of patients or study materials (RYY, JF); administrative, technical, or logistic support (RYY, KG, MJ, ERD, JF); and supervision (SAF, GDB).

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