Utility of hand-held ultrasound performed by cardiology fellows in patients presenting with suspected ST elevation myocardial infarction

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Abstract

Background: In academic hospitals, cardiology fellows may be the first point of contact for patients presenting with suspected STE elevation myocardial infarction (STEMI) or acute coronary syndrome (ACS). In this study, we sought to determine the role of handheld ultrasound (HHU) in patients with suspected acute MI (AMI) when used by fellows in training, its association with year of training in cardiology fellowship, and its influence on clinical care. **Methods**: This prospective study's sample population was comprised of patients who presented to Loma Linda University Medical Center Emergency Department with suspected acute STEMI. On call cardiology fellows performed bedside cardiac HHU at time of AMI activation. All patients subsequently underwent standard TTE. The impact of the detection of WMA on HHU in regards to clinical decision making, including whether the patient would undergo urgent invasive angiography, was also evaluated. **Results**: 82 patients (mean age 65 years, 70% male) were included. The use of HHU by cardiology fellows resulted in a concordance correlation coefficient of 0.71 (95% confidence interval: 0.58 - 0.81) between HHU and TTE for LVEF, and a concordance correlation coefficient of 0.76 (0.65 - 0.84) for wall motion score index (WMSI). Patients with WMA on HHU were more likely to undergo invasive angiogram during hospitalization (96% vs 75%, $p<0.01$). The time interval between performance of HHU to initiation of cardiac catheterization (time-to-cath) was shorter in patients with abnormal vs normal HHU exams (58 ± 32 minutes versus 218 ± 388 min, $p=0.06$). Lastly, among patients who underwent angiography, those with WMA were more likely to undergo angiography within 90 minutes of presentation (96% vs 66%, $p<0.001$). **Conclusion**: HHU can be reliably used by cardiology fellows in training for measurement of LVEF and assessment of wall motion abnormalities, with good correlation to findings obtained via standard TTE. HHU-identified WMA at first contact were associated with higher rates of angiography as well as sooner angiography compared to patients without WMA.

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Results : 82 patients (mean age 65 years, 70% male) were included. The use of HHU by cardiology fellows resulted in a concordance correlation coefficient of 0.71 (95% confidence interval: 0.58 - 0.81) between HHU and TTE for LVEF, and a concordance correlation coefficient of 0.76 (0.65 - 0.84) for wall motion score index (WMSI). Patients with WMA on HHU were more likely to undergo invasive angiogram during hospitalization (96% vs 75%, $p<0.01$). The time interval between performance of HHU to initiation of cardiac catheterization (time-to-cath) was shorter in patients with abnormal vs normal HHU exams (58 ± 32 minutes versus 218 ± 388 min, $p=0.06$). Lastly, among patients who underwent angiography, those with WMA were more likely to undergo angiography within 90 minutes of presentation (96% vs 66%, $p<0.001$).

Conclusion : HHU can be reliably used by cardiology fellows in training for measurement of LVEF and assessment of wall motion abnormalities, with good correlation to findings obtained via standard TTE. HHU-identified WMA at first contact were associated with higher rates of angiography as well as sooner angiography compared to patients without WMA.

Keywords: Handheld ultrasound (HHU), cardiology fellow in training (FIT), STEMI, wall motion abnormalities (WMA), left ventricular ejection fraction (LVEF)

Manuscript

Introduction

As ultrasound technology becomes more readily accessible, the use of hand-held devices (HHU) is becoming increasingly prevalent in assessing most organ systems. In the high-stakes and time-sensitive field of cardiology, point of care ultrasound has been shown to be a valuable tool for evaluating cardiovascular status (1-3). Examples include revealing the presence of reversible causes of cardiovascular compromise (including cardiac tamponade, hypovolemia, myocardial infarction, and pulmonary embolism), as well as estimating left ventricular ejection fraction (LVEF) and cardiac wall motion abnormalities (4-6). These findings may play crucial roles in the clinical decision-making process in regards to whether or not a patient should be sent to the catheterization laboratory as well as in the discernment of the etiology of the acute myocardial injury (AMI). The information acquired through the use of HHU has been shown to change patient management in acute settings (7-9) by helping to direct the clinicians towards a diagnosis, such that focused ultrasound has become an important part of the evaluation of patients undergoing AMI workup (10).

The need to rapidly diagnose and triage AMI patients makes the use of HHU appealing, particularly in patients with an equivocal diagnosis and treatment options. In these patients, the ability to estimate LVEF and identify wall motion abnormalities can often change the course of patient's management and this is the area in which a rapid bedside HHU (as opposed to standard TTE, which may not be readily available) can prove to be of significant utility. As a result, it is important to determine the reliability of the information acquired by HHU and its agreement with the gold standard TTE, as well as the possible ways in which HHU can affect care in patients presenting with suspected AMI.

As the first responders to AMI activations, the quality of images acquired by cardiology fellows and their confidence in the interpretation of HHU studies are important factors in determining the reliability and precision of the study results and in subsequent rapid identification of cases that need urgent interventions. Furthermore, despite the proven benefits of HHU, adoption of this tool has remained heterogeneous and sporadic among both academic and community centers alike. In this study we hypothesized that HHU, when performed and interpreted by trained cardiology fellows, provides accurate diagnostic capabilities compared with standard TTE in patients with AMI and could lead to changes in clinical management and improvement in treatment workflows.

Methods:

Patient selection : This was a prospective study of 95 patients over 18 years of age who triggered ST elevation myocardial infarction (STEMI) activation after arrival to the emergency room at Loma Linda University Medical Center and underwent HHU by an on-call cardiology fellow as part of initial evaluation. Patients were enrolled between October 2018 and December 2020.

Equipment : Standard TTE was performed using a Philips (Bothell, WA) ultrasound device. Cardiac HHUs were done using Butterfly (Burlington, Massachusetts) or GE-V-scan (Waukesha, WI) devices. The HHU examination included 2-dimensional images from the standard long and short axis parasternal, and apical windows. The interpretations were then documented by the fellows on a standardized form to collect the data.

Echocardiographic examination : The standard echocardiograms were performed by experienced sonographers in a comprehensive a manner as part of standard care. Images were then read by cardiology attendings. The cardiac HHU examination was done prior to obtaining the TTE and included 2-dimensional images from the standard long and short parasternal, as well as apical windows. 14 cardiology fellows (seven in first year and seven in second or third year of training) performed all the HHU studies. Fellows interpreted images to visually estimate the LVEF, presence of LV regional wall-motion abnormality (based on the 16-segment model (11) for generating a wall motion score index (WMSI)), presence of pericardial effusion (graded based on the common classification), segmental endocardial border visualization, and level of confidence interpreting the data (supplemental figure 1).

Endpoint: The primary endpoint of the study was the agreement between LVEF and WMAs identified on HHU with subsequently performed clinically indicated TTE. Secondary endpoints included the role of HHU on clinical decision making, including whether angiography was performed and the timing in which it was initiated (supplemental figure 2).

Statistical analysis : Continuous variables were reported as mean +/- SD or median (interquartile range). Categorical variables were reported as number (%) of the total group and p values calculated using Chi square test. The agreement between the cardiac HHU and standard TTE was measured for LVEF which was also stratified based on cardiology fellows' year of training. For continuous variables, Lin's concordance correlation coefficients (r values) were estimated by variance components. Agreement was also assessed using

Bland-Altman methodology (12). Results from the standard TTE were considered the gold standard for this study. Microsoft Excel was used for all of the statistical analyses.

Results :

Patient characteristics:

This study enrolled 95 patients, of which 75 were included for LVEF and 82 were included for wall motion abnormality (WMA) studies. This was because some patients either did not undergo standard TTE during hospitalization or the LVEF and WMAs were not recorded by HHU user. The characteristics of the study patients are outlined in Table 1. Mean age was 65± 13 years, and 70% were male. Coronary angiography was performed on 74 patients (90%). Index hospital treatment included percutaneous coronary intervention in 55 patients (67%), surgical intervention (CABG) in 2 patients (3%), and medical treatment alone in 25 patients (30%).

Agreement on LVEF and wall motion abnormalities assessed by TTE and HHU:

To measure the agreement level, the concordance correlation coefficient (r) was calculated for both TTE and HHU (Fig 1A). The r-value for LVEF between the standard TTE and HHE was 0.71 (95% confidence interval [CI]: 0.58 to 0.81, p value < 0.0001). Figure 1C shows the Bland-Altman plot for agreement between HHE and TEE for assessing LVEF: the majority of measurements fell within the 95% confidence interval indicating the high agreement between the two methods.

The concordance correlation coefficient for WMSI between the standard TTE and HHE was 0.76 (95% CI: 0.65 to 0.84, p value < 0.0001) (Fig 1B). Similarly, a Bland-Altman graph generated from the WMSI data showed that majority of measurements for wall motion abnormalities were seen within the range of the 95% confidence interval (Fig 1D). The largest difference in WMSI between the HHU and standard TTE occurred in the mid to upper to end of the reported range, between 1.5 and 2.5.

We also calculated the agreement for the presence of segmental regional wall-motion abnormalities between the HHU and standard TTE for each of the 16 segments of left ventricle. Agreement was variable among different LV segments with r-values ranging between 0.48 to 0.80. It was highest for the mid inferoseptal wall (0.80) on apical view and mid inferolateral wall (0.77) on parasternal long axis, and lowest for the basal anterior (0.5) and basal inferior (0.51) walls on parasternal short axis views (Table 2).

Cardiology fellows' HHU image quality and effect of HHU results on clinical decision making:

To describe their image quality, cardiology fellows gave a score to segmental endocardial border visualization (2 = good, 1 = poor, 0 = invisible). The mean endocardial visibility grade was 1.41 ± 0.58. When asked to rate their level of confidence interpreting the study (2 = confident, 1 = intermediate, 0 = uncertain), the mean level of confidence was 1.30 ± 0.67. Fellows were also able to recognize pericardial effusions, identifying eight patients with small effusions on HHU of which all were confirmed with TTE.

Fellows reported that in 32% of the patients, the HHU study influenced their clinical decision making (Table 3). This was corroborated with several objective findings. First, patients with WMA on HHU were more likely to undergo invasive angiography during hospitalization (96% vs 75%, $p<0.01$). Second: the mean time-to-cath in patient with abnormal HHU findings of WMA tended to be shorter than among patients without WMA (58 ± 32 minutes versus 218 ± 388 min, $p=0.06$). Finally, among patients undergoing angiography, those with WMA were more likely to undergo an angiogram within 90 minutes of presentation (96% vs 66%, $p<0.001$).

Correlation between cardiology fellows' year of training and HHU interpretation:

To determine whether the number of years in training had any significant influence on the HHU interpretation, all the HHU measurements were stratified for either first year cardiology fellows (fellow in training [FIT] = 1) or those in second year and above (FIT [?] 2). The correlation coefficient for LVEF between the standard TTE and HHU were 0.64 (95% CI: 0.41 – 0.79) and 0.80 (CI: 0.64 – 0.89) for FIT = 1 and FIT

[?] 2, respectively (Fig 2A-B). A similarly significant increase in the correlation coefficient was found when we compared the WMSI acquired from standard TTE against HHU obtained by cardiology fellows, with r = 0.70 (CI: 0.51 – 0.82) for FIT = 1 and r = 0.87 (CI: 0.76 – 0.93) for FIT [?] 2 (Fig 2C-D). The higher correlation in FIT [?] 2 was also reflected in recognizing WMA when comparing each wall segment separately (Table 2).

The influence of number of years in training was also evident in other factors reported by the fellows. These included higher scoring for visualization of segmental endocardial borders (1.45 +- 0.55 in FIT [?] 2 versus 1.39 +- 0.61 in FIT = 1, p=0.34), higher scores for level of confidence interpreting the studies (1.47 +- 0.60 in FIT [?] 2 versus 1.13 +- 0.68 in FIT = 1, $p<0.01$), and a higher percentage of fellows-reported clinical decisions being affected by HHU results: 42% in FIT [?] 2 group versus 24% in FIT =1, $p<0.05$) (Table 3).

Discussion :

Among AMI activation cases, there is heterogeneity and uncertainty impacting whether an immediate coronary angiogram and PCI is warranted based on an equivocal ECG and the patient's symptoms. This is especially challenging in most training centers where cardiology fellows in training are the first contact provider. These may be situations in which HHU can be of significant help in clinical decision making. Such areas where HHU can influence next steps are estimating LVEF, evaluating for pericardial pathology, and identifying the locations of abnormalities in cardiac wall motion, which will help in localizing the location of coronary artery occlusions. These findings may eventually translate into improved diagnosis and better patient care. Thus, it is imperative to determine 1) how reliable the information acquired by HHU is when compared against the gold standard TTE, and 2) whether HHU is associated with a potential change in care in terms of the need for angiography as well as the urgency of angiography, and whether it influences cardiovascular trainees to help make informed decisions.

In this study we found that there is a high correlation for LV function and overall wall-motion abnormality assessment between HHU and standard TTE (concordance correlation coefficient: 0.71 and 0.75) when performed and interpreted by cardiovascular fellows. Furthermore, we found that the absence of WMA on HHU was associated with an ability to defer or delay angiography, which can have important implications for the evaluation and triage of patients presenting with suspected STEMI.

The high degree of correlation between HHU and TTE that we demonstrated in this study can be supported by the fact that cardiology fellows could acquire relatively high-quality images and demonstrate a high level of confidence in their interpretation of the studies. We also found that the accuracy of data acquired by HHU had a positive linear correlation with years of training amongst fellows in detecting wall motion abnormalities, visualizing endocardial borders, and also with their self-reported level of confidence. As a result, second- and third-year fellows relied more heavily on the results of their HHU for making the next clinical decisions in terms of the need for and timing of cardiac catheterization.

Prior work has demonstrated good correlation between HHU and standard TTE for LVEF when experienced users perform the HHU exams (13-20). Liebo*et al* . in their cross-sectional study of 97 patients concluded that the rapid acquisition of images by skilled ultrasonographers who use pocket mobile echocardiography yields accurate assessments of ejection fraction and some, but not all, cardiac structures in many patients (13). In another similar study, Prinz *et al* ., using handheld ultrasound, showed that in relation to the basic assessment of cardiac morphology and function, the interpretation by experienced echocardiographers of images obtained using handheld echocardiographic devices demonstrated a moderate to very good correlation with standard echocardiography ($r > 0.8$, $p < 0.01$ for wall motion abnormalities, and $r > 0.6$, $p < 0.01$ for LVEF assessments) (14).

When compared with existing literature, our study shows comparable findings for correlation between HHU and standard TTE measurements, particularly for LVEF (15-16). Furthermore, there have been similar variable discrepancies in wall motion abnormalities between HHU and TTE in prior work, even in the hands of experienced users (17). This can be explained by lower image resolution and the limited amount of time users often spend optimizing images with HHU. Of note, the mean endocardial visibility score reported in this study (1.41 +- 0.58) was almost similar to what previously reported (1.60 +- 0.50) (18).

In addition to demonstrating that HHU performed by cardiology fellows is efficacious in assessment of suspected STEMI, we highlighted the possible ability of key HHU findings to affect care in this population. Patients with suspected STEMI are a heterogenous group, with a broad differential diagnosis (21). In addition to history, physical exam, and laboratory values, HHU may have the ability to further risk stratify patients. This may occur due to the finding of a competing explanatory diagnosis, such as pericarditis, pericardial effusion, pulmonary embolism, etc. However, even in the absence of alternative findings, lack of WMAs on presentation may not be clinically suggestive of a STEMI (22). We extend similar findings to HHUs performed by cardiology fellows at the point of care in the emergency room. The ability to risk stratify patients is potentially important due to ability to defer invasive angiography, which has been shown to be safe among patients with non-ST elevation MI (23) or consider alternative diagnoses. The ability to safely determine the timing of care may be especially important in the off-hours or in the setting of limited catheterization lab space or requirement for decision making regarding patient transfer to a STEMI center, especially among smaller or community hospitals. The use of HHU for risk stratification for suspected STEMI, as well as other patient populations presenting with suspected AMI, deserves further evaluation in larger studies.

An important consideration in using HHU for decision making in the acute setting is that operators should be familiar with these tools and, more importantly, how to interpret the imaging results. Specific training in this area, therefore, is central to effective use and improved outcomes.

Limitations:

This study represents a small cohort from a single institution. TTEs were done as part of routine care, and could have been performed several hours after HHU, as well as after coronary angiography or revascularization, by which time wall motion may have changed. This potentially could be a confounding factor, affecting accuracy of comparing wall motion on HHU with wall motion on TTE. The HHUs in our study were performed by 14 cardiology fellows, with first year fellows carrying out two-thirds of the studies. This increases interobserver variability which has previously been shown to contribute to disagreement between the HHU and TTE (15). Decision making regarding proceeding to angiography and timing of angiography may have been made based on factors other than HHU, including patient preference and other clinical characteristics.

It should be pointed out that the influence of HHU on cardiology fellows' clinical management of each patient was a subjective report by each fellow as part of the checklist; however, other findings including higher rates of catheterization and shorter time-to-cath timeframes provide supporting evidence that validate the influence of HHU on fellows' better clinical decisions.

Conclusion :

In summary, we found that cardiac HHU is a feasible method for cardiology fellows in-training in rapidly determining LVEF and wall motion abnormalities in critical situations of a suspected STEMI, when timing and accuracy of clinical decision making is paramount. We also found that cardiology fellows with higher level of training could obtain more accurate results from HHU with higher confidence in their interpretations. Additionally, the presence of WMAs on HHU was associated with higher rates of angiography and faster angiography, which may have important implications for the triage and early management of patients presenting with suspected STEMI.

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Figures captions :

FIGURE 1: (A and B) Linear correlation between standard TTE and HHU for (A) LVEF and (B) WMSI, with a concordance correlation coefficient of 0.71 for LVEF and 0.76 for WMSI. (C and D) Bland–Altman correlation between standard TTE and HHU for (C) LVEF and (D) WMSI. The dark horizontal line in the middle represents the mean of the difference between TTE and HHU. The light dashed lines represent 2 SDs away from the mean difference. (C) For LVEF, Bland–Altman correlation demonstrates a larger difference between the TTE and HHE within the mid-range of LVEF, whereas for WMSI, largest difference between the HHU and standard TTE occurred in the mid to upper to end of the reported range, between 1.5 and 2.5.

Abbreviations: HHU, handheld ultrasonography; LVEF, left ventricular ejection fraction; SD, standard deviation; TTE, transthoracic echocardiography; WMSI, wall motion score index.

FIGURE 2: Stratification of linear correlation between standard TTE and HHU for LVEF (A and B) and WMSI (C and D) based on (A and C) FIT =1 and (B and D) FIT [?] 2, showing a concordance correlation coefficient of 0.64 versus 0.80 for A and B, and 0.70 versus 0.87 for C and D, respectively. Abbreviations: FIT, fellow in training.

Table 1: Clinical and echocardiographic characteristics of the study population. Data are presented as n (%), mean +- SD, or median (interquartile range).

Table 2: LV regional wall motion abnormality between HHU and standard TTE for each wall segment.

Table 3: Fellow-reported HHU image quality and reported effect of HHU results on clinical decisions. Data are presented as mean +- SD of scores to segmental endocardial border visualization (2 = good, 1 = poor, 0 = invisible), mean +- SD of scores to level of confidence interpreting the study (2 = confident, 1 = intermediate, 0 = uncertain), and n (%) for number of studies that influenced patient care.

Supplemental Figure 1: The survey used to collect echocardiographic data (ejection fraction, wall motion abnormalities, pericardial effusion, segmental endocardial border visualization, level of confidence, and influence of study on patient care) at the time of performing hand-held ultrasound in STEMI activation patients.

Supplemental Figure 2: Organization of the hand-held ultrasound studies based on wall motion abnormalities followed by their stratification based on cardiac catheterization results.

HHU, hand-held ultrasound; n, number of patients; WMA, wall motion abnormalities; Cath, cardiac catheterization; LAD, left anterior descending, LCx, left circumplex; RCA, right coronary artery; PCI, percutaneous intervention.

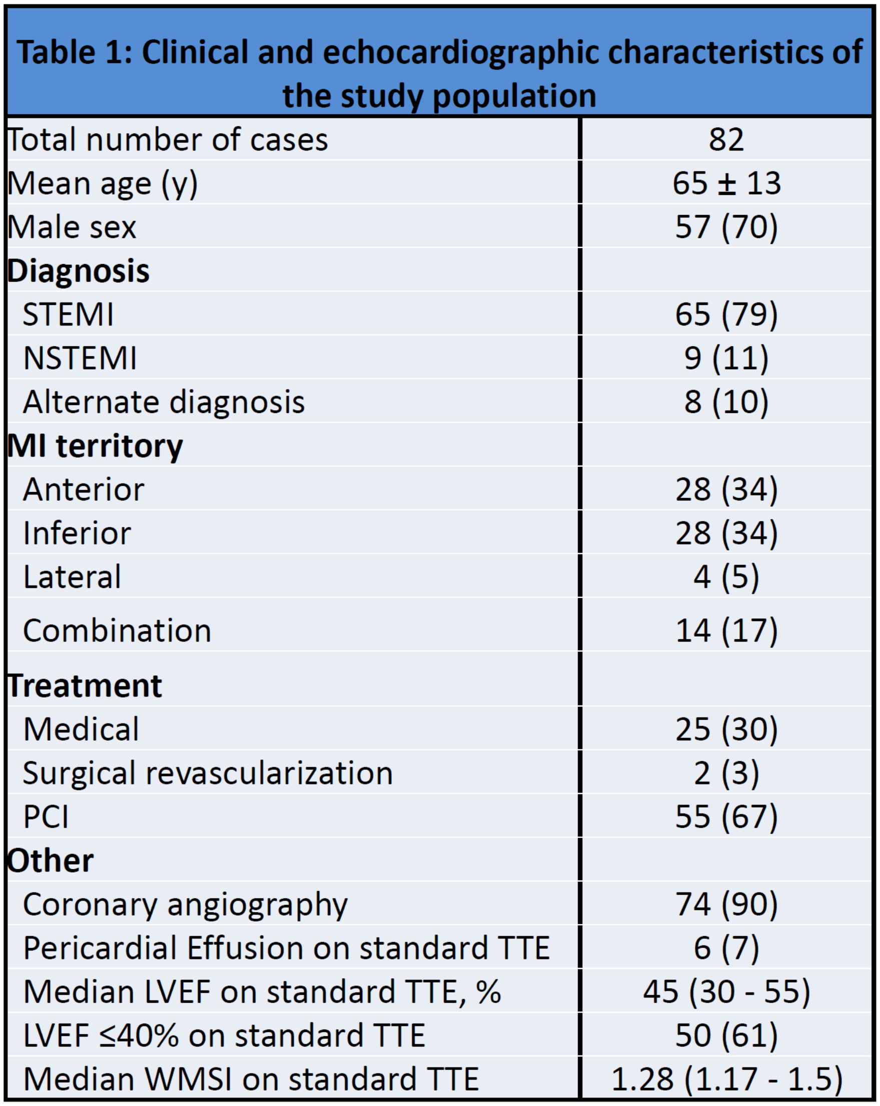
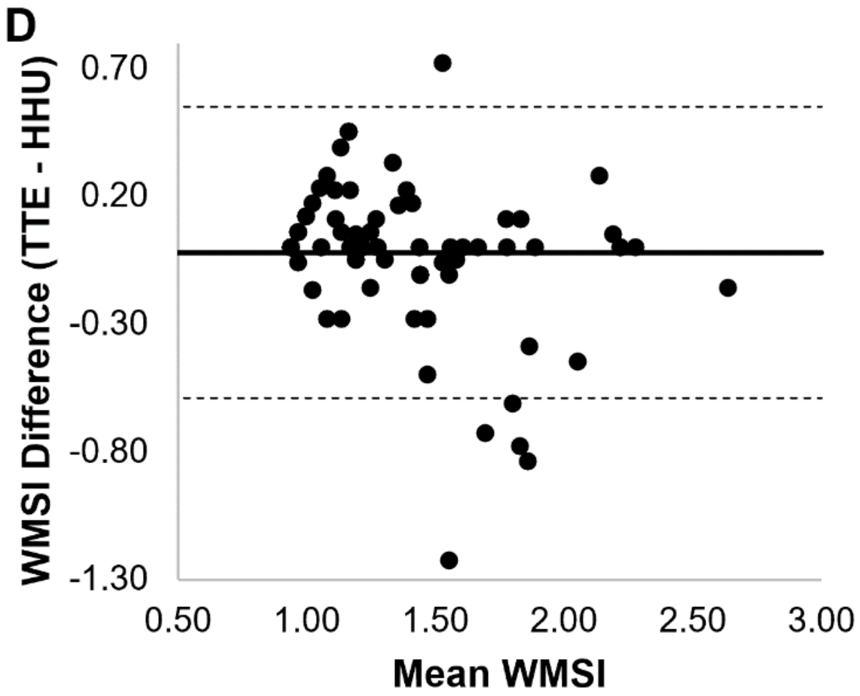
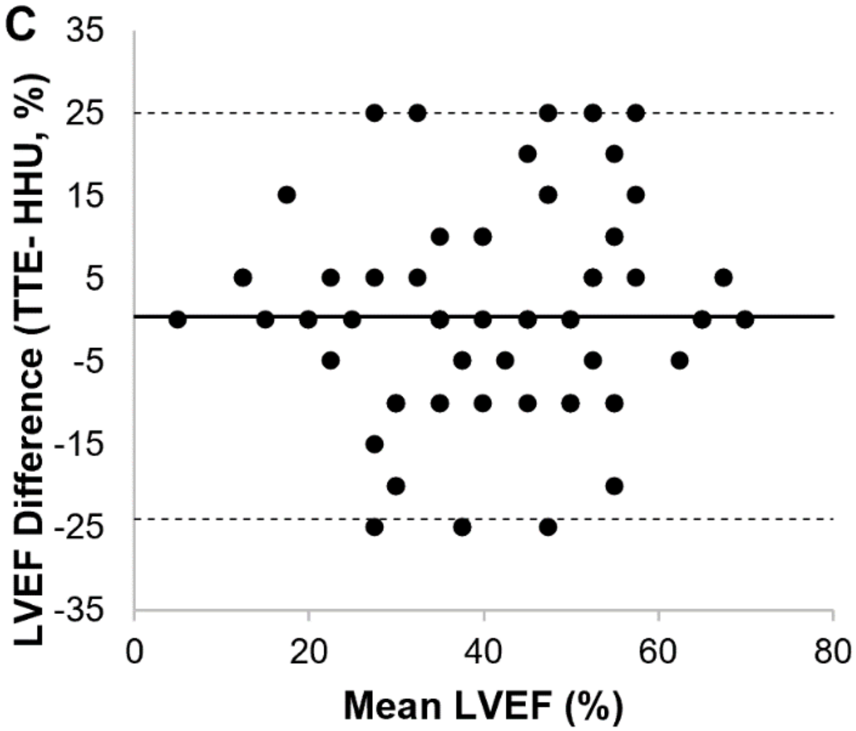


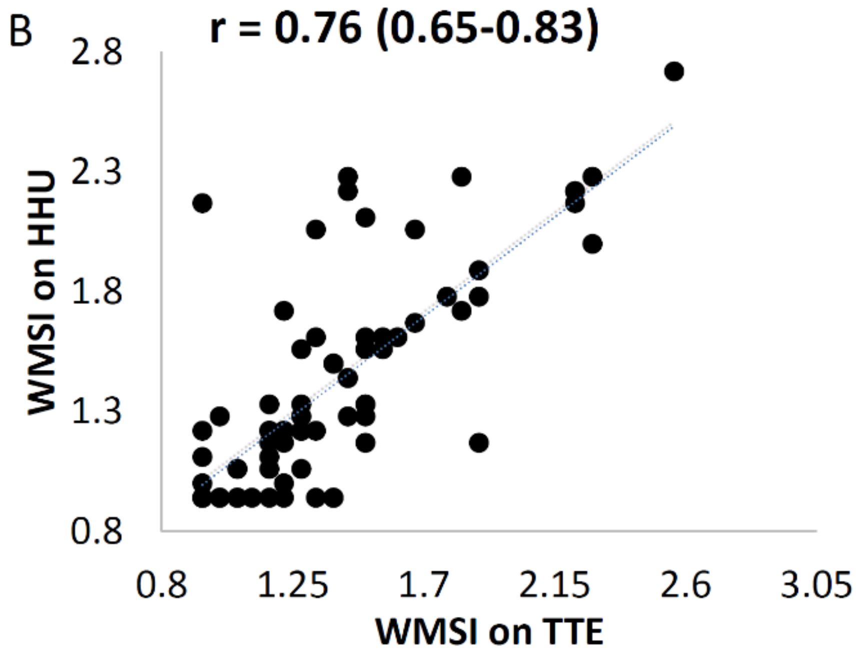
Table 1: Clinical and echocardiographic characteristics of the study population

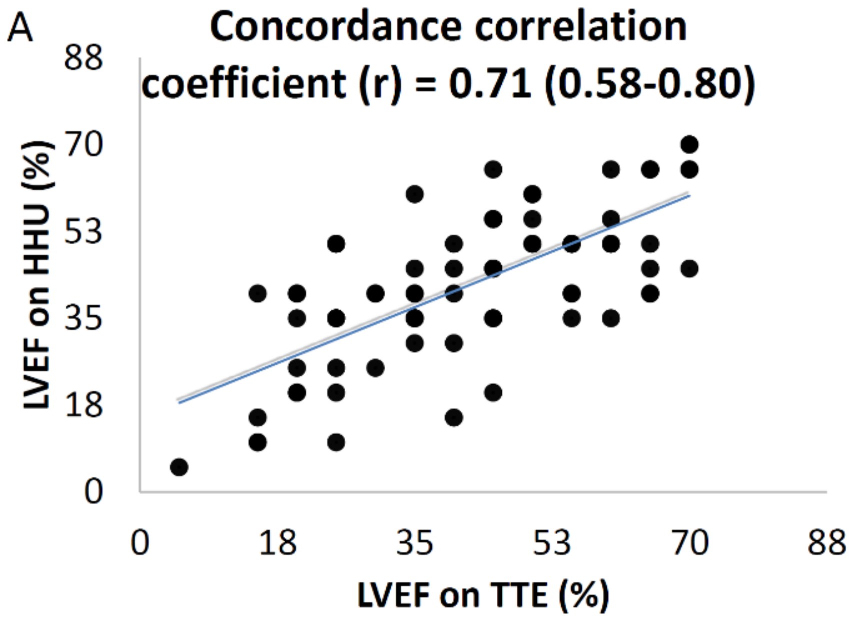
Total number of cases	82
Mean age (y)	65 ± 13
Male sex	57 (70)
Diagnosis	
STEMI	65 (79)
NSTEMI	9 (11)
Alternate diagnosis	8 (10)
MI territory	
Anterior	28 (34)
Inferior	28 (34)
Lateral	4 (5)
Combination	14 (17)
Treatment	
Medical	25 (30)
Surgical revascularization	2 (3)
PCI	55 (67)
Other	
Coronary angiography	74 (90)
Pericardial Effusion on standard TTE	6 (7)
Median LVEF on standard TTE, %	45 (30 - 55)
LVEF ≤40% on standard TTE	50 (61)
Median WMSI on standard TTE	1.28 (1.17 - 1.5)

FIGURE 1:


D
WMSI Difference (TTE - HHU)
0.70
0.20
-0.30
-0.80
-1.30
0.50
1.00
1.50
2.00
2.50
3.00
Mean WMSI


C
LVEF Difference (TTE- HHU, %)
35
25
15
5
-5
-15
-25
-35
0
20
40
60
80
Mean LVEF (%)


B
r = 0.76 (0.65-0.83)
WMSI on HHU
2.8
2.3
1.8
1.3
0.8
0.8
1.25
1.7
2.15
2.6
3.05
WMSI on TTE


A
Concordance correlation coefficient (r) = 0.71 (0.58-0.80)
LVEF on HHU (%)
88
70
53
35
18
0
0
18
35
53
70
88
LVEF on TTE (%)

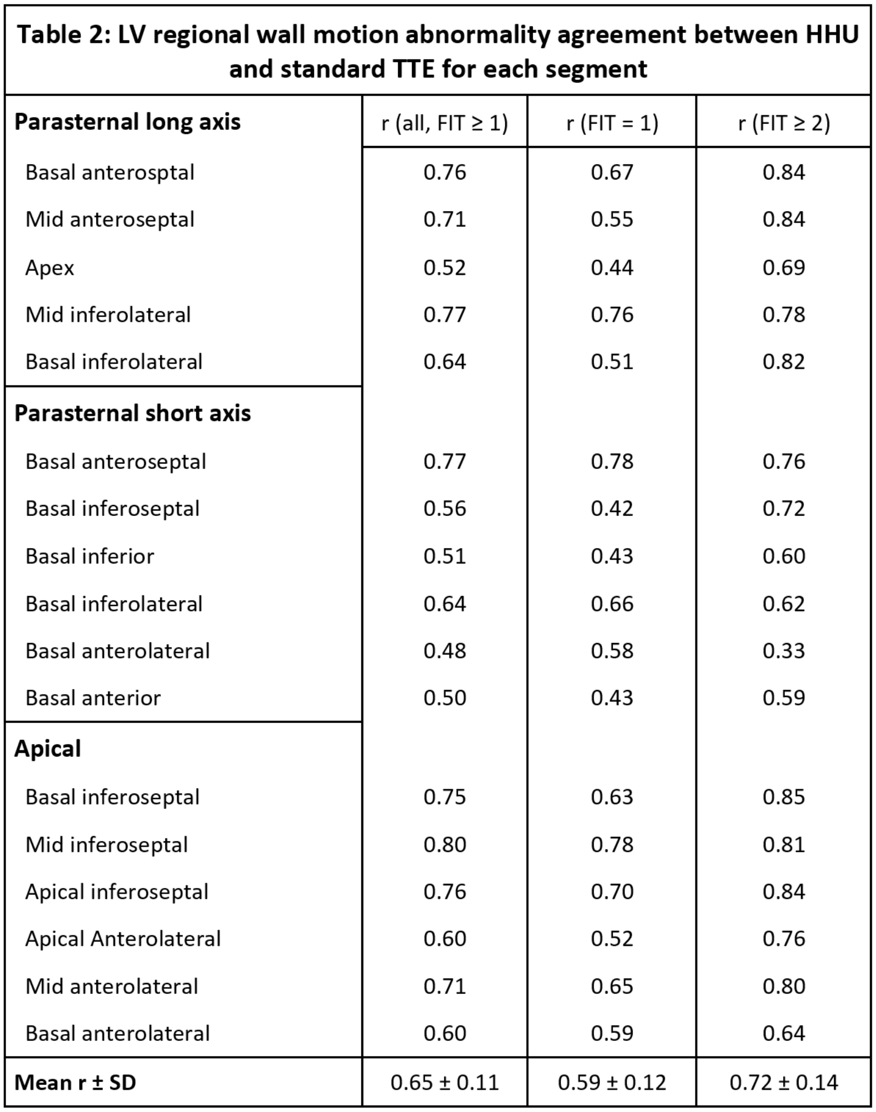


Table 2: LV regional wall motion abnormality agreement between HHU and standard TTE for each segment

Parasternal long axis	r (all, FIT ≥ 1)	r (FIT = 1)	r (FIT ≥ 2)
Basal anterosptal	0.76	0.67	0.84
Mid anteroseptal	0.71	0.55	0.84
Apex	0.52	0.44	0.69
Mid inferolateral	0.77	0.76	0.78
Basal inferolateral	0.64	0.51	0.82
Parasternal short axis			
Basal anteroseptal	0.77	0.78	0.76
Basal inferoseptal	0.56	0.42	0.72
Basal inferior	0.51	0.43	0.60
Basal inferolateral	0.64	0.66	0.62
Basal anterolateral	0.48	0.58	0.33
Basal anterior	0.50	0.43	0.59
Apical			
Basal inferoseptal	0.75	0.63	0.85
Mid inferoseptal	0.80	0.78	0.81
Apical inferoseptal	0.76	0.70	0.84
Apical Anterolateral	0.60	0.52	0.76
Mid anterolateral	0.71	0.65	0.80
Basal anterolateral	0.60	0.59	0.64
Mean r ± SD	0.65 ± 0.11	0.59 ± 0.12	0.72 ± 0.14

FIGURE 2:

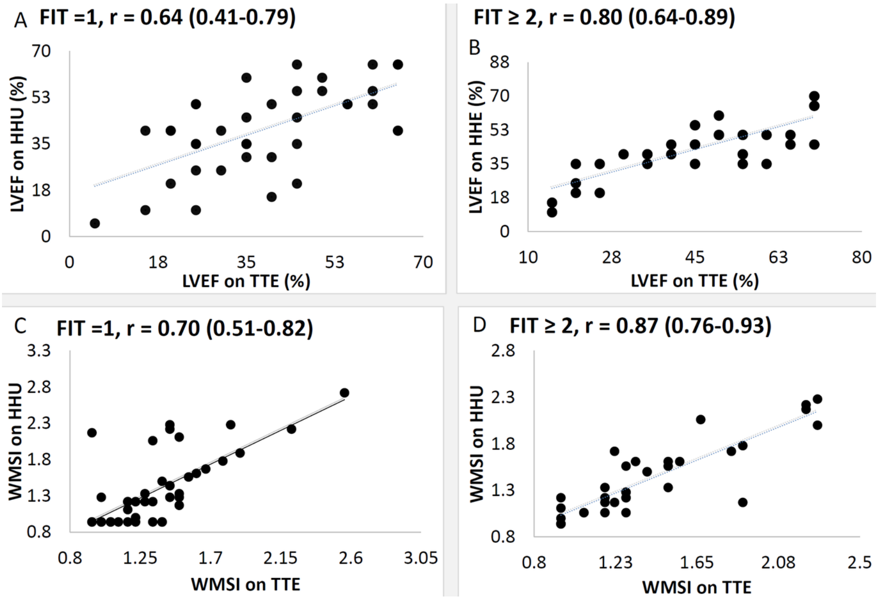
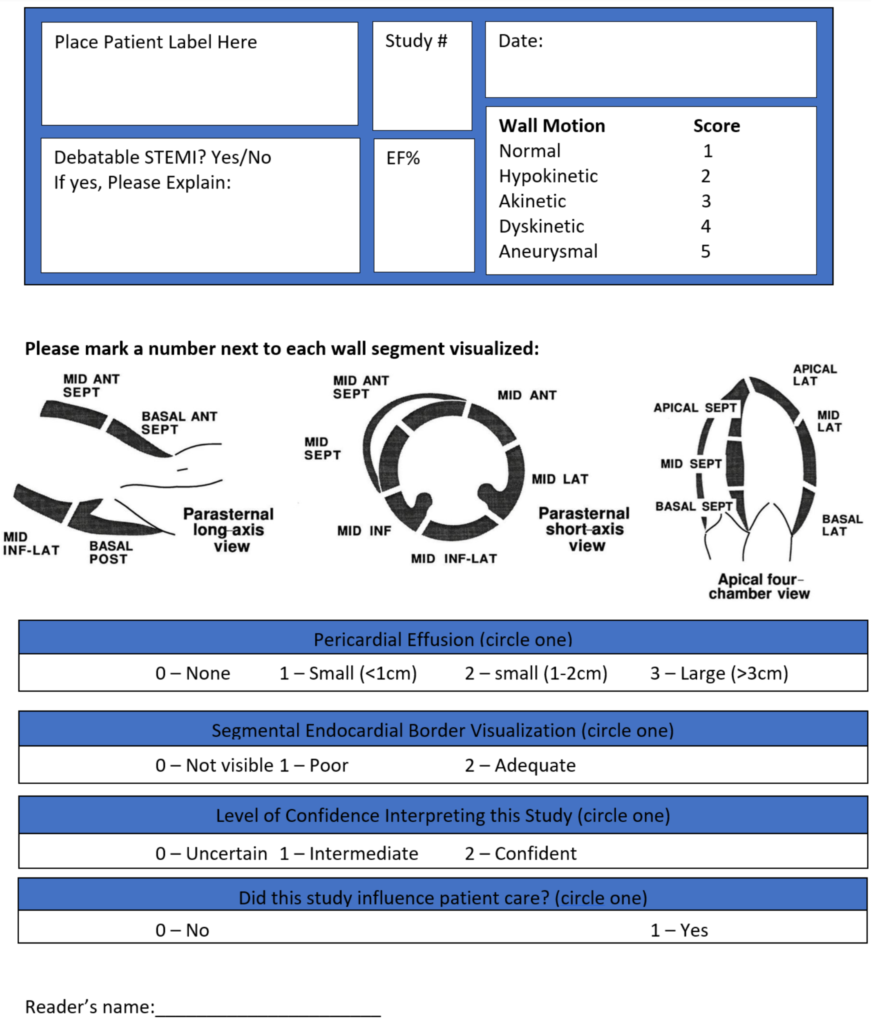


Table 3: Fellow-reported HHU image quality and reported effect of HHU results on clinical decisions	FIT = 1	FIT ≥ 2	All (FIT ≥ 1)
Visualized segmental endocardial border score	1.39 ± 0.61	1.45 ± 0.55	1.41 ± 0.58
Level of Confidence interpreting study, score	1.13 ± 0.68	1.47 ± 0.60	1.30 ± 0.67
Clinical decisions affected by HHU (%)	11 (24)	15 (42)	26 (32)

Supplemental figure 1:



Place Patient Label Here

Study #

Date:

Debatable STEMI? Yes/No
If yes, Please Explain:

EF%

Wall Motion	Score
Normal	1
Hypokinetic	2
Akinetic	3
Dyskinetic	4
Aneurysmal	5

Please mark a number next to each wall segment visualized:

Pericardial Effusion (circle one)

0 – None 1 – Small (<1cm) 2 – small (1-2cm) 3 – Large (>3cm)

Segmental Endocardial Border Visualization (circle one)

0 – Not visible 1 – Poor 2 – Adequate

Level of Confidence Interpreting this Study (circle one)

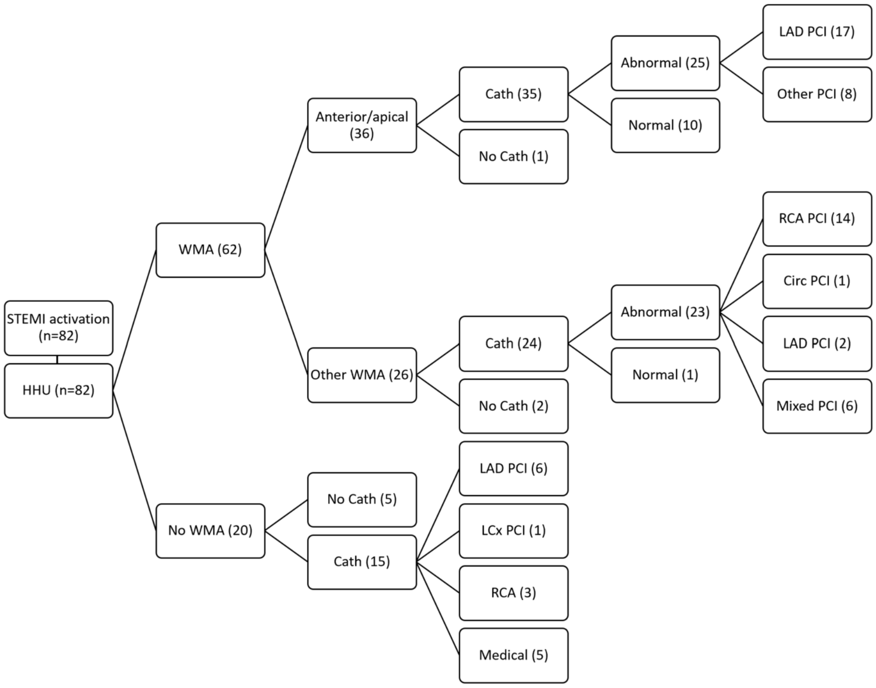
0 – Uncertain 1 – Intermediate 2 – Confident

Did this study influence patient care? (circle one)

0 – No 1 – Yes

Reader's name:________________________

Supplemental figure 2:


STEMI activation (n=82)
HHU (n=82)
WMA (62)
No WMA (20)
Anterior/apical (36)
Other WMA (26)
Cath (35)
No Cath (1)
Abnormal (25)
Normal (10)
LAD PCI (17)
Other PCI (8)
Cath (24)
No Cath (2)
Abnormal (23)
Normal (1)
RCA PCI (14)
Circ PCI (1)
LAD PCI (2)
Mixed PCI (6)
No Cath (5)
Cath (15)
LAD PCI (6)
LCx PCI (1)
RCA (3)
Medical (5)