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Prognostic Value of Baseline and Changes in Circulating Soluble ST2 Levels and the Effects of Nesiritide in Acute Decompensated Heart Failure

W.H. Wilson Tang
Heart and Vascular Institute

Yuping Wu
Cleveland State University, y.wu88@csuohio.edu

Justin L. Grodin
Heart and Vascular Institute

Amy P. Hsu
Heart and Vascular Institute

Adrian F. Hernandez
Duke Clinical Research Institute

See next page for additional authors

Authors
W.H. Wilson Tang, Yuping Wu, Justin L. Grodin, Amy P. Hsu, Adrian F. Hernandez, Javed Butler, Marco Metra, Adriaan A. Voors, Michael G. Felker, Richard W. Troughton, Roger M. Mills, John J. McMurray, Paul W. Armstrong, Christopher M. O'Connor, and Randall C. Starling

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ABBREVIATIONS AND ACRONYMS

CI = confidence interval

HF = heart failure

HR = hazard ratio

IQR = interquartile range

NT-proBNP = aminoterminal pro-B-type natriuretic peptide

OR = odds ratio

sST2 = soluble growth stimulation expressed gene 2

Growth stimulation expressed gene 2 (ST2) is a transmembrane protein and a member of the Toll-interleukin 1 receptor superfamily (1,2). ST2 binds interleukin-33 in response to cardiac disease or injury and elicits a cardioprotective effect by mitigating the maladaptive responses of the myocardium to overload states (3,4). A truncated soluble form of ST2 (soluble ST2 [sST2]) competes with the membrane-bound form in this interleukin-33 binding. Elevated levels of sST2 signal the presence and severity of adverse cardiac remodeling and tissue fibrosis, which may occur in response to an acute coronary syndrome event or worsening heart failure (HF) (3,5). Higher levels of sST2 are associated with more severe clinical symptoms and with other objective measures of HF severity, such as higher C-reactive protein, higher natriuretic peptide levels, lower left ventricular ejection fraction, and higher diastolic filling pressures (6–12). Elevated circulating sST2 levels have been associated with an increased risk for mortality and sudden cardiac death in outpatients with HF (9,13–15), as well as in acute HF (16). However, most studies have only measured sST2 at a single timepoint (predominantly at baseline) and only described the relationship with long-term all-cause mortality.

In this post-hoc study utilizing blood specimens collected serially in the ASCEND-HF (Acute Study of Clinical Effectiveness of Nesiritide in Decompensated Heart Failure) trial, we examined the relationship between baseline and serial levels of sST2 and dyspnea status, hospitalization (at 30 days), and death (at 180 days). We also examined the effect of nesiritide therapy on sST2 levels, hypothesizing that the vasodilatory effects of nesiritide may relieve volume overload more effectively than a placebo, thereby potentially achieving greater reduction in sST2 levels.

METHODS

STUDY POPULATION. Details of the ASCEND-HF Trial (NCT00475852) have been described elsewhere (17). Briefly, this was a multinational, multicenter, prospective randomized controlled trial of 7,141 subjects presenting with signs and symptoms of acute decompensated HF comparing nesiritide (a recombinant B-type natriuretic peptide with vasodilatory properties) to placebo added to standard care. In our study cohort, 858 subjects (12% of the total population) consented to participate in the biomarker substudy. A large majority of subjects in the biomarker substudy were recruited from North American sites (n 824). Compared to the rest of the North American study cohort (n 2,419), there were no differences in race (p 0.422), heart rate (p 0.157), atrial fibrillation (p 0.124), blood urea nitrogen (p 0.384), creatinine (p 0.499), time to randomization (p 0.051), or beta-blockers (p 0.073). Nevertheless, age (66.6 ± 14.9 vs. 64.5 ± 15.4 years, p 0.001) and left ventricular ejection fraction (31.6 ± 15 vs. 30.4 ± 15, p 0.035) were significantly different.

STUDY DESIGN. The intent of the biomarker substudy was to collect venous blood samples at randomization ("baseline"), 48 to 72 h following randomization, and at the 30-day follow-up visit. Blood samples were collected in ethylenediaminetetraacetic acid-plasma, immediately centrifuged at the study sites, and stored at -80°C for subsequent analysis at a central core laboratory. Aminoterminal pro-B-type natriuretic peptide (NT-proBNP) levels were determined by the VITROS NT-proBNP Assay (Ortho-Clinical Diagnostics, Raritan, New Jersey).

SOLUBLE ST2 ASSAY. Plasma sST2 levels were measured by the Presage ST2 Assay (Critical Diagnostics, San Diego, California) at a College of American Pathologists/Clinical Laboratory Improvements Amendments-approved core laboratory independent of the sponsors. This is a quantitative sandwich enzyme-linked immunosorbent assay using a mouse monoclonal antihuman sST2 capture antibody on microtiter plate wells and a second biotinylated mouse monoclonal antihuman sST2 tracer antibody with a measuring range of 3.1 to 200 ng/ml and a coefficient of variation <5%; the limit of detection is at 1.8 ng/ml, and the limit of quantification at 2.4 ng/ml.

CLINICAL ENDPOINTS. The following adjudicated endpoints were analyzed: 30-day death, 180-day death, 30-day HF hospitalization or death, and the composite of persistent or worsening HF or death from any cause. We also used the ASCEND-HF trial's coprimary dyspnea endpoint (moderately or markedly improved relative to the time of randomization measured by a 7-point Likert-type scale at 6 or 24 h) to assess the association between sST2 levels and symptom relief.

STATISTICAL ANALYSES. Clinical characteristics are presented as a percentage (%) for categorical variables, mean ± SD for normally distributed continuous variables, and median (interquartile range [IQR]) for non-normally distributed continuous variables. The Cochran-Armitage test was used to test for trend in baseline characteristics across increasing tertiles of sST2 at baseline. Survival curves are estimated for each group, considered separately, using the Kaplan-Meier method and compared statistically using the log-rank test. The association between sST2 and outcomes was performed using both univariate and multivariate logistic regression analysis (for 30-day outcomes) or Cox proportional hazards analysis (for 180-day mortality). Logistic regression was used in the analyses of dyspnea improvement. sST2 and NT-proBNP were both log transformed, and odds ratios (ORs) and hazard ratios (HRs) were analyzed using increments of sST2/NT-proBNP per log increase in sST2. For the multivariate analysis, we adjusted the covariates identified from the overall ASCEND-HF study population to be prognostically relevant (the ASCEND-HF risk model) (Online Table 1). We used the robust covariance matrix estimates to adjust the variance-covariance matrix of both logistic regression and Cox models to correct for correlated responses from cluster (multicenter) samples (18). To assess if the addition of sST2 to the ASCEND-HF risk model with NT-proBNP improves outcome prediction, we used the category-free net reclassification index by the Pencina method (19,20). Levels of sST2 at all time points and changes in sST2 from baseline were compared between subjects receiving nesiritide and placebo using the Wilcoxon rank sum test or Student *t* test. All statistical analyses were performed using Stata 13.1 software (StataCorp LP, College Station, Texas) and R 3.1.0 (Vienna, Austria). A 2-sided p value of <0.05 was considered statistically significant.

RESULTS

PATIENT CHARACTERISTICS. Baseline characteristics of the study population are illustrated in Table 1. The median time between presenting to the hospital and randomization (baseline) was 16 h. In our study cohort, median sST2 levels were 71.2 (IQR: 48.2 to 111.1) ng/ml at baseline, decreasing to 46.9 (IQR: 32.4 to 70.3) ng/ml at 48 to 72 h and 39.5 (IQR: 27.8 to 63.8) ng/ml at 30 days. In other words, 89% (763 of 858) of patients had sST2 levels above the diagnostic cutoff value of 35 ng/ml for chronic HF. Subjects with impaired or preserved left ventricular ejection fraction had similar levels of baseline sST2 (72.4 [IQR: 49.2 to 116.0] ng/ml vs. 68.9 [IQR: 45.1 to 108.3] ng/ml; p 0.178, respectively).

BASELINE sST2 LEVELS AND PROGNOSIS. There were 24 (2.8%) deaths and 77 (9.2%) HF rehospitalizations by 30 days, and 97 (11.4%) deaths by 180 days. Higher baseline sST2 level was associated with a higher risk of death at 30 days (OR: 2.33; 95% confidence interval [CI]: 1.05 to 5.19; p 0.038) and at 180 days (HR: 2.21; 95% CI: 1.56 to 3.13; p < 0.001), as well as death/worsening HF before discharge (OR: 2.23; 95% CI: 1.28 to 3.90; p 0.005) (Table 2). Figure 1A shows that increasing quartiles of baseline sST2 was associated with greater 180-day mortality risk by Kaplan-Meier estimates. In contrast, symptomatic relief at 6 h and at 24 h was not associated with higher levels of baseline sST2 (p > 0.29, data not shown). After adjusting for other risk covariates in the ASCEND-HF risk model, only 180-day mortality risk was associated with higher levels of baseline sST2 (adjusted HR: 1.79; 95% CI: 1.22 to 2.62; p 0.003 (Table 2). However, further adjustment with the ASCEND-HF risk model plus baseline NT-proBNP levels demonstrated that the prognostic value of baseline sST2 was no longer significant (Table 2, as dichotomous variables in Online Table 2); this was true despite the fact that adding baseline sST2 to the ASCEND-HF risk model, plus baseline NT-proBNP, correctly reclassified 10.76% of subjects for the 180-day death endpoint (with 8.64% events correctly classified and 2.12% nonevents correctly classified) (Online Table 3A). Interestingly, interaction testing between baseline sST2 and baseline NT-proBNP was statistically significant only for the 30-day death/HF rehospitalization endpoint in both unadjusted (p 0.03) and adjusted (p 0.02) models (Online Table 4). Specifically, there was a positive association between baseline sST2 and outcomes for high (above median) baseline NT-proBNP, and a negative association between sST2 and outcomes for

TABLE 1 Baseline Characteristics

	Baseline sST2					
	Total (n 858)	Quartile 1 (n 215)	Quartile 2 (n 214)	Quartile 3 (n 214)	Quartile 4 (n 215)	p Value
Range, ng/ml		<48.2	48.2 71.2	71.2 111.1	≥111.1	
Age, yrs	65.5 ± 15.2	62.27 ± 15.48	64.6 ± 14.4	68.3 ± 14.82	66.9 ± 15.5	<0.001
Female, %	31.6	37.7	34.1	26.6	27.9	<0.001
White, %	67.8	60.5	67.8	69.6	73.5	<0.001
Systolic BP, mm Hg	127.3 ± 19.9	129.3 ± 21.4	129.9 ± 21.1	126.2 ± 18.8	123.8 ± 17.4	0.004
Heart rate, beats/min	80.2 ± 16.3	80.2 ± 14.3	79.5 ± 17.4	80.0 ± 17.0	81.1 ± 16.3	0.896
Atrial fibrillation, %	41.3	32.1	36.9	52.3	43.7	<0.001
Hypertension, %	78.3	83.3	81.3	75.2	73.5	<0.001
BUN, mg/dl	28.3 ± 16.8	24.0 ± 13.0	26.5 ± 15.9	30.7 ± 19.1	32.0 ± 17.5	<0.001
Creatinine, mg/dl	1.44 ± 0.6	1.34 ± 0.5	1.37 ± 0.5	1.49 ± 0.61	1.54 ± 0.6	<0.001
Sodium, mmol/l	138.6 ± 4.0	138.9 ± 3.5	139.3 ± 3.6	138.7 ± 3.8	137.6 ± 4.6	0.004
NT proBNP (n 752), pg/ml	5,545 (2,856 11,097)	2,917 (1,368 6,370)	4,616 (2,894 9,372)	6,134 (3,538 11,357)	9,388 (5,291 14,839)	<0.001
LVEF, %	26 (20 40)	30 (20 40)	26 (20 40)	25 (20 40)	25 (20 40)	0.280
Time from presentation to randomization, h	16.3 ± 9.4	17.26 ± 10.78	16.29 ± 8.74	14.45 ± 8.32	17.15 ± 9.27	0.387
Ischemic etiology, %	60.3	55.3	60.3	62.1	63.3	<0.001
Beta blockers, %	75.3	73.0	74.8	77.6	75.8	<0.001
ACEi or ARB, %	64.7	65.1	67.3	62.1	64.2	<0.001
MRA, %	23.8	23.3	24.8	22.4	24.7	<0.001

Values are mean ± SD or median (interquartile range), unless otherwise indicated. All p values were from test of trend (Jonckheere-Terpstra test for continuous and Cochran-Armitage test for categorical variables).

ACEi angiotensin-converting enzyme inhibitor; ARB angiotensin receptor blocker; BP blood pressure; BUN blood urea nitrogen; LVEF left ventricular ejection fraction; MRA mineralocorticoid receptor antagonist; NT-proBNP aminoterminal pro-B-type natriuretic peptide; sST2 soluble growth stimulation expressed gene 2.

low baseline NT-proBNP (Online Figure 1). In contrast, there was no interaction between baseline sST2 and NT-proBNP for the 180-day death endpoint (p 0.77) (Online Table 3). In particular, those with both elevated baseline sST2 and baseline NT-proBNP (stratified by their median values) portended the highest 180-day mortality risk (Online Figure 2). Cubic spline analyses also supported the linearity of

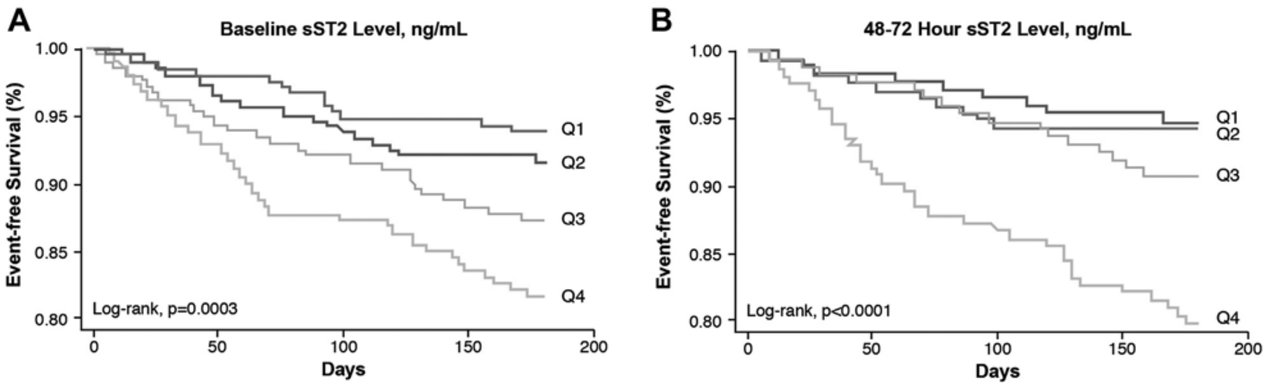
TABLE 2 Baseline sST2 Levels and Adverse Clinical Outcomes and Interactions With the ASCEND-HF Trial Risk Model and NT-proBNP

Model	30-Day Death	p Value	30-Day Death/HF Rehospitalization	p Value	180-Day Death	p Value
Baseline sST2						
Univariate model	2.30 (1.15 4.74)	0.019	1.67 (1.17 2.39)	0.005	2.21 (1.57 3.13)	<0.001
Adjusted model 1	1.95 (0.91 4.16)	0.085	1.37 (0.93 2.02)	0.117	1.91 (1.33 2.72)	<0.001
Adjusted model 2	1.52 (0.66 3.50)	0.324	1.07 (0.68 1.67)	0.775	1.35 (0.90 2.03)	0.145
Event rates	24/856 (2.8)		82/667 (12.3)		97/858 (11.3)	
48 72 h follow up sST2						
Univariate model	1.85 (0.81 4.20)	0.145	2.11 (1.42 3.13)	<0.001	2.64 (1.82 3.84)	<0.001
Adjusted model 1	1.47 (0.61 3.59)	0.387	1.52 (0.98 2.37)	0.063	2.12 (1.42 3.16)	<0.001
Adjusted model 2	1.07 (0.40 2.86)	0.889	1.32 (0.82 2.12)	0.255	1.77 (1.14 2.74)	0.011
Event rates	16/662 (2.4)		82/667 (12.3)		97/858 (11.3)	
30 day follow up sST2†						
Univariate model					2.29 (1.46 3.62)	<0.001
Adjusted model 1					2.29 (1.35 3.88)	0.002
Adjusted model 2					2.16 (1.22 3.80)	0.008
Event rates					41/589 (7.0)	

Values are odds ratio (95% confidence interval) or n/N (%). Both sST2 and NT-proBNP were both log transformed, increments per log increase; adjusted model 1 ASCEND-HF (Acute Study of Clinical Effectiveness of Nesiritide in Decompensated Heart Failure) trial risk model according to endpoints (Online Table 1); adjusted model 2 Model 1 plus NT-proBNP (with corresponding time point). †All deaths before 30 days were excluded from the 30-day follow-up analysis.

HF heart failure; other abbreviations as in Table 1.

FIGURE 1 Kaplan-Meier Analysis for 180-Day Survival



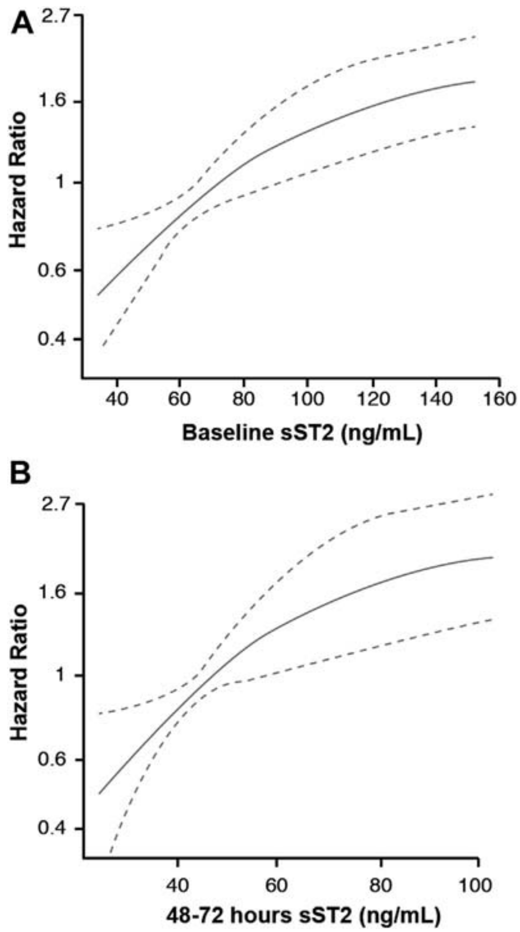
Kaplan Meier analysis for 180 day survival, stratified by quartiles of **(A)** baseline and **(B)** 48 to 72 h follow up plasma soluble growth stimulation expressed gene 2 (sST2) levels. Baseline sST2 tertile ranges: Quartile 1 (Q1) <48.2 ng/ml; Quartile 2 48.2 to 71.2 ng/ml; Quartile 3 71.3 to 111.2 ng/ml; Quartile 4 >111.2 ng/ml. 48 to 72 h sST2 tertile ranges: Quartile 1 <32.4 ng/ml; Quartile 2 32.4 to 46.8 ng/ml; Quartile 3 46.9 to 70.3 ng/ml; Quartile 4 >70.3 ng/ml.

the 180-day mortality risk for baseline sST2 levels (Figure 2A).

FOLLOW-UP sST2 LEVELS AND PROGNOSIS. At 48 to 72 h after enrollment, higher sST2 levels portend increased risk of all-cause death at both 30 and 180 days, as well as death/rehospitalization at 30 days (Table 2). Elevated follow-up sST2 was also associated with increased risk of death/worsening HF before discharge (OR: 2.41; 95% CI: 1.25 to 4.63; p 0.008). After adjustments for the ASCEND-HF risk model, the prognostic significance of follow-up sST2 levels was only relevant for 180-day death, and remained borderline significant with the addition of baseline NT-proBNP to the ASCEND-HF risk model (adjusted HR: 1.61; 95% CI: 1.00 to 2.60; p 0.051) (Table 2). Examining the Kaplan-Meier curves revealed that the divergence of 180-day mortality risk occurred between the third and fourth quartile of the 48- to 72-h follow-up sST2 level (71.2 ng/ml). Furthermore, adding 48- to 72-h follow-up sST2 to the ASCEND-HF risk model, plus follow-up NT-proBNP, correctly reclassified 15.6% of subjects for the 180-day death endpoint (with 13.85% events correctly classified and 1.75% nonevents correctly classified; Online Table 3B). Cubic spline analyses supported the linearity of the risk at follow-up (Figure 2B). In addition, 30-day follow-up sST2 levels also provide incremental prognostic value in either of the adjusted models (Table 2, Online Figure 3), with similar modest reclassification to the 48- to 72-h follow-up data (Online Table 3C).

CHANGES IN sST2 LEVELS AND PROGNOSIS. Among the 858 subjects in the biomarker substudy, 680 had samples for both baseline and 48 to 72 h time points. Compared to baseline, an overall 64.4% and 51.6% reduction in absolute levels of sST2 levels occurred at 48 to 72 h and at 30 days after randomization, respectively. The median absolute change in sST2 from baseline to 48 to 72 h was -22.80 (IQR: -44.70 to -6.44) ng/ml. At 48 to 72 h, there was no lowering of sST2 absolute levels from baseline in 14.4% of subjects; this was associated with poorer outcomes, including 30-day death/HF readmission (OR: 2.50; 95% CI: 1.45 to 4.32; p 0.001) and 180-day death (HR: 1.98; 95% CI: 1.15 to 3.42; p 0.013) when compared with subjects showing any decrease in sST2 (Figure 3). After adjustments for the ASCEND-HF risk model and baseline NT-proBNP, the prognostic value of the lack of sST2 lowering at 48 to 72 h from baseline was significant for the outcome of 30-day death/HF readmission (adjusted OR: 1.94; 95% CI: 1.01 to 3.72; p 0.046), but not for the 180-day death endpoint (adjusted HR: 1.27; 95% CI: 0.69 to 2.35; p 0.442). Because the combined biologic/analytic variability for sST2 has been previously reported as ~30% (21,22), we further defined a clinically relevant sST2 reduction as a >30% decrease in sST2 levels from baseline to 48 to 72 h (which occurred in 377 subjects, or 55%). Compared to those with a ≤30% sST2 reduction, subjects who demonstrated a >30% reduction in sST2 had lower event rates in all endpoints except for 30-day death (Online Figure 4).

FIGURE 2 **Cubic Spline Curve**



Cubic spline curve for **(A)** baseline; and **(B)** follow up (48 to 72 hr) sST2 levels associated with 180 day death. sST2 soluble growth stimulation expressed gene 2.

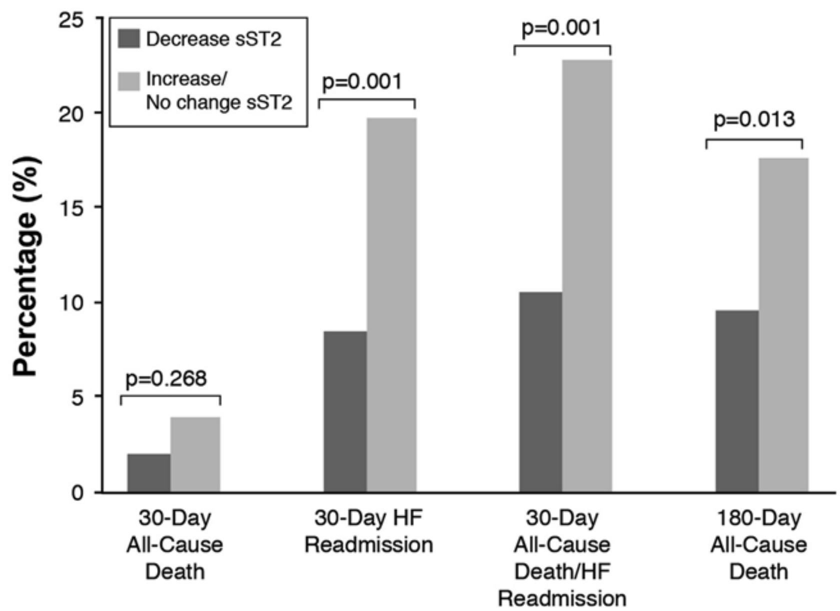
To further examine whether there is a threshold of follow-up sST2 level that conferred heightened risk, Online Table 5 outlines the baseline characteristics of subgroups according to changes from baseline to 48- to 72-h sST2 levels, stratified at a baseline median sST2 level of 71.2 ng/ml (Online Figure 5 presents the CONSORT diagram for subgroup distributions). In the cohort with elevated baseline sST2 levels (>71.2 ng/ml), we further observed a 3-fold increase in 180-day mortality risk between those with persistently high sST2 (>71.2 ng/ml) versus low (≤71.2 ng/ml) at 48- to 72-h follow-up (**Figure 4**, also Online Figure 6 for all subgroups); this finding remained statistically significant in multivariate analysis after adjusting for the ASCEND-HF risk model and baseline NT-proBNP (**Table 3**).

CHANGES IN sST2 LEVELS AND TREATMENT. Overall, 502 subjects (257 assigned to nesiritide, 245 assigned to placebo) had samples collected at all 3 time points. There were no significant differences in baseline characteristics between the nesiritide and placebo treatment groups, including similar mean NT-proBNP levels (8,910 ± 10,492 pg/ml vs. 8,968 ± 9,577 pg/ml; p 0.329). Both groups demonstrated a significant reduction in sST2 levels from baseline to 48- to 72-h follow-up, and further lowering of sST2 levels was observed at the 30-day visit in both groups (**Table 4**). The absolute changes in sST2 from baseline to 48 to 72 h was significantly greater in the placebo group than in the nesiritide group (respective median absolute changes -26.11 ng/ml vs. -18.05 mg/l; p 0.005), but the 2 groups did not differ by treatment regarding absolute changes in sST2 from baseline to 30 days (**Table 4**). Additionally, sST2 levels at 30-day follow-up and absolute changes in sST2 levels from baseline to 30 days were similar between the 2 treatment groups (**Table 4**).

DISCUSSION

There are 4 major findings from this study. First, we observed that baseline sST2 levels elevated in the acute HF setting were comparable with earlier reports (23–26), and were higher than those reported in the chronic setting (cutoff at 35 ng/ml) (9,15). Second, the prognostic findings for sST2 at baseline for 180-day outcomes were generally neutral after adjustments for the ASCEND-HF risk model and NT-proBNP, despite the significant univariate findings. In contrast, follow-up (48 to 72 h or 30 days) sST2 appeared to provide incremental prognostic value, albeit diminished following covariate and NT-proBNP adjustments. Third, consistent with previous reports sST2 levels tend to fall after medical therapy (23,27,28), but we found that 1 in 7 patients demonstrated no fall in sST2 levels following medical therapy. Meanwhile, persistently elevated sST2 levels (above baseline median of 71.2 ng/ml), or lack of any lowering of sST2 levels despite medical therapy, may define a higher-risk subset of patients compared to those who demonstrated a fall in sST2 level following medical therapy as seen in a smaller series (23). Finally, contrary to our hypothesis, nesiritide did not demonstrate any significant effects on lowering sST2 levels over standard therapy in the long-term. Conversely, the placebo group showed a greater fall in sST2 levels from baseline to 48 to 72 h than the nesiritide group, even though such difference did not extend to the 30-day timepoint. Therefore, persistently

FIGURE 3 **Comparison of Adverse Clinical Outcomes**

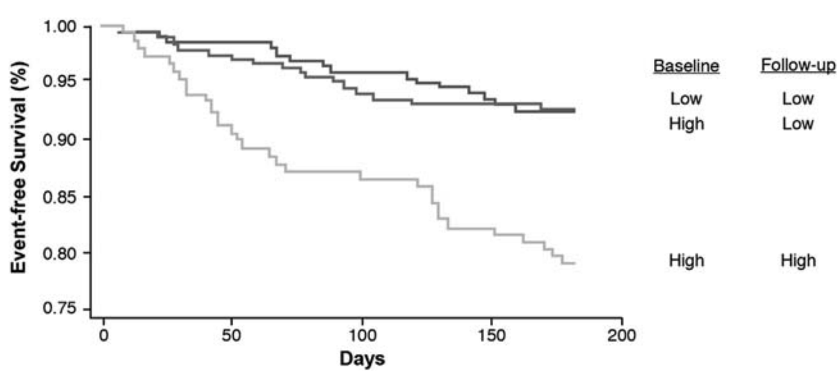


Comparison of adverse clinical outcomes in patients with a decrease versus increase/no change in absolute levels of sST2. HF heart failure; sST2 soluble growth stimulation expressed gene 2.

elevated sST2 following stabilization during acute HF hospitalization may identify a higher risk cohort even after clinical risk factors and NT-proBNP levels have been considered.

The lack of incremental prognostic significance of baseline sST2 with the addition of NT-proBNP levels to the standard ASCEND-HF risk model was unexpected, because previous studies have demonstrated an incremental prognostic value of sST2 levels—even when adjusting for the levels of various natriuretic peptide assays (6,16,29). Although there are some inconsistencies between the Cox models and the reclassification analysis, it has been increasingly recognized that the latter may in some cases

FIGURE 4 **Serial sST2 Levels and Adverse Clinical Outcomes**



Kaplan Meier survival analysis stratified by high versus low baseline and follow up (48 to 72 h) sST2 levels (cutoff at 71.2 ng/ml), excluding the small subset of subjects with low sST2 at baseline and elevated sST2 at follow up (n 15).

TABLE 3 HRs for Death at 180 Days by Change Trends in sST2 From Baseline to 48-72 h (Using Median sST2 of 71.2 ng/ml as Cutoff)

	High Versus Low sST2 at Baseline; Low at 48-72-h Follow-Up			High at Baseline; High Versus Low sST2 at 48-72-h Follow-Up		
	Low→Low	High→Low	p Value	High→Low	High→High	p Value
Unadjusted HR	1.0	1.03 (0.54 1.98)	0.924	1.0	3.01 (1.63 5.59)	<0.001
Adjusted HR (model 1)	1.0	0.82 (0.42 1.59)	0.552	1.0	2.60 (1.38 4.89)	0.003
Adjusted HR (model 2)	1.0	0.66 (0.34 1.29)	0.226	1.0	2.42 (1.27 4.61)	0.007
Event rates	23/315 (7.3)	15/196 (7.7)		15/196 (7.7)	31/147 (21.1)	

Values are HR (95% confidence interval) or n/n (%).
HR hazard ratio; other abbreviations can be found in Table 1.

overestimate the incremental value of a biomarker even in independent validation data (30). Interestingly, many of the earlier studies that conducted multivariate analyses had limited covariate(s) or single cutoff values, and the majority of these studies conducted utilized research-based assays (6,8,29). Also, most previous studies had a more extended period of follow-up beyond 180 days (6,8,16), and did not include blood urea nitrogen, which is a widely available and robust prognostic covariate (31). Furthermore, in a clinical trial population such as the ASCEND-HF trial, there were specific inclusion and exclusion criteria, where a number of extreme phenotypes would have been excluded. The lower comorbidity in a clinical trial population than in single-center observational cohorts and the cardiac nonspecific nature of sST2 (7,21,32) might have also tracked better with long-term adverse outcomes than intermediate adverse outcomes following hospital discharge from acute HF. Nevertheless, our findings corroborate 2 recent post-hoc biomarker analysis from well-characterized large clinical trials of chronic HF, both of which observed that the prognostic value of sST2 was less robust when natriuretic peptide levels were included in the multivariate models (9,33). In fact, recent studies that measure transcardiac gradient of sST2 levels have even challenged the cardiac origin of circulating sST2 (7,34). Because natriuretic peptide testing is so widely available and its clinical utility for diagnosis and prognosis in the setting of acute HF has been well established, further studies that explore the incremental value of sST2 testing in a multimarker strategy with natriuretic peptides are warranted before broad clinical adoption.

Because insights can be gained not only from the absolute circulating ST2 levels, but from changes following medical stabilization, we compared subjects that did not show a reduction in sST2 levels (1 of 7 subjects in our cohort) versus subjects who did. As reported in the published data, one of the advantages of sST2 is the relatively low assay and biological variability compared with other cardiac biomarkers, which may favor its reliability in serial testing (22,35). Previous studies have demonstrated that either a 15% reduction in sST2 or a lower sST2 ratio (<75%) within 2 weeks was observed in destabilized HF patients with no subsequent events compared to those with events (27). Our sensitivity analyses (using both a clinically relevant sST2 reduction of >30% or below a threshold of 60 ng/ml) further demonstrate the prognostic importance of lowering sST2 levels in those with elevated baseline sST2, and a 4-fold increase in mortality risk between those with sST2 levels above versus below 60 ng/ml at 48- to 72-h follow-up (Online Figure 4). The observed ranges were similar to sST2 levels measured in a smaller cohort with serial samples measured at baseline and at day 4 (23).

The lack of long-term differences in absolute changes of sST2 levels over time between nesiritide and placebo is consistent with the primary results of the ASCEND-HF trial. In fact, the short-term reduction in absolute levels of sST2 appeared to be significantly larger in the placebo group, even though both groups achieved similar urine volumes and similar median blood pressures or rates of hypotension.

TABLE 4 Impact of Nesiritide Therapy on Absolute Changes in sST2 Levels

sST2 Levels (ng/ml)	Placebo (n 245)	Nesiritide (n 257)	p Value
Baseline	70.69 (51.40 to 102.54)	69.24 (46.86 to 108.05)	0.567
48 72 h	42.13 (30.85 to 60.81)	48.46 (32.52 to 67.67)	0.067
30 days	39.25 (28.12 to 61.94)	39.74 (27.52 to 67.20)	0.590
Changes from baseline to 48 72 h	26.11 (45.88 to 12.03)	18.05 (41.20 to 4.37)	0.005
Changes from baseline to 30 days	26.26 (52.10 to 6.13)	21.01 (52.27 to 2.62)	0.26

p value from nonparametric test.
Abbreviations as in Table 1.

STUDY STRENGTHS. The strengths of this study include: 1) meticulously collected serial samples in a prospective biomarker study in a large representative patient population; 2) adjudicated endpoints including HF rehospitalizations and dyspnea relief as part of a multicenter randomized clinical trial; and 3) a large study population compared to previous studies using the Food and Drug Administration-cleared assay.

STUDY LIMITATIONS. The number of events, relatively small size of the study groups (particularly with subgroup analyses), and relatively short (180-day) mortality endpoint may have reduced the power to detect the incremental prognostic value of sST2. Given our present findings from this post-hoc analysis, the incremental value of sST2 testing in a multimarker strategy with natriuretic peptides may depend on the appropriate timing (at follow-up rather than at baseline) and patient population (in those with high rather than low NT-proBNP levels); this should be further investigated. Furthermore, the clinical relevance of assessing changes in sST2 should be further investigated in these patient subsets.

CONCLUSIONS

Elevated levels of sST2 at baseline and follow-up were associated with an increased risk of adverse clinical events. However, the addition of baseline sST2 to a standard risk model plus NT-proBNP levels did not improve the prediction of 180-day outcomes, yet failure to lower sST2 levels portends a poor prognosis. Nesiritide did not demonstrate any significant effects on lowering sST2 levels over standard therapy.

REPRINT REQUESTS AND CORRESPONDENCE: Dr. W.H. Wilson Tang, Heart and Vascular Institute, Cleveland Clinic, 9500 Euclid Avenue, Desk J3-4, Cleveland, Ohio 44195. E-mail: tangw@ccf.org.

PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: Elevated sST2 levels at follow-up, but not at baseline, provided incremental prognostic value for 180-day mortality beyond clinical covariates and natriuretic peptide levels.

TRANSLATIONAL OUTLOOK: Further studies that explore the incremental value and timing of sST2 testing in a multimarker strategy with natriuretic peptides are warranted before broad clinical adoption. In the interim, the lack of incremental reduction in sST2 by nesiritide also calls into question the role of myocardial stress as the underlying mechanisms of sST2 generation in the setting of heart failure.

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