

Analysis of Electrocardiographic Recordings Associated with Acute Myocardial Infarction

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OBJECTIVE

Evaluate correlations between variations in electrocardiogram (ECG) recordings and acute myocardial infarction.

METHODS

Use of a low-cost software to digitalize printed and/or “.pdf” file format ECG recordings. Calculation of ST-segment area and amplitudes of the J and Y points.

RESULTS

The amplitude of the Y point holds maximum correlation with troponin concentration. ST-segment elevation is not a good statistical indicator of myocardial infarction severity. There is a strong negative correlation between the amplitude of the J point and the amount of magnesium ions, but no statistical correlation with sodium or calcium ions. Neither method for calculating the ST-segment area (pixel counts and interpolation) indicated any significant differences in the results.

CONCLUSION

The software used proved to be functional and cost-effective. Y point amplitude is a sensitive marker of myocardial infarction, and is also a calculation method both simpler to use and less subject to error than the calculation of the ST-segment elevation area.

KEY WORDS

Acute myocardial infarction, telemedicine, electrocardiogram.

Acute myocardial infarction is caused by the interruption of blood flow to the coronary arteries. Early diagnosis is essential for the reduction of mortality and potential sequelae to the patient.

One of the most accurate tools for this diagnosis is the electrocardiogram (ECG), performed with a device that measures the electrical impulses that travel through the cardiac muscle and provides a characteristic tracing that allows the identification of heart diseases. Currently this device can be found at healthcare facilities, but ECG recordings must be interpreted by specialists who are not always at the site the moment the exam is performed. In these situations, physicians can rely on the remote transmission of ECG signals to other healthcare units where specialists can receive and interpret these signals in real time. This resource consists of modern digital ECG devices with ports designed for computerized data management. However, there are still many analogical devices in operation that generate ECG tracings on paper strips, making this remote analysis unfeasible.

The *Hospital das Clínicas of the Universidade Federal de Uberlândia (HCU)* has a highly qualified team to assist patients experiencing cardiac emergencies. However, as is the case in other teaching units in the country, their equipment has not been updated. There are still many analogical ECG devices being used that generate ECG tracings on paper strips that will be analyzed later. If these results could be stored in a computer, their analysis and filing would be significantly optimized, generating positive results both in terms of cost reduction and speed in treating the patients.

The ECG and acute myocardial infarction - As the electrical impulse generated by the cardiac cells travels throughout the heart, electrical currents spread through the surrounding tissues and small fractions emerge at the surface of the body generating an electrical field on the entire body surface. As mentioned by Guyton & Hall⁹, since body fluids are good conductors of electricity, if electrodes are placed on the skin on opposite sides of the heart it is possible to record the potential fluctuations that represent the algebraic sum of the action potentials of myocardial fibers. This record, performed with an appropriate amplifier, is called electrocardiogram (fig. 1).

ECG waves are identified by letters from P to T, each of them representing phases of the cardiac cycle. For easier analysis, the waves may be considered isolated or in groups known as segments or complexes.

The ST-segment begins at the J point where the inscription of the QRS complex ends, with an upward concavity in normal circumstances (fig. 2). Its end, however, is not very well defined as it diffusely connects with the ascending branch of the T wave. The earliest sign of acute myocardial infarction is the straightening of the ST-segment, i.e., the loss of the slight concavity that normally exists at the transient ascension of the ST-segment.

In the hyperacute phase, an infarctus blockage usually occurs associated with the ST-segment elevation and increased amplitude of the T wave. The ST-segment initially curves with an upward concavity and positive T wave. This is the worst moment in the progression of the disease because of the greater possibility of ventricular fibrillation (fig. 3).

Analysis of the correlation between ST-segment changes and acute myocardial infarction (AMI) began in the 1970s.¹⁰ Later on, Schweitzer¹¹ observed an interesting association between ST-segment elevation and the greater efficacy of streptokinase for the thrombolytic treatment. The author concluded that the larger the number of leads with ST-segment elevation, the more effective the treatment, thus increasing the chances of performing coronary reperfusions in infarction patients.

Approximately 50% of infarction patients do not show ST-segment elevations on the first ECG. Serial ECGs may reduce the chances of diagnostic errors to 10%-20%.¹² In a twelve-lead ECG, the ST-segment elevation associated with chest pain has a 91% specificity and a 46% sensitivity for the diagnosis of AMI¹³. In acute coronary syndromes three types of changes may be observed on the ECG¹⁴.

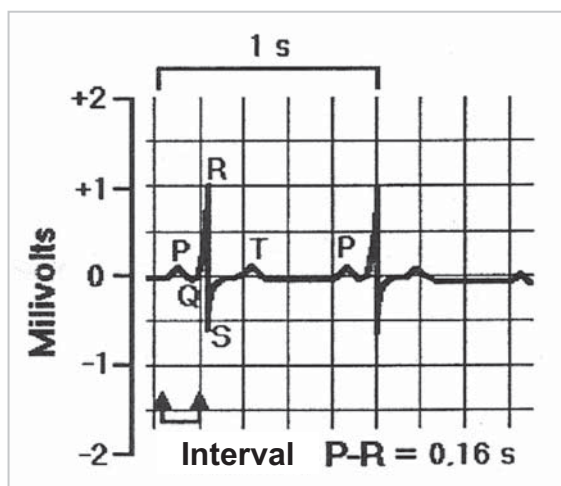


Fig. 1 - Recording of a normal electrocardiogram⁹.

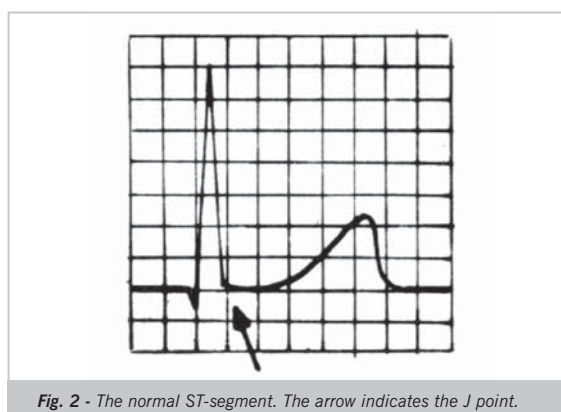


Fig. 2 - The normal ST-segment. The arrow indicates the J point.

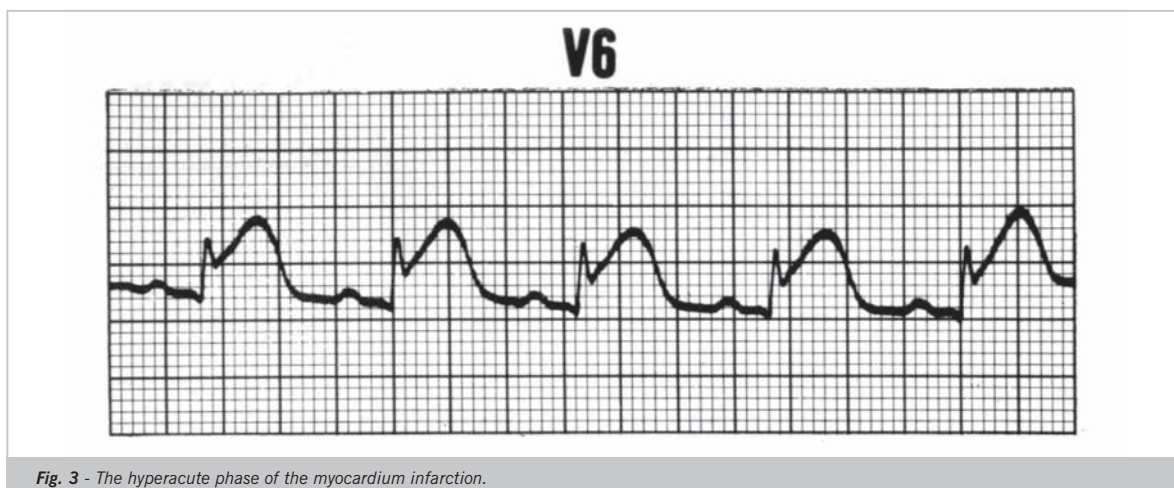


Fig. 3 - The hyperacute phase of the myocardium infarction.

- Abnormal Q wave: the abnormality is detected when the Q wave is wider than one-third of the QRS complex indicating that there is an area with no electrical activity in the myocardium, that is, an infarcted area.
- Inverted T wave.
- ST-segment elevation: detected at the moment the infarction occurs.

According to the *Sociedade Brasileira de Cardiologia*¹⁵ (Brazilian Society of Cardiology), there is a sequence of electrocardiographic changes following the occlusion of a coronary artery: 1. initial minutes: ample, positive, peaked and symmetric-based T waves, with ≥ 0.1 mV elevation; 2. after 20 minutes: ST-segment elevation that morphologically tends to become convex; 3. hours later: detection of pathological Q waves and loss of R waves; 4. a few days later: ST-segment returns to baseline, and T wave is negative, deep and symmetrical. A prolonged ST-segment elevation after six weeks following the acute event may suggest the occurrence of ventricular aneurysm; 5. months after the acute event: the T wave may become positive.

In spite of being an important indicator, the ST-segment elevation may also be caused by other diseases such as pericarditis, hypothermia, left bundle branch block, early repolarization, or artificial cardiac stimulation¹⁵.

This paper represents our first step towards processing analogical ECG recordings, so that to analyse the correlations between ST changes and AMI seriousness. This could contribute towards the development of automated diagnosis techniques, according to trends of the literature below.

In this paper our study focuses on the determination of the ST-segment elevation area, the amplitude of the J point (that delimits the beginning of the ST-segment elevation), as well as the amplitude of the Y point (which begins 40 milliseconds after the occurrence of the J point).

METHODS

Cinical data - Data were collected at the *Hospital de Clínicas de Uberlândia HCU/UFU* - One hundred and twenty medical charts of acute myocardial infarction patients admitted to HCU/UFU from 1/1/2004 to 12/31/2004 were selected. This sample was further screened based on the criteria below that establish the subject profile required for this study.

- (C1) Admission diagnosis: acute transmural infarction of the anterior myocardium wall.
- (C2) First ECG made after manifestation of infarction: it should be performed within six hours, maximum, after the infarction, which is necessarily indicated by precordialgia signs.
- (C3) Changes in the ST-segment on the ECGs: patients selected were only those whose ECGs indicated ST-segment elevation in any of the leads, except aVr as this lead is not used to check ST-segment elevation due to being inverted.
- (C4) Changes in the amount of troponin and Ck-mb enzymes present in cardiac tissue: the values should be elevated, typically over 500 nanograms/deciliter.

The selection of medical charts was also based on the following exclusion criteria:

- (C5) Acute infarction caused by total bundle branch block (either left or right);
- (C6) Acute infarction due to total atrioventricular block.

Fifteen medical charts complied with these requirements. As the medical chart selection was completed, data collection was performed by filling out a form with patient data, characteristics of the infarction (affected leads, time elapsed since the first symptoms, medications, etc.). The forms were completed for all fifteen patients, and all ECGs recordings of these patients were set apart for analysis.

Data collection at the *Instituto de Telemedicina*

do Brasil – ITMS – Brasil - ECGs recordings of twenty patients who had suffered acute myocardium infarction were selected from an electronic database containing PDF files corresponding to digital ECG recordings sent to ITMS-Brazil headquarters by telephone. All ECG presented ST-segment elevation, and we considered the same selection criteria as described in the previous subsection. Notice that clinical data were not collected.

Digitalization software – Eletrocheckup - The Eletrocheckup software was developed as a low-cost alternative for the digitalization of ECG printouts¹⁶.

Calculation of ST elevation, J and Y points - The graphic morphology of an ECG allows the easy identification of the wave components by analyzing the digital value matrix, considering the X axis as the interval of time elapsed. Upon identification of the starting point coordinates, and scanning the amplitudes in the data matrix, the values (voltages) tend to increase. When this trend is inverted, the point immediately before is considered as P point, and the values keep on decreasing. When this trend is inverted again, the Q point is identified and so on.

The J point is defined as the end of the QRS complex and the beginning of the T wave. On a normal ECG, it is located at baseline level. After the point that identifies the S wave, the values begin to increase linearly. The J point can be identified by comparing these values with the baseline¹⁷.

The Y point is located 40 milliseconds after the J point. Its amplitude can be obtained by analyzing the ECG points located right after the J point.

In order to identify the amplitude of the J point, considering the case of an ECG recording associated an AMI patient, one needs first to locate the R point, from which a horizontal scan is made on the Y axis up to the point wherein the ECG plot changes its derivative. The Y point is established when the Y axis is scanned horizontally, 40 milliseconds after the J point.

For the calculation of the area, the following methods were used: *Method 1 – Pixel counts* - The digitalized graphic images consist of points that are invisible when viewed from a distance, generating the optical impression of lines, solid filled areas, etc. The unit of measurement that represents the density of points per inch, known as “resolution”, is given in “pixels”, also known as dots per inch (dpi) or points per inch. Therefore, an image with 300 –pixel resolutions has 300 points in each linear inch, either in vertical or in horizontal orientation.

Usually, a type of graph paper is used for the electrocardiogram record, with 1 millimeter of distance between every two horizontal or vertical lines. Therefore, the smallest unit of area determined on the paper corresponds to a 1 mm side square (fig. 4)¹⁸.

In a resolution where each 1 mm square contains 10 pixels, whether vertical or horizontal, the result is an area containing 100 pixels. The initial and end points in the portion of interest in the electrocardiographic tracing are

identified for calculation purposes. An imaginary line is drawn vertically as from the initial point, and an imaginary line is drawn horizontally as from the end point, thus establishing the desired area. The pixel counts are made on the delimited area and, when all of them are summed up, the value of the area is obtained (fig. 5).

Method 2 – Traditional integration - The second method used to estimate the area consists again of identifying the initial and end points of the desired electrocardiographic tracing. An imaginary line is drawn vertically from the initial point and horizontally from the end point. Then, the latter is divided into small rectangular areas, which are established by points selected along the tracing. Summing up these small areas lead to the final (figs 6 and 7).

In order to choose the points, we used the interpolation technique which consists of determining a polynomial that takes on known values at given points, called as interpolation nodes, to be properly set up. Generally speaking, the set of interpolation functions is established by a finite number of parameters. In the case of polynomials, these parameters are their coefficients, which should be equal to the number of conditions imposed, that is, the number of nodes, so that only one solution is obtained.

RESULTS

Comparison between the area calculation methods - To calculate the areas, we used ECG .pdf files supplied by ITMS-Brazil.

We obtained the results shown on Table 1 with both methods. After estimating the area, the error between the areas obtained by the two methods discussed above is calculated as per the following formula:

$$Error = A1 - A2 \quad (1)$$

where A1 is the area calculated by method 1, and A2 is the area calculated by method 2. Other values in Table 1 are described next.

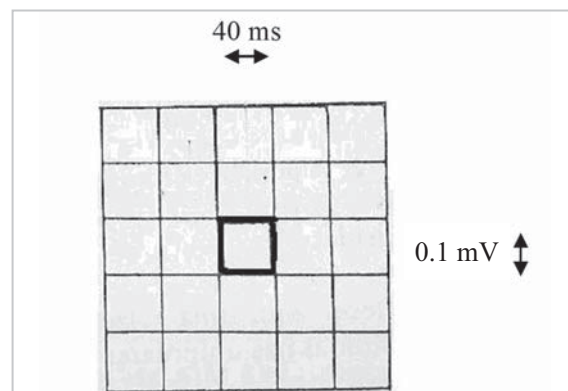


Fig. 4 - The Cartesian system of the electrocardiogram.

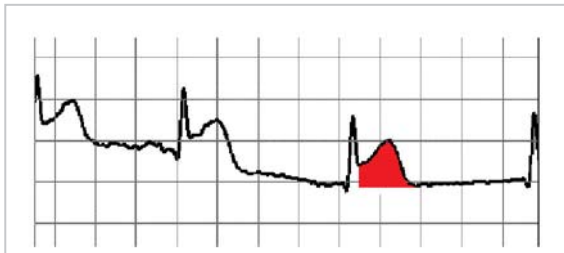


Fig. 5 - ECG area selected for calculation in pixels.

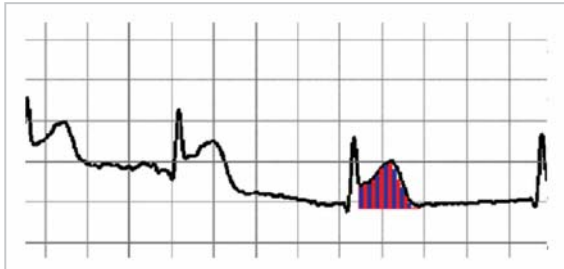


Fig. 6 - ECG area selected for calculation using interpolation.

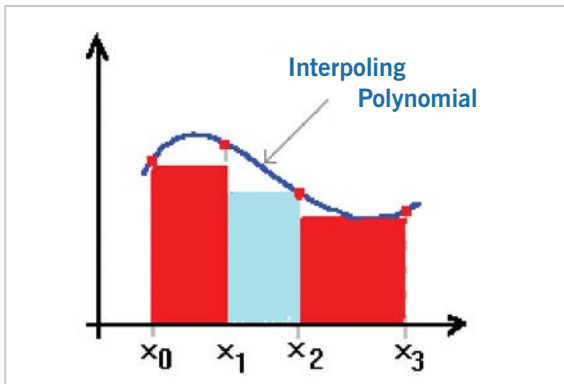


Fig. 7 - Interpolation in four points.

$$V = \sum_{i=1}^n (A_i - MV)^2 / n \quad (2)$$

where V is the variance, n is the number of patients, A_i is the area of the ST segment elevation associated to the patient, and MV is the mean value of A_i .

$$NV = V / E[x^2] \quad (3)$$

$$E[x^2] = \sum_{i=1}^n A_i^2 / n \quad (4)$$

where NV is the normalized variance.

The calculation of the mean error value specified in Table 1 points out us to conclude that both methods generate similar results. At the same time, since the

values of error variance associated with the several leads are small, both methods are sound relative to the type of variation considered. Consequently, the methods have very similar performance. Considering that method 1 is more efficient from a computational point of view, it was used for the subsequent analyses in this study.

Calculation of the correlation between ST-segment elevation and acute myocardial infarction -To perform the calculations, ECGs from the HCU/UFU were used in order to assess the statistical correlation between two sets of X and Z variables, defined below.

$$X = \{A, H_j, H_y\} \quad (5)$$

where: X = represents the set of variables associated to characteristics of the ST-segment on the ECG; A = Area of ST-segment elevation [mV.ms]; H_j = Height of the J point on the ECG [mV]; H_y = Height of the Y point on the ECG [mV].

The “characteristic ECG” of each patient is established as the first recording taken six hours after the first manifestation of AMI. In general, this ECG corresponds to the first measurement made in the emergency room at the HCU/UFU. However, considering the frequent illegible printouts and the poor graphic quality of the analogical ECG recordings, the characteristic ECG did not always correspond to the first measurement. In this case, it was chosen as the first chronologically most readable ECG among the series of registers made at the emergency room.

From the characteristic ECG, the initial and end final points of the ST-segment elevation were highlighted, always using three leads for each ECG. The values of A, H_j and H_y were estimated for each one of the three leads in each characteristic ECG. Finally, the final characteristic values of the ST-segment elevation area, amplitude of the J point, and amplitude of the Y point associated to each patient correspond to an arithmetic mean involving all the corresponding values of A, H_j and H_y , considering the three leads of each characteristic ECG.

Table 2 shows the characteristic values of the X variables for each patient, obtained by average of the ECG data collected with the form.

Next, the other set of variables is defined.

$$Z = \{Tr, Ck, k, Na, Ca, Mg, Gl, VF, Le\}$$

where: Z = represents the set of variables associated to clinical tests performed with blood samples of acute myocardial infarction patients; Tr = concentration of troponin enzyme [nanogram/deciliter]; Ck = concentration of the Ck-mb enzyme [unit/liter]; K = concentration of potassium ion [milliequivalent/liter]; Na = concentration

Table 1 – Calculation of the ST-segment area for digital ECG (mV.ms)

Patients	aVf Lead			II Lead			III Lead		
	Method 1	Method 2	Error	Method 1	Method 2	Error	Method 1	Method 2	Error
1	87.48	85.80	1.68	92.04	90.52	1.52	66.88	66.96	-0.08
2	79.68	78.68	1.00	75.96	74.76	1.20	71.88	70.68	1.20
3	76.48	75.80	0.68	80.20	79.56	0.64	83.64	82.92	0.72
4	16.20	15.80	0.40	24.60	24.56	0.04	35.72	35.52	0.20
5	14.80	14.56	0.24	31.20	31.12	0.08	5.40	5.36	0.04
6	6.04	6.00	0.04	10.52	10.48	0.04	15.48	14.92	0.56
7	11.56	11.32	0.24	28.20	27.92	0.28	15.88	15.44	0.44
8	63.24	63.28	-0.04	26.72	26.60	0.12	151.32	151.04	0.28
9	159.36	158.16	1.20	139.12	138.20	0.92	167.60	166.00	1.60
10	29.52	29.16	0.36	41.64	41.24	0.40	17.48	17.16	0.32
11	62.00	61.68	0.32	1.32	1.16	0.16	189.68	189.00	0.68
12	360.08	354.68	5.40	346.04	343.68	2.36	385.40	379.48	5.92
13	169.28	168.92	0.36	38.64	38.56	0.08	295.24	295.48	-0.24
14	179.28	177.44	1.84	125.52	124.12	1.40	231.24	229.20	2.04
15	236.48	236.20	0.28	191.08	191.12	-0.04	267.36	266.60	0.76
16	61.60	61.40	0.20	69.80	69.68	0.12	55.28	55.24	0.04
17	56.68	56.64	0.04	21.96	21.92	0.04	131.08	130.92	0.16
18	95.64	95.60	0.04	52.92	52.84	0.08	186.60	186.56	0.04
Mean value (MV)	98.08	97.28	0.79	77.64	77.11	0.52	131.84	131.03	0.82
Variance (V)	7,999.88	7,831.40	1.54	6,562.39	6,483.86	0.44	11,585.09	11,410.28	1.87
Normalized Variance (NV)	0.45	0.45	0.71	0.52	0.52	0.61	0.40	0.40	0.74

of sodium ion [milliequivalent/liter]; Ca = concentration of calcium ion [milliequivalent/liter]; Mg = concentration of magnesium ion [milliequivalent/liter]; Gl = blood glucose [milliequivalent/liter]; CV = closed vessel (CV = 1) or not (CV = 0). Binary variable; PI = percentage of lesion [%].

Important notes: 1) considering the variability in the concentration level of troponin and CK-mb enzymes, the maximum amplitude concentration, provided by the corresponding data collection form, was chosen as the characteristic value of each patient. 2) in terms of ion concentrations (K, Na, Ca and Mg) and blood glucose, the first amount provided in the form was chosen as the characteristic value for each patient. This amount represents the first measurement taken after the occurrence of the AMI. 3) closed Vessel (CV) and percentage of Lesion (PI) variables are obtained from the catheterization data. If the lesion is considered mild, P1 is set to 50%; if the lesion is moderate, 70%, and, finally, if the lesion is severe, then P1 is set to 90%. However, if the patient's form presents the percentage of vessel.

Table 2 shows the characteristic values of the Z measurements for each patient obtained from the data collected with the form. Absent values (blank fields) could not be obtained from the medical records.

The correlation coefficients between X and Z were calculated based on the following formulas:

$$CC(X,Z) = E\{((X - X(MV)) * (Z - Z(MV)))\} / (\sqrt{X(V)} * \sqrt{Z(V)}) \quad (6)$$

where CC (X,Z) is the correlation coefficient

$$X(MV) = \sum_{i=1}^n X_i / n \quad (7)$$

$$X(V) = \sum_{i=1}^n (X_i - X(MV))^2 / n \quad (8)$$

where X (MV) is the mean value of X (area, H-j and height H-y), Z(MV) is the mean value of Z (Troponin, Ck-mb, K⁺, Na⁺, Ca⁺, Mg⁺⁺, Blood Glucose, Closed Vessel and % of lesion), X_i (Area, H-j and H-y) is the value that corresponds to patient i, Z_i (Troponin, Ck-mb, K⁺, Na⁺, Ca⁺, Mg⁺⁺, Blood Glucose, Closed Vessel and % of lesion) is the value that corresponds to patient i, and n is the number of patients (in this case, n = 15).

DISCUSSION

The correlation coefficients of Table 3 do not take into consideration the alpha error associated with the concept of "significance", and the number of patients is quite low, leading to a poor statistical accuracy. Moreover, although most of the database is composed of ECGs recorded later than six hours after the AMI has taken place, this condition is not verified for all of them.



Considering all the limitations discussed in the previous paragraph, the results in Table 3 lead to the following conclusions:

- (C1) The amplitude of the Y point has maximum correlation with troponin concentration, and is therefore an indicator of cardiac lesion due to AMI. However, in medical literature,¹⁸⁻²⁰ the amplitude of the Y point is more sensitive and specific for the diagnosis of chronic ischemia. Physiologically, it can be considered an important marker for the assessment of AMI seriousness, since it may indicate that the function of the sodium-potassium pump associated with cardiomyocytes is significantly hampered by the extent of tissue necrosis.
- (C2) ST-segment elevation, as indicated by the A measurement, is not a good statistical indicator of infarction seriousness as it has a close association only with the amount of potassium ions. The fact that the correlation between the latter and the ST-segment areas is negative should be associated with cardiomyocyte membrane repolarization.
- (C3) No significant correlation was observed between the concentration of troponin and CK-MB enzymes, and the percentage of lesion (PI) with the area of ST-segment elevation (A). This may be explained by the fact that the thrombolytic treatment unclogged the vessel, or that the wave associated with cell necrosis was small.
- (C4) There is a high negative correlation between the closing of the vessel (CV) and the ST-segment elevation (A). This may be explained by the fact that the catheterization was performed later.
- (C5) There is a strong negative correlation between the amplitude of the J point and the amount of

magnesium ions, leading to possible studies on the effect of magnesium ions on cardiac action potential. At the same time, there is no statistical correlation between the amplitude of the J point and the concentration of sodium and calcium ions. Indeed, the latter does not take part in ion exchange mechanisms during this phase of the cardiac action potential.

Despite the limitations imposed by the small sampling of data available for testing, the analysis suggests that the Y point amplitude is a sensitive marker of AMI. Additionally, the estimation of this variable is simpler and less subject to errors than the calculation of the ST-segment elevation area, commonly reported in medical literature as an indicator of AMI.

Current results lead to the following topics as future work: search for accurate statistical markers to speed up AMI diagnosis, based on signal processing theories (e.g., linear prediction and wavelets); inclusion of a greater number of patients in the clinical database; use of statistical tools that can yield more accurate correlation analysis; extension of physiological discussions pointed out by the analysis, with respect to medical and biological literature.

The project carried out by Hermiada et al²¹ with 103 patients at the Amiens Picardie Hospital in France pointed out that the elevation of the J point is also a strong indicator of the Brugada syndrome. ECG analyses were performed in patients with clinical suspicion of the syndrome. The results showed an elevation > 0.16mV in lead -2V, with 100% specificity and positive predictivity, 40% sensitivity, and 28% negative predictivity.

The study conducted by Kaluzay et al²² with diagnosis of AMI, also including manual analysis of the same examinations by means of a magnifying glass. The study

Table 2 - Characteristic values for each patient and corresponding mean value (MV)

Patients	A	Hj	Hy	Tr	Ck	K	Na	Ca	Mg	GI	Catheterization	
											CV	PI
1	7.779	0.106	0.130	4.760	606.800	4.500	142.800	8.700	1.200	140.000	1	90
2	2.629	0.034	0.043	1.400	1194.000	4.700	131.600		3.400		0	90
3	2.812	0.055	0.064	2.490	306.500	5.000	139.000	8.400	2.200	224.500	1	52
4	2.110	0.031	0.024	2.200	191.600	4.400	137.400	8.800	1.900	135.000	1	45
5	5.904	0.043	0.084	5.500	198.000	4.100	139.000	8.400	1.920	143.000	1	90
6	7.651	0.066	0.465	35.200	252.700	4.400	136.200	7.200		132.100	1	90
7	5.370	0.073	0.088	3.400	125.600	4.000	137.300	8.900		123.800	0	90
8	8.827	0.108	0.131	15.750	892.000	4.500	137.100		2.400	291.000		
9	6.392	0.068	0.086	4.160	95.000	4.800	138.100	9.300	2.300		1	90
10	19.523	0.308	0.285		561.400	3.600	141.700	8.300	1.200		1	90
11	66.860	0.187	0.337	9.790	287.200	3.700	133.500	8.900	1.900	91.900	0	90
12	59.815	0.214	0.461		1555.000	4.300	140.000			97.100		
13	35.857	0.221	0.264		210.000	4.500	132.000	9.200	1.900	109.000		60
14	58.018	0.199	0.319		198.500	3.200	132.400	8.600	1.700		0	50
15	26.516	0.362	0.240	8.790	73.100	5.400	136.900	8.400	1.700			
Mean Value (MV)	21.071	0.138	0.201	8.495	449.827	4.340	137.000	8.592	1.977	161.940	0.636	77.250

Table 3 – Normalized correlation coefficients

Y \ X	A	Hj	Hy
Tr	0.120	0.119	1,000
Ck	0.448	-0.351	-0.414
K	-0.841	-0.164	-0.583
Na	-0.530	0.003	-0.167
Ca	0.277	0.023	-0.671
Mg	-0.402	-0.809	-0.535
Gl	-0.634	-0.233	-0.577
CV	-0.722	-0.162	-0.389
PI	-0.337	0.479	0.168

was based on 85 ECGs, which were randomly withdrawn from the ENTIRE-TIMI-23 study. The ECGs were scanned at 203 dpi and graphically enlarged. A vertical line was drawn perpendicular to the J point (or in 3, 6 or 12 J points of consecutive recordings). A perpendicular line was also drawn 20 ms after the J point. The calibration

signal and ST-segment intersections with the lines drawn were marked for each lead. The results showed that the ST-segment elevation 20 ms after the J point are greater than at the J point itself, for all infarct sites. In addition, the computerized analysis was more accurate than the manual analysis, presenting a reliability index of 0.991 (95% CI 0.990 - 0.992) against 0.995 (95% CI 0.995 - 0.996) for the software analysis.

Acknowledgements

To Dr. Sílvia Alessi and Dr. André Navarro, at the *Instituto de Telemedicina do Brasil – ITMS – Brasil*. To Professor Dr. Wilson Felipe Pereira, at the *Instituto de Ciências Biomédicas - ICBIM/UFU*.

Potencial Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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