Prospective Analysis of Electrocardiographic Variables as Markers for Extent and Location of Acute Wall Motion Abnormalities Observed During Coronary Angioplasty in Human Subjects

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To assess the usefulness of different electrocardiographic variables as markers for the presence, extent and location of new wall motion abnormalities seen after sudden controlled coronary occlusion, 23 patients with isolated left anterior descending (n = 12), or right (n = 11) coronary artery disease and a normal baseline left ventriculogram were prospectively studied during transluminal coronary angioplasty. A simultaneous 12 lead electrocardiogram was recorded before passing the balloon catheter and again at 30 seconds into the fourth inflation cycle. Using a second arterial catheter, a left ventriculogram was obtained at 40 seconds into the fourth inflation cycle. The extent of wall motion abnormalities was described as the percent of left ventricular perimeter showing hypocontractility.

During balloon inflation, 19 of the 23 patients developed new hypocontractility ranging from 3 to 40%. ST segment elevation in lead V2 was the most sensitive marker for anterior wall hypocontractility and ST segment elevation in lead III was the most sensitive marker for inferior wall hypocontractility. Highly significant correlations were observed between the extent of the hypocontractile perimeter and 1) the sum of ST segment elevation in all 12 leads; 2) the magnitude of ST segment elevation in either lead V2 or lead III; and 3) the total number of leads with ST elevation ≥0.5 mV. No significant changes were seen in the sum of R wave amplitudes, but a significant prolongation of the QT interval was seen during ischemia.

In conclusion, acute ST segment elevation parallels the development of new asynergy during transluminal coronary angioplasty. The close association between ST segment elevation and the extent of asynergy may be useful in predicting the impact of sudden coronary dissection and occlusion on ventricular function during coronary angioplasty.

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Clinical investigations reviewing the electrocardiographic (ECG) changes seen during the early phase of acute coronary thrombosis or coronary spasm indicate that several ECG patterns may be observed. The most common change observed is ST segment elevation (1,2). Some investigators (3) observed that T wave peaking occurred before ST segment elevation, whereas others (4–6) observed that acute increases in R wave amplitude occurred along with ST segment elevation. A few investigators (7,8) have even observed transient Q waves within minutes of acute myocardial ischemia.

Patients with coronary artery disease undergoing elective percutaneous transluminal coronary angioplasty provide a model of sudden cessation of anterograde blood flow. Using this model, one can prospectively assess the changes seen on the 12 lead ECG that occur within the first minutes of coronary occlusion. Furthermore, by using a second arterial catheter for contrast left ventriculography during angioplasty balloon occlusion, correlations can be measured between different ECG variables and the size of the acute wall motion abnormality induced by coronary occlusion. In this fashion, we prospectively studied 23 patients to assess the usefulness of different ECG indexes as markers for the presence, extent and location of new wall motion abnormalities seen during controlled coronary occlusion by an inflated angioplasty balloon.

Methods

Study patients. Patients were prospectively selected from 142 consecutive patients undergoing elective transluminal coronary angioplasty. All patients had: 1) single vessel coro-
nary disease of either the left anterior descending or a dominant right coronary artery and 2) normal global and segmental left ventricular function. Patients with the following characteristics were excluded: 1) history of hypertension, (diastolic pressure >90 mm Hg), additional noncoronary cardiac disease, chronic obstructive lung disease, anemia or bleeding diathesis; 2) peripheral vascular disease compromising arterial access or renal insufficiency and 3) baseline ECG showing pathologic Q waves, left ventricular hypertrophy, bundle branch block or ST segment deviation of >0.5 mV. Twenty-six patients met these criteria and gave informed consent for this study, which was approved by the Mount Sinai Hospital institutional review board. Three patients were excluded from this analysis because ECGs obtained during the transluminal coronary angioplasty were inadequate for analysis. The baseline clinical and angiographic characteristics of the remaining 23 patients are described in Table 1. Patients with left circumflex artery angioplasty were excluded because of the lack of a well-established method for quantifying the extent of posterior wall motion abnormalities.

Cardiac catheterization and angioplasty protocol. The principles of our coronary angioplasty premedications, hemodynamic monitoring, guiding and balloon dilation catheters and guide wires have been described in previous publications (9,10). In addition to the routine angioplasty catheter system, a 5F pigtail catheter (Cook) was advanced through the femoral artery for left ventriculography.

Electrocardiography. Standard 12 lead ECGs were recorded using a Hewlett-Packard 4700A Pagewriter model which acquires into memory all 12 leads within 10 seconds. Precordial leads were monitored using X-ray-transparent electrodes. Recordings were made during held end-expiration, standardization was 1.0 mV = 1.0 cm and paper speed was 25 mm/s. ST segment elevation, ST segment depression, R wave amplitude and the corrected QT interval (QTc) were measured on all ECG tracings. New hyperacute T waves or sudden inversion of T waves as compared with the baseline ECG tracing were noted. ST segment elevation above the baseline (as defined by two consecutive PR segments) was measured to the closest 0.5 mm 0.02 second after the J point (11). The magnitude of ST segment elevation in each lead showing elevation was measured and summed over the 12 leads. The total number of leads showing ST segment elevation was also calculated. ST segment depression ≥0.5 mm below the baseline 0.08 second after the J point in any lead was considered significant.

R wave amplitude was measured to the closest 0.5 mm as the vertical distance from the preceding PR interval to the peak of the R wave. The sum of R wave amplitudes in all 12 leads was calculated. The sum of R wave amplitudes in only those leads with ST segment elevation during ischemia was also noted.

The QT interval was measured to the closest 0.02 second in each of the 12 leads and, using Bazett’s formula (12), was expressed as the QTc interval. The longest QTc interval in each lead was noted and, in addition, the sum of the QTc intervals in all 12 leads was calculated for each electrocardiogram. Heart rate was calculated from a Honeywell Electronics for Medicine recording console.

All ECG measurements were made manually by one of us (S.J.S.), who was completely unaware of the clinical and ventriculographic impact of balloon inflation during transluminal coronary angioplasty. In five randomly chosen patients, two consecutive baseline ECGs were recorded before angioplasty to assess the intrinsic variability of our ECG measurements. The difference between the two measurements of the sum of ST segment elevation, the sum of R wave amplitudes, the QTc interval and the sum of the 12 QTc intervals for each of the five patients was analyzed and the standard deviation of the mean value of the differences was calculated; intrinsic variability was described as ±2 SD. The sum of ST segment elevation varied by ±0.5 mm, the sum of R wave amplitude varied by ±7.6 mm, the QTc interval varied by ±0.04 second and the sum of the 12 QTc intervals varied by ±0.6 second.

Arteriography and left ventriculography. All lesions dilated in the right coronary artery were situated proximal to the posterior descending artery. All lesions dilated in the left anterior descending artery were in the proximal or mid-segments of this vessel. The Diasonics/Fischer digital subtraction imaging system was used for creation and analysis of the left ventricular images obtained from injection of 40 cc of Renografin-38% (meglumine diatrizoate) contrast directly into the left ventricle in the right anterior oblique view. Left ventricular ejection fraction was calculated using the area-length method of Dodge et al. (13). The extent of segmental wall motion abnormalities induced by angioplasty balloon occlusion was quantified using the radial axis model of Ingels et al. (14,15). In this model, radii are spaced 5° apart around the centroid and radial shortening <2 SD below the mean value for a normal population (14,15) defined a “hypocontractile segment.” The “percent hypocontractile perimeter” was defined as the length of the hypocontractile segment divided

Table 1. Preangioplasty Clinical and Angiographic Characteristics of 23 Patients

| Age (yr) | 57 ± 8 |
| Sex (male/female) | 18/5 |
| Duration of angina (mo) | 5.2 ± 7.9 |
| Left ventricular ejection fraction (%) | 65.5 ± 5.4 |
| Percent stenosis of lesion dilated | 88 ± 11 |
| Vessel dilated | |
| Left anterior descending artery | 12 |
| Proximal/distal | 7/5 |
| Right coronary artery | 11 |
| Proximal/distal | 7/4 |
Figure 1. Patient 20. A. From left to right, the pretransluminal coronary angioplasty (Pre TCA) electrocardiogram (ECG) and left ventriculogram, respectively. B. From left to right, the ECG and left ventriculogram during balloon inflation (During TCA). In comparison with the preangioplasty ECG, the recording during balloon inflation reveals a sum of ST elevation = 10 mm. In comparison with the normal preangioplasty left ventriculogram (%Hyp = 0), the ventriculogram during balloon inflation reveals hypocontractility involving 40% of the left ventricular perimeter (%Hyp = 40).

Study protocol. 1) Baseline pretransluminal coronary angioplasty. A 12 lead ECG was obtained followed by a left ventriculogram in the 20° right anterior oblique view using the 5F pigtail catheter. Routine transluminal coronary angioplasty proceeded and several minutes after the third balloon inflation, the “study” cycle began.

Figure 2. Patient 16. A. From left to right, the preangioplasty electrocardiogram (ECG) and left ventriculogram, respectively. B. From left to right, the ECG and left ventriculogram during balloon inflation. In comparison with the preangioplasty ECG, the recording during balloon inflation reveals a sum of ST elevation = 16 mm. In comparison with the normal preangioplasty left ventriculogram (%Hyp = 0), the ventriculogram during balloon inflation reveals hypocontractility involving 30% of the left ventricular perimeter (%Hyp = 30). Abbreviations as in Figure 1.
2) Study cycle during transluminal coronary angioplasty. At 30 seconds into the fourth balloon inflation, a simultaneous 12 lead ECG was repeated. At 40 seconds, a left ventriculogram was acquired. Examples of the ECGs and left ventriculograms obtained before and during balloon inflation in two patients are shown in Figures 1 and 2.

Statistical analysis. The study patients were classified into two groups: Group I, 12 patients with left anterior descending artery dilation and Group II, 11 patients with right coronary dilation. Each group was analyzed separately. All continuous variables are presented as the mean ± SD. The examination of the differences between the baseline cycle and the angioplasty inflation cycle involved the paired t test. The relation between the ECG variables 1) sum of ST segment elevation and 2) magnitude of ST segment elevation in lead V2 or lead III and the percent hypocontractile perimeter was best fitted by applying a second order polynomial equation and a correlation coefficient was calculated. The relation between the ECG variable and the number of leads with ST segment elevation with the percent hypocontractile perimeter was assessed by applying non-parametric statistics and calculating the Spearman rank correlation coefficient. Probability (p) values ≥0.05 were considered not significant.

Results

ECG detection of the presence and location of new wall motion abnormalities. Sudden coronary occlusion by the angioplasty balloon resulted in significant myocardial ischemia in the majority of patients. Left ventriculography during balloon inflation revealed that 19 of the 23 patients exhibited new areas of hypocontractility ranging from 3 to 40% of the left ventricular perimeter. The patients experiencing changes in ST segments or T waves are listed in Table 2 according to left versus right coronary dilation. Sixteen of the 19 patients who developed new wall motion abnormalities developed acute ST segment elevation >0.5 mm compared with their baseline ECG. In contrast, only 13 of these 19 patients manifested ST segment depression. In two patients with a midright coronary artery lesion and a hypocontractile segment of only 3 and 5%, respectively, the only ST or T segment change observed was isolated ST segment depression in the inferior leads. In one other patient with a midright coronary lesion and a hypocontractile segment of only 5%, no ECG changes were observed. Four patients had no new wall motion abnormalities; none of these patients had any ST or T wave changes. None of the 23 patients had significant T wave changes in the absence of ST segment shifts. Comparing ST segment and T wave changes, acute ST segment elevation was the most sensitive

| Table 2. Number of Patients With ST Segment or T Wave Shifts in Each Lead |
|-----------------|----|----|----|----|----|----|----|----|----|----|----|----|
| Artery Occluded | I  | aVL| V1 | V2 | V3 | V4 | V5 | V6 | II | III| aVF|
|-----------------|----|----|----|----|----|----|----|----|----|----|----|----|
| LAD (n = 12)    | 2  | 5  | 6  | 10 | 9  | 7  | 3  | 1  | 0  | 0  | 0  | 0  |
| RCA (n = 11)    | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 6  | 6  | 5  |

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ECG indicator of new asynergy (sensitivity = 85%, specificity = 100%, predictive value = 100%).

Among the 19 patients with new asynergy, 10 had anterior wall and 7 had inferior wall asynergy. All of the 10 patients with new anterior wall asynergy experienced ST segment elevation in lead V2 ≥ 0.5 mm (Table 2). No other lead was more sensitive in localizing new anterior wall asynergy. One patient had a greater magnitude of ST segment elevation in lead V3 than in lead V2, but both leads demonstrated ST segment elevation. Among the seven patients with new inferior wall motion abnormalities, five exhibited ST segment elevation in leads II and III ≥ 0.5 mm; lead aVF was less sensitive.

Changes in R wave amplitude and QT interval between the baseline cycle and the inflation cycle were analyzed in those patients with new asynergy (Table 3). No significant difference was observed between the sum of R wave amplitudes on the inflation cycle ECG compared with the baseline ECG. When this analysis was carried out summing the R waves only in those leads in which there was ST segment elevation there was still no significant change in the sum of R wave amplitude during coronary occlusion. In contrast, both groups of patients experienced a significant prolongation in the sum of the QTc interval during ischemia (Table 3). When one examined only the lead with the longest QTc interval, before and during balloon occlusion, only the patients undergoing left anterior descending dilation demonstrated a significant prolongation in the longest QTc interval during ischemia.

ECG correlation with extent of new wall motion abnormalities (Fig. 3 to 5). Three ECG variables utilizing ST segment elevation were analyzed to assess the correlation between the ECG and the extent of the new hypocontractile segment. Using a second order polynomial equation to describe the relation between the sum of ST segment elevation and percent hypocontractility, a highly significant correlation was observed for left coronary as well as for right coronary artery occlusion (r = 0.96 and 0.89, respectively) (Fig. 3). Because the prior analysis revealed that lead V2 and lead III were the most sensitive individual leads for anterior and inferior asynergy, respectively, we analyzed the relation between the magnitude of ST segment elevation in only one lead (lead V2 or lead III) and percent hypocontractile segment. A highly significant correlation was observed for leads V2 (r = 0.92) and III (r = 0.90) (Fig. 4). Last, there was a significant positive correlation between the total number of leads with ST segment elevation and the percent hypocontractile perimeter (Spearman rank r = 0.77 for the left anterior descending artery and r = 0.92 for the right coronary artery) (Fig. 5).

**Discussion**

Our study constitutes the first prospective analysis of the relation between the ECG and an angiographic estimate of the extent of the ischemic segment assessed within minutes of sudden coronary occlusion by balloon inflation in a large group of human subjects with fixed, severe atherosclerotic heart disease. Using the angioplasty model described, we assessed the ECG variables of ST segment elevation, ST segment depression, R wave amplitude and corrected QT interval and examined the acute changes in these variables relative to the extent of ischemic wall motion abnormalities. Our observations suggest that in humans there is a highly significant relation between ST segment elevation and the size of the ischemic hypocontractile zone.

**Previous studies comparing ST segment changes with infarct size.** Using epicardial electrodes in a dog model of sudden ischemia, Maroko et al. (16) suggested that the sum of ST segment elevation and the number of leads showing ST elevation correlated well with pathologic estimates of infarct size. In 1975, Muller et al. (17), using a dog model, showed that the sum of ST segment elevation obtained from precordial leads also correlated well with infarct size. Using a pig model of sudden ischemia, Holland and Brooks (18, 19) showed that infarct size correlated with ST segment elevation in precordial but not in epicardial measurements of ST elevation.

![Figure 3](https://example.com/figure3.png)

**Figure 3.** The relation between the sum of ST segment elevation during coronary occlusion (abscissa) and the percent hypocontractile perimeter (%Hyp) (ordinate). **Left panel,** Twelve patients with left anterior descending coronary (LCA) balloon dilation; **right panel,** 11 patients with right coronary artery (RCA) balloon dilation.
ST deflections. In addition, they outlined several nonspatial factors that could have a major impact on the extent of ST segment elevation. Work in humans, however, has yielded conflicting results. Whereas two groups of investigators (20,21) observed poor correlation between the sum of ST segment elevation and infarct size estimated from creatine kinase washout curves, two other groups (22,23) observed good correlation between these variables.

Our observations indicate that both the sum of ST segment elevation and the number of leads with ST segment elevation observed within the first minute of ischemia correlate well with angiographic estimates of the size of the ischemic hypococontractile zone. This good correlation applies to patients with either left or right coronary occlusion. The curves that best describe this relation have a steep early rise followed by a plateau. This would indicate that above a certain size of hypococontractile zone other factors probably play a role in determining the ultimate extent of the ST segment elevation (18,19). A greater number of patients would be needed, however, to further validate the correlations we observed. Because full 12 lead ECGs may not be readily available during routine coronary angioplasty, we analyzed the relation between the magnitude of ST elevation in the most sensitive lead for either anterior or inferior asynergy and extent of hypococontractility and found that monitoring just one lead gave a good reflection of the extent of the ischemic zone. This finding is in keeping with the observations of Capone and Most (24), who showed a good correlation between the magnitude of ST segment elevation in a single precordial lead and the sum of ST segment elevation. In several of our patients, however, minimal ECG changes were observed despite total balloon occlusion. Therefore, other factors, such as site of balloon occlusion, duration of occlusion or good collateral flow, may account for the extent of ECG changes.

Previous studies on R wave amplitude and QT intervals during ischemia. Earlier investigators (4–6) suggested that giant R waves were a common early sign of acute ischemia. Using atrial pacing to induce ischemia, David et al. (25) observed an increase in R wave amplitude in lead V5 in 15 of 17 patients. Barnhill et al. (26) assessed the changes in the QRS complex using digital computer analysis in five patients with spontaneous variant angina and observed significant changes in the absolute height of the QRS complex during ischemia. In contrast, Myers et al. (27) measured spatial R wave amplitude during exercise testing and observed no relation between changes in R wave height and evidence of ischemia based on thallium-201 imaging. Recently, Feldman et al. (28), using precordial and intracoronary unipolar ECGs during angioplasty, failed to show any acute changes in R wave height during balloon occlusion.

In the present study, no significant differences were observed between the R wave amplitudes during ischemia compared with baseline. In an attempt to minimize any dilutional effect of random changes in R wave height, an additional analysis was performed of R wave changes only in those leads showing ischemic ST segment elevation. This too, revealed no significant differences. Several individual patients did manifest a large change in R wave height. However, analysis of two repeated baseline measurements revealed a large intrinsic variability in R wave amplitude. Therefore, given the size of our patient group, the changes observed did not reach statistical significance.

Mandel et al. (29) observed a significant shortening in the refractory period within the ischemic zone early after
coronary occlusion in a dog model, suggesting that ischemia may affect the QT interval. In a prospective study in humans, Cinca et al. (30) measured the QT interval within 6 hours of acute transmural infarction. They observed a relative shortening in the QT interval in the lead overlying the ischemic zone in the early phase, followed by a prolongation after 12 hours. Other investigators (31,32) suggested that QT interval prolongation was relatively common in the early phase of acute myocardial infarction. Furthermore, data from Ahnve et al. (33) indicate that QT prolongation after myocardial infarction may be associated with a higher postinfarction mortality rate.

Our study indicates that within the first minute of coronary occlusion there is a small but significant increase in the QTc interval assessed over all 12 leads for both left and right coronary occlusion. Because previous investigations used only one particular lead to assess changes in the QTc interval, we also analyzed the lead with the longest QT interval. Significant prolongation occurred in patients with left occlusion but not with right coronary occlusion. The implication of these QT changes in any one lead, however, should be viewed with caution because of the relatively large intrinsic variability observed in our analysis of two repeated baseline ECGs.

Clinical implications. The ECG is a very sensitive and simple tool for assessing sudden onset of myocardial ischemia during coronary angioplasty. Of the ECG variables analyzed, ST segment elevation best parallels the development of new asynergy during transmural coronary angioplasty. The close association between ST segment elevation and extent of asynergy may be useful in predicting the impact of sudden coronary dissection and occlusion on ventricular function during coronary angioplasty. This knowledge may help the physician better assess the need for emergency revascularization after such a complication.

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References

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