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Selected Topics: Cardiology Commentary

UPWARDLY CONCAVE ST SEGMENT MORPHOLOGY IS COMMON IN ACUTE LEFT ANTERIOR DESCENDING CORONARY OCCLUSION

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□ Abstract—ST elevation (STE) in anterior precordial leads, in association with upwardly convex morphology (M) or straightM, is associated with anterior acute myocardial infarction (aAMI). Upwardly concaveM is characteristic of pseudoinfarction patterns such as early repolarization. A retrospective review was done of diagnostic electrocardiograms (EKG) of consecutive patients presenting to our Emergency Department (ED) who underwent emergent primary percutaneous intervention (PCI) and had proven left anterior descending (LAD) occlusion. If all leads from V2–V6 were upwardly concave, the EKG was classified as concaveM. If one lead was convex, the EKG had convexM. If no leads were convex and at least one was straight, it had straightM. Non-concaveM was defined as either convexM or straightM. Borderline STE was defined if the EKG did not have 2 consecutive leads with ≥ 2 mm of STE. "Subtle," as opposed to "diagnostic," morphology was defined as concaveM without terminal QRS distortion. Data were analyzed with descriptive statistics. There were 37 patients identified who met the inclusion criteria and whose records were available for review. ConcaveM was found in 16 of 37 (43%), 4 with terminal QRS distortion. Measurements resulted in a classification of borderline STE in 15 of 37 (41%) (9 of whom had subtle morphology) for Rater 1 and 12 of 37 (32%) (7 of whom had subtle morphology) for Rater 2, while 19% to 24% had both "subtle" morphology and borderline ST elevation. ConcaveM, as compared with convexM or terminal QRS distortion, was associated with a shorter duration of symptoms (p < 0.05). It is concluded that concave morphology cannot be used to exclude STEMI with LAD occlusion. Many patients with LAD occlusion have borderline ST elevation with subtle morphology. Concave morphology is associated with a shorter duration of symptoms. © 2006 Elsevier Inc.

□ Keywords—ST segment elevation myocardial infarction; electrocardiography; ST segment morphology

INTRODUCTION

ST segment elevation (STE) in anterior precordial leads is associated with left anterior descending (LAD) coronary artery occlusion, and acute anterior myocardial infarction (AMI). Rapid reperfusion therapy is essential for a good outcome. Unfortunately, reperfusion therapy is consistently underutilized, or utilized with inappropriate and costly delay (1–5). This shortcoming is mostly a result of uncertain electrocardiographic (EKG) interpretation (6–14). An EKG with a large amount of ST-segment elevation and depression is "visually alarming," and leads to more emergent management. However, those with less obvious ST-segment elevation are treated less expeditiously, or not at all (3,11,12). Moreover,

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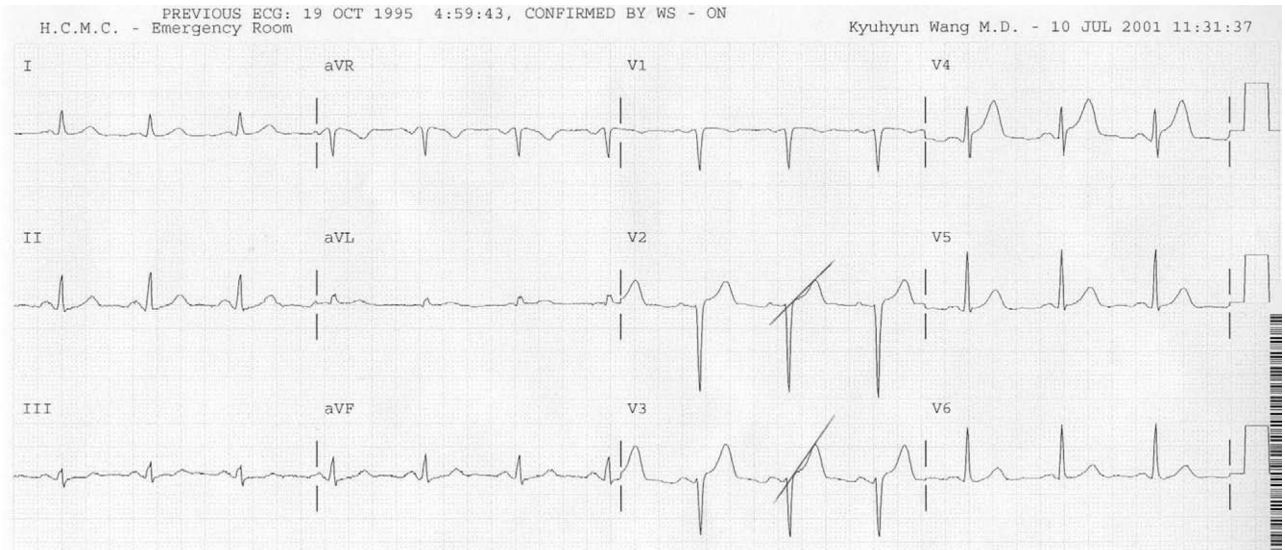

Figure 1. LAD occlusion with concave morphology and borderline ST elevation, with lines showing method of determining morphology.

EKG computer algorithms, though they have good specificity, often under-diagnose STEMI (15,16).

Multiple studies have shown that the majority of STE in patients with ischemic symptoms is due to non-acute myocardial infarction (AMI) etiologies; in one study this proportion was 85% (10,17–20). Up to 90% of normal young males have a baseline EKG with STE of at least 1 mm, and up to 3 mm (21).

The normal morphology of the ST segment leads is upward concavity (concave morphology, see Figure 1). Leads with normal T-wave inversion, especially aVR and lead V1, are exceptions. It is frequently taught that in other upright leads, upward convexity or a straight ST segment (non-concave morphology, see Figures 6–8) is associated with acute ST elevation myocardial infarction (STEMI) and that STE from a non-STEMI etiology ("pseudoinfarction") can be distinguished from STEMI by the presence or absence of concave morphology (22). No study could be found to support this assertion with data.

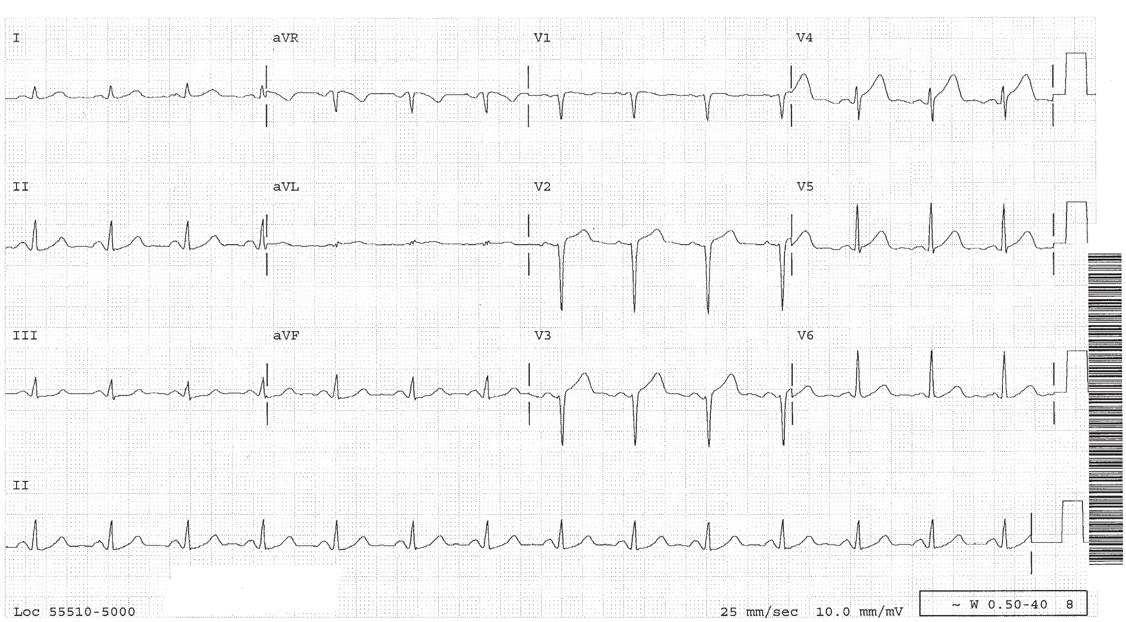

Figure 2. An example of concave morphology with borderline ST elevation ("subtle morphology" with borderline STE).

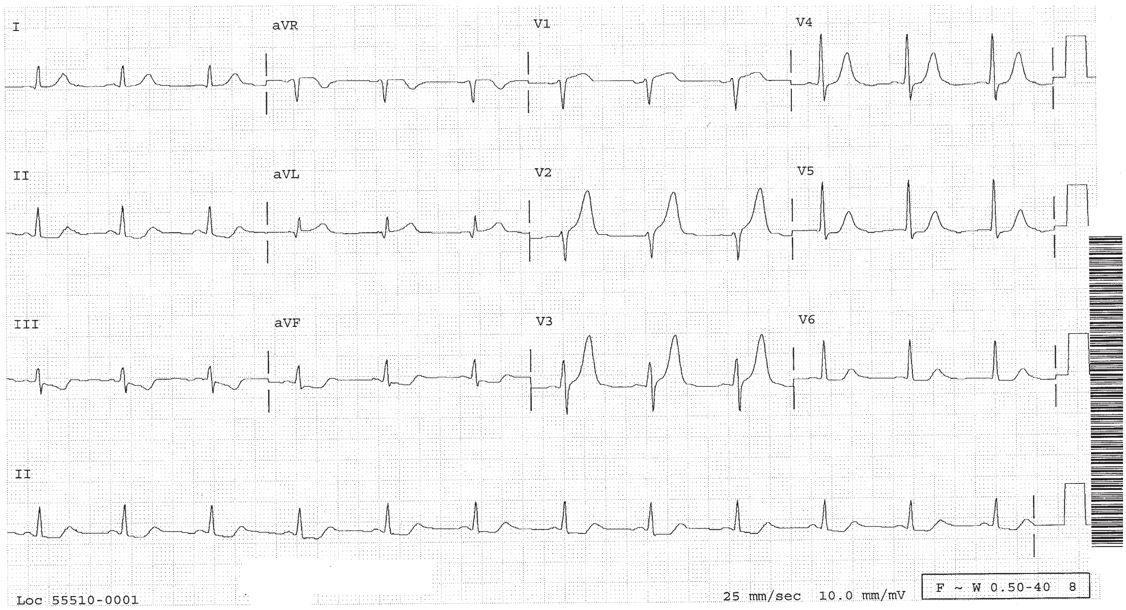

Figure 3. An example of concave morphology with borderline ST elevation ("subtle morphology" with borderline STE).

METHODS

Study Design

This study is a retrospective analysis of the electrocardiograms (EKGs) of all patients who presented to the Emergency Department (ED) from April 1, 1998 to May 11, 2002 with symptoms of acute coronary syndrome (ACS), were taken for primary percutaneous coronary intervention (PCI) for STEMI, and had proven LAD occlusion. The investigational review board approved the study; it was exempt from full review because it only involved the use of existing records.

Study Setting and Population

The setting of the study was a county hospital ED with an annual patient volume of 95,000 serving a primarily urban

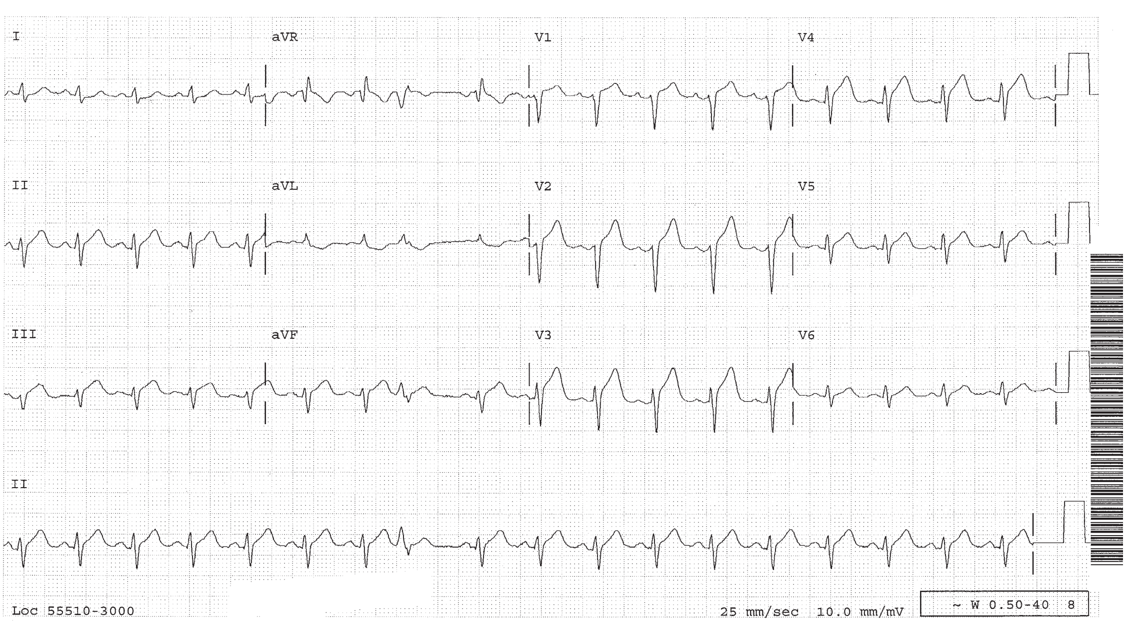

Figure 4. An example of concave morphology with relatively high ST elevation ("subtle morphology" with non-borderline STE).

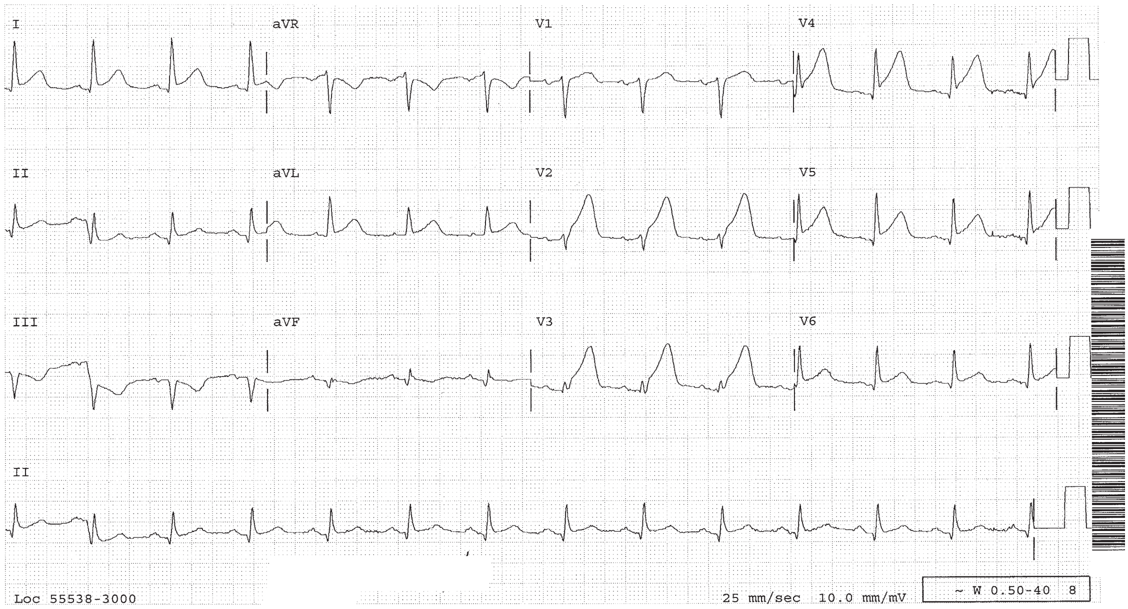

Figure 5. Both concave morphology and terminal QRS distortion are shown, as the QRS slurs into the ST segment without any S-wave, which in the absence of ischemia would otherwise be present. This distortion, in combination with the non-borderline STE, makes the diagnosis of myocardial infarction obvious despite concave morphology ("diagnostic morphology" without borderline STE).

area. Interventional cardiology was on call to perform primary PCI for patients with STEMI 24 h a day and 7 days a week during the entire study period. During much of the time period, thrombolytic therapy was considered appropriate and was not infrequently employed, though almost exclusively during evenings, nights, and weekends. There was no protocol directing therapy based on patient characteristics.

The databases of the National Registry of Myocardial Infarction-3 (NRMI-3) and NRMI-4 for Hennepin County Medical Center were searched for all patients with acute anterior STEMI. From this group, all who underwent immediate angiography with primary PCI for proven acute LAD coronary occlusion were chosen. In order to be included, the LAD had to be persistently occluded or, in the

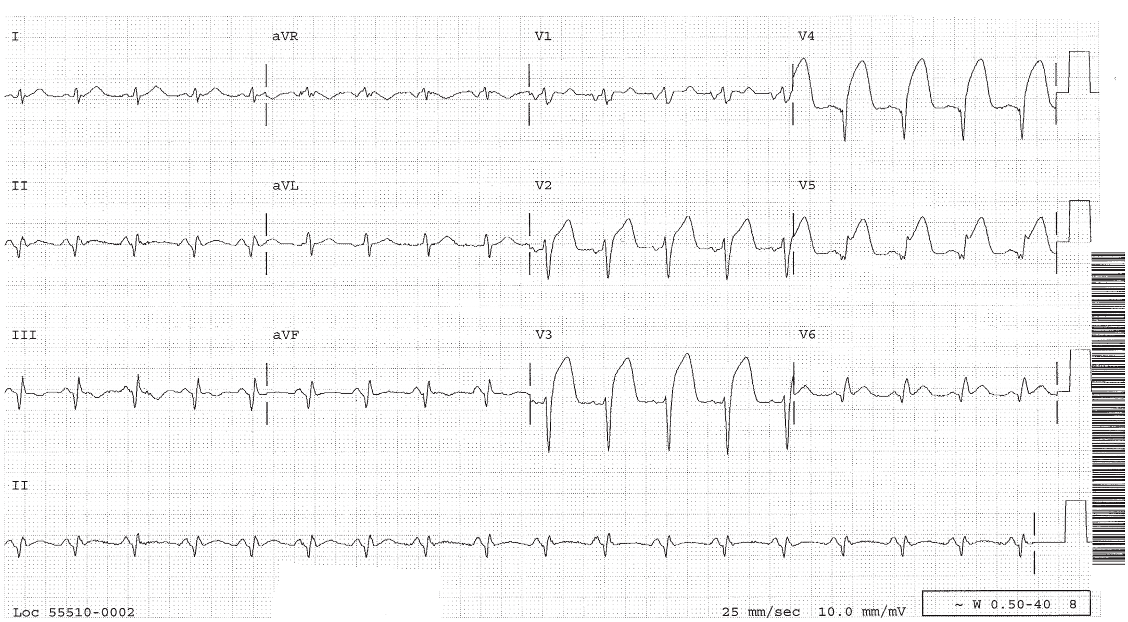

Figure 6. Obvious convexity and high STE are shown. Note, however, that convexity is not present in all 5 leads from V2–V6.

Table 1. Morphology

Total anterior STEMI (LAD occlusion)	Concave: 16 (43%)		Non-concave = 21 (57%)			
			Straight: 12 (32%)		Convex: 9 (24%)	
	ND**	D	ND	D	ND	D
37	12	4	8	4	4	5
Group	Subtle: 12 (32%)		Diagnostic: 25 (68%)			

* D = terminal QRS distortion; ** ND = no terminal QRS distortion.

opinion of the interventionalist, occluded at the time of the EKG; that is, there had to be thrombus or a culprit lesion indicating evidence of occlusion near the time of the EKG. The hospital records of these patients were reviewed to be certain that the NRMI data were correct and that the patient had presented to and been diagnosed in the ED. Those with simultaneous STEMI in another location were excluded, as were those with intraventricular conduction delay (IVCD) or bundle branch block (BBB). The diagnostic EKGs were reviewed.

Measurements

Two independent raters performed the ST segment measurements. Rater 1 was an attending ED physician (the author); Rater 2 was a research assistant with experience in reading EKGs and was instructed on how to do the measurements, but had no further guidance. Rater 2 was blinded to the objective of the study. ST segments were measured at the J-point, relative to the PR segment, and to the nearest 0.5 mm. Measurements were entered into an Excel database.

Definitions and Determinations of Morphologies

For leads V2–V6, a straight line was placed from the J-point to the inflection of the T-wave near its peak (Figure 1). Concave morphology was defined as the presence of any area below this line in all 5 leads (Figures 1–5). Convex morphology was defined as any area above the line in at least one lead (Figures 7, 8). Straight morphology (SM) was defined by no area above the line in any lead, and no area below the line in at least one lead (Figure 8). "Non-concave" morphology was defined as convex morphology or straight morphology; thus, non-concave morphology was defined as no area below the line in one or more leads. "Terminal QRS distortion," which has previously been associated with AMI and with adverse outcomes, was determined if the QRS slurred into the ST segment without any S-wave (Figure 5) (23).

The two raters, after independent analysis, reached a consensus on ultimate morphology determination. Because EKGs with non-concave morphology and those with terminal QRS distortion are relatively easily recognized as STEMI, patients were divided into two groups, "diagnostic morphology" and "subtle morphology." The "subtle" group comprised those with concave morphology *and* no terminal QRS distortion; the "diagnostic" group comprised those with either non-concave morphology or terminal QRS distortion.

Time of symptom onset to artery opening was recorded for all patients. Time to first positive troponin I and maximal troponin I were recorded. Borderline STE was defined if the ECG did not have 2 consecutive precordial leads with at least 2.0 mm of STE.

Statistics

Data were analyzed with descriptive statistics. For ST measurements, interrater reliability was summarized by intraclass correlation, taking subjects and leads into account. Duration of symptoms, time to first positive troponin, and

Table 2. Percentage of LAD Occlusion with Both Borderline ST Elevation and Subtle Morphology

Morphology	Borderline STE ($\leq$ 2 mm STE in 2 consecutive leads)		ST elevation > 2 mm in 2 consecutive precordial leads	
	Rater 1	Rater 2	Rater 1	Rater 2
Either	15 (41%)	12 (32%)	22	25
"Subtle" (Concave and no terminal QRS distortion)	9 (24%)	7 (19%)		
"Diagnostic" (Non-concave or terminal QRS distortion)	6	5		

"Diagnostic" means that interpreting the EKG as STEMI is not problematic because there is non-concave morphology or because terminal QRS distortion reveals the etiology of STE.

Table 3. Time (in Minutes) from Symptom Onset to EKG, Comparison of "Subtle" vs. "Diagnostic" EKGs

Morphology	Time (± confidence intervals)	p Value, compared with concave, one-tailed
"Subtle" (Concave and no QRS distortion)	196 (105)	
"Diagnostic" (Non-concave or QRS distortion)	392 (198)	0.10

peak troponin levels were compared between those with concave morphology and those with 1) convex morphology and 2) non-concave morphology, by Student's *t*-test.

RESULTS

There were 524 and 458 patients with AMI identified through NRMI-3 and -4, respectively; 80 and 79, respectively (total, 159) of these were anterior in location, with or without STE, 24 and 27, respectively (total, 51) of whom were admitted through the ED and underwent primary PCI. Fourteen were excluded for the following reasons: for two patients, no records were available; in one, ST elevation was due to postinfarction regional pericarditis; in three, there was neither proof of LAD occlusion nor of very recent LAD occlusion; in six, there was right BBB; in one, there was left BBB, and in one, there was concurrent inferior AMI.

Thus, 37 patients were identified who met the inclusion criteria and whose records were available for review; there were 14 women and 23 men. The mean age was 60.1 (SD 15.0; confidence interval [95% CI] 4.8), with a range of 37–89. The mean duration of symptoms before the diagnostic EKG was 328 min (SD 435; CI 140).

Results of Morphologic Analysis

Of the 37 EKGs, concave morphology was manifest in 16 (43%) patients (4 with terminal QRS distortion), straight morphology in 12 (32%) (4 with QRS distortion), and convex morphology in 9 (24%) (5 with QRS distortion) (Table 1). Thus, non-concave morphology was present in 21 (57%) (9 with QRS distortion). Twelve of 37 (32%) had both concave morphology and no QRS distortion (Group 1, "subtle morphology"), and 25 of 37 (68%) had either non-concave morphology or terminal QRS distortion ("diagnostic" morphology) (Table 2).

ST Measurements

Measurement of ST elevation had excellent interrater reliability, with correlations equaling 0.95 for measurement at both the J-point and at 60 ms after the J-point. By Rater 1's measurements, borderline ST elevation was present in 15 of 37 (41%) cases. Of these 15, 9 had subtle morphology (24% of all EKGs). By Rater 2's measurements, borderline ST elevation was present in 12 of 37 (32%) cases. Of these 12, 7 had subtle morphology (19% of all EKGs).

Thus, the sensitivity of convex morphology among the patients who were diagnosed with STEMI and had angiographically confirmed LAD occlusion was 9 of 37 (24%). The sensitivity of non-concave morphology was 21 of 37 (57%), and that of "diagnostic" morphology was only 68%. Depending on the rater, diagnostic morphology *or* ST elevation > 2 mm in two consecutive leads was present in 76% to 81%; in other words, and conversely, "subtle morphology" was present with borderline ST elevation in 19% to 24% of cases.

The time from symptom onset to EKG recording showed a trend towards longer duration in the group with diagnostic morphology (Table 3). By several comparisons of concave or concave/straight vs. convex or convex/QRS distortion, concave and straight morphologies were associated with significantly shorter time from symptom onset to EKG than were those with convex morphology or QRS distortion (Tables 4, 5).

There were no significant differences in first or highest troponin measured among the groups.

Table 4. Time (in Minutes) from Symptom Onset to EKG, Comparison of Concave with Other Morphologies

Morphology	n	Time (± confidence intervals)	p Value, compared with all concave, one-tailed
Concave (all*)	16	208 (102)	—
Straight (all)	12	300 (242)	0.23
Non-concave (all)	21	421 (221)	0.071
Convex or QRS distortion	17	497 (273)	0.046
Convex (all)	9	582 (421)	0.021

* Whether distorted or not.

Table 5. Time (in Minutes) from Symptom Onset to EKG, Comparison of Concave or Straight Morphologies with Others

Morphology	Time (confidence intervals)	*p* Value, compared with concave or straight, one-tailed
Concave or straight (but no QRS distortion)	186 (81)	
Convex (all)	582 (421)	0.022
Convex or distorted**	497 (273)	0.014

** Whether concave, straight, or convex.

See Figures 1–8 for examples of the various morphologies. Figures 1–3 are examples of "subtle" morphology with borderline ST elevation.

DISCUSSION

These data demonstrate that concave morphology cannot be used to rule out the diagnosis of STEMI, even when ST segment elevation is borderline. Non-concave morphology (straight or convex), even when added to those with concave morphology and terminal QRS distortion, is not a sensitive indicator of STEMI. Non-concave morphology was not found in even a single lead from V2–V6 in 43% of LAD occlusions.

Furthermore, concave morphology is associated with a significantly shorter duration of symptoms before the first EKG than convex morphology.

A recent article by Brady et al. found that, among 171 patients with STE who presented with symptoms of acute coronary syndrome and 56 of whom had AMI, non-concave morphology had a sensitivity and specificity for AMI of 77% and 97%, respectively, with positive predictive (PPV) and negative predictive values (NPV) of 94% and 88% respectively (24). There are several differences between the two studies. First, the former analysis was not limited to anterior MI; rather, it included all MI locations, and included no subgroup analysis for anterior MI. Second, diagnosis of AMI was by biochemical markers, not by angiographic proof of coronary occlusion. Third, when the EKG was eligible for analysis due to precordial STE, it was eligible only if at least 2 mm of STE was present. Fourth, there seemed to be no defined method of measurement of ST elevation. Most importantly, in the former study, it was not specified how many leads needed to be concave or non-concave in order for the overall morphology to be so classified. Lastly, terminal QRS distortion was not considered in the previous study.

An earlier study from Japan found that, of 77 consecutive anterior STEMI with proven LAD occlusion, 24 (31%) had concave morphology (25). Fifty-three manifested non-concave morphology, comprised of 41 with

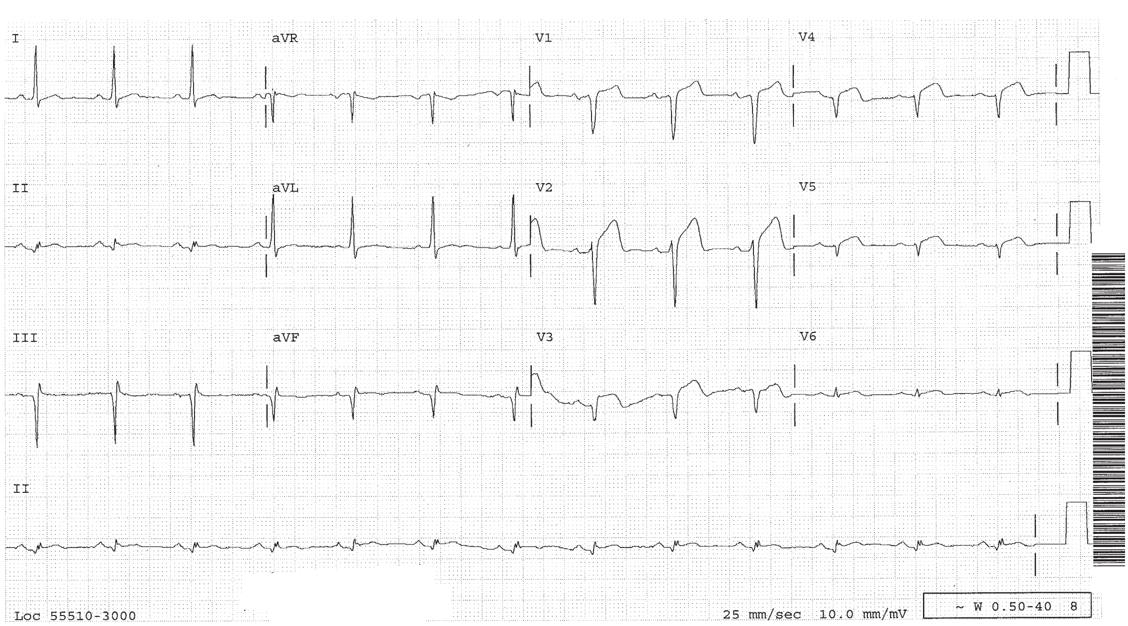

Figure 7. Less obvious convexity and non-borderline STE are shown. It is classified as convex due to the ST segments in leads V4 and V5, which arc just slightly above an imaginary line drawn from the J-point to the peak of the T-wave.

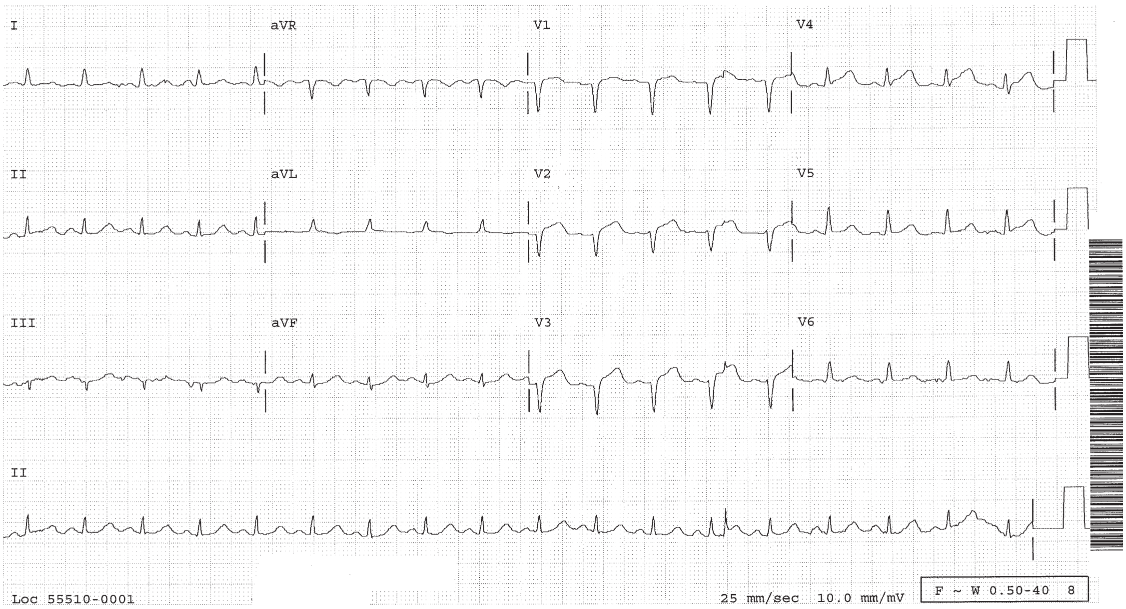

Figure 8. An example of straight morphology because the ST segment in V2 is straight, though it is concave in V3–V6. This is an example of diagnostic morphology (straight) with borderline STE.

straight morphology (SM) and 12 with convex morphology. Convex morphology was associated with a larger infarct as measured by CK-MB release, and with a lower ejection fraction.

Limitations

Unlike the present study, the data presented by Brady et al. addressed the specificity of non-concave morphology for STEMI and found it very specific, although no data on each MI location were presented (24). In the present study, the specificity of concave and of non-concave morphology was not ascertained because the EKGs of all patients with symptoms of acute coronary syndrome were not evaluated; instead, only those patients who were identified as having STEMI, underwent emergency primary PCI, and had proven occlusion were included. Second, many patients who had STEMI during this period received fibrinolytic therapy. In order to include only EKGs associated with proven LAD occlusion, the thrombolytic group was excluded because they did not have immediate angiography proving LAD occlusion. Although the decision to use thrombolytics vs. PCI was based almost exclusively on time of arrival, there may have been more use of thrombolytics in those whose EKGs were obviously diagnostic. If these patients indeed had LAD occlusion, and if a higher proportion of these patients had non-concave morphology than the group studied, then the sensitivity of non-concave morphology for STEMI would be underestimated.

CONCLUSIONS

In our population, among patients who were taken to angiography and had proven acute LAD occlusion, upwardly convex or straight ST segment morphology (“non-concave morphology”) was not a sensitive (57%) finding on the EKG. Forty-three percent were upwardly concave. “Diagnostic” morphology, defined as non-concave *or* manifesting terminal QRS distortion, was present in only 68%, whereas 32% had “subtle” morphology. Moreover, 32% to 41% had borderline ST elevation, and 19% to 24% had both borderline ST elevation and subtle morphology. Concave morphology cannot be used to exclude STEMI with LAD occlusion. Many patients with LAD occlusion have borderline ST elevation with subtle morphology. Concave morphology is associated with a shorter duration of symptoms.

REFERENCES

1. Barron HV, Bowlby LJ, Breen T, et al. Use of reperfusion therapy for acute myocardial infarction in the United States: data from the National Registry of Myocardial Infarction 2. Circulation 1997;97: 1150–6.
2. Berger AK, Schulman KA, Gersh BJ, et al. Primary coronary angioplasty vs. thrombolysis for the management of acute myocardial infarction in elderly patients. JAMA 1999;282:341–8.

3. Krumholz HM, Murillo JE, Chen J, et al. Thrombolytic therapy for eligible elderly patients with acute myocardial infarction. JAMA 1997;277:1683–8.
4. Thiemann DR, Coresh J, Schulman SP, Gerstenblith G, Oetgen WJ, Powe NR. Lack of benefit for intravenous thrombolysis in patients with myocardial infarction who are older than 75 years. Circulation 2000;101:2239–46.
5. Magid DJ, Calonge BN, Rumsfeld JS, et al. Relation between hospital primary angioplasty volume and mortality for patients with acute MI treated with primary angioplasty vs. thrombolytic therapy. JAMA 2000;284:3131–8.
6. Fesmire FM, Percy RF, Wears RL, MacMath TL. Initial ECG in Q wave and non-Q wave myocardial infarction. Ann Emerg Med 1989;18:741–6.
7. Boisjolie CR, Sharkey SW, Cannon CP, et al. Brief reports: impact of a thrombolysis research trial on time to treatment for acute myocardial infarction in the emergency department. Am J Cardiol 1995;76:396–8.
8. Jayes RL, Larsen GC, Beshansky J, D'agostino RB, Selker HP. Physician electrocardiogram reading in the emergency department: accuracy and effect on triage decisions. J Gen Intern Med 1992; 7:392.
9. Brady WJ, Perron A, Ullman E. Errors in emergency physician interpretation of ST-segment elevation in emergency department chest pain patients. Acad Emerg Med 2000;7:1256–60.
10. Brady WJ, Perron AD, Chan T. Electrocardiographic ST segment elevation: correct identification of AMI and non-AMI syndromes by emergency physicians. Acad Emerg Med 2001;8:349–60.
11. Hirvonen TP, Halinen MO, Kala RA, Olkinuora JT. Delays in thrombolytic therapy for acute myocardial infarction in Finland. Results of a national thrombolytic therapy delay study. Finnish Hospitals' Thrombolysis Survey Group. Eur Heart J 1998;19:885–92.
12. Sharkey SW, Berger CR, Brunette DD, Henry TD. Impact of the electrocardiogram on the delivery of thrombolytic therapy for acute myocardial infarction. Am J Cardiol 1994;73:550–3.
13. Sharkey SW, Brunette DD, Ruiz E, et al. An analysis of time delays preceding thrombolysis for acute myocardial infarction. JAMA 1989;262:3171–4.
14. Berger AK, Radford MJ, Krumholz HM. Factors associated with delay in reperfusion therapy in elderly patients with acute myocardial infarction: analysis of the cooperative cardiovascular project. Am Heart J 2000;139:985–92.
15. Massel D, Dawdy JA, Melendez LJ. Strict reliance on a computer algorithm or measurable ST segment criteria may lead to errors in thrombolytic therapy eligibility. Am Heart J 2000;140:221–6.
16. Kudenchuk PJ, Ho MT, Weaver WD, et al. Accuracy of computer-interpreted electrocardiography in selecting patients for thrombolytic therapy. J Am Coll Cardiol 1991;17:1486–91.
17. Rude RE, Poole WK, Muller J, et al. Electrocardiographic and clinical criteria for recognition of acute myocardial infarction based on analysis of 3,697 patients. Am J Cardiol 1983;52:936–42.
18. Otto LA, Aufderheide TP. Evaluation of ST segment elevation criteria for the prehospital electrocardiographic diagnosis of acute myocardial infarction. Ann Emerg Med 1994;23:17–24.
19. Miller DH, Kligfield P, Schreiber TL, Borer JS. Relationship of prior mycardial infarction to false-positive electrocardiographic diagnosis of acute injury in patients with chest pain. Arch Intern Med 1987;147:257–61.
20. Brady WJ. ST segment elevation in ED adult chest pain patients: etiology and diagnostic accuracy for AMI. J Emerg Med 1998;16: 797–8.
21. Surawicz B, Parikh SR. Prevalence of male and female patterns of early ventricular repolarization in the normal ECG of males and females from childhood to old age. J Am Coll Cardiol 2002;40: 1870–6.
22. Wang K, Asinger RW, Marriott HJ. ST-segment elevation in conditions other than acute myocardial infarction. N Engl J Med 2003;349:2128–35.
23. Birnbaum Y, Kloner RA, Sclarovsky S, Cannon CP, McCabe CH, Davis VG. Distortion of the terminal portion of the QRS on the admission electrocardiogram in acute myocardial infarction and correlation with infarct size and long-term prognosis (Thrombolysis in Myocardial Infarction 4 Trial). Am J Cardiol 1996;78:396–403.
24. Brady WJ, Syverud SA, Beagle C, et al. Electrocardiographic ST segment elevation: the diagnosis of acute myocardial infarcton by morphologic analysis of the ST segment. Acad Emerg Med 2001;8: 961–7.
25. Kosuge M, Kimura K, Ishikawa T, et al. Value of ST-segment elevation pattern in predicting infarct size and left ventricular function at discharge in patients with reperfused acute anterior myocardial infarction. Am Heart J 1999;137:522–7.