

Refinement and Interobserver Agreement for the Electrocardiographic Sclarovsky-Birnbaum Ischemia Grading System

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Abstract: Background: Electrocardiogram-derived grades of ischemia at the time of patient presentation with acute myocardial infarction have proved useful in predicting the salvageability by reperfusion therapy, final infarct size, severity of left ventricular dysfunction, and short- and long-term prognosis. **Subjects and Methods:** The Sclarovsky-Birnbaum Ischemia Grading System based on the relation between the acute appearances of the T wave, the ST segment, and the QRS complex was considered as a means of enhanced ECG analysis in this group of patients. The evaluation of a training population (n = 46) resulted in refinement of the published description of the Sclarovsky-Birnbaum Ischemia Grading System, and a test population (n = 50) was utilized for investigating the interobserver agreement among 5 observers in determining the grade of ischemia. **Results:** The agreement among the observers applying the "refined" Sclarovsky-Birnbaum Ischemia Grading System was 0.89. Complete agreement was found for the ECGs of 80% of the patients, and the most common reason for disagreement was the application of the terminal T-negativity criterion. **Conclusions:** The refined Sclarovsky-Birnbaum Ischemia Grading System can be performed manually with low interobserver variability. It has potential for support of the acute myocardial infarction triage decision as an electrocardiographic method for evaluating the level of ischemic protection at the time of either pre-hospital or emergency-department presentation. **Key words:** Acute myocardial ischemia, electrocardiography, grades of ischemia.

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Myocardial reperfusion via either intravenous thrombolytic therapy or percutaneous coronary intervention is currently the accepted therapy to attain optimal clinical outcome in patients with acute ST-segment elevation myocardial infarction. A successful outcome with favorable myocardial salvage is influenced by several elements, such as duration of ischemia, collateral and residual antegrade flow, and ischemic preconditioning (1–4). For evaluation of the interventional impact, a method for estimating the level of myocardial pro-

tection via ischemic preconditioning and/or collateral flow at the time of the acute event, and thus predicting salvageability based on the presenting electrocardiogram, would be of great clinical importance.

Sclarovsky, Birnbaum, and colleagues (5) have developed an electrocardiographic algorithm, initially described in relation to prognostic significance for anterior acute myocardial infarction, and more recently proven useful in predicting the extent and severity of left ventricular dysfunction after anterior acute myocardial infarction (6). The Sclarovsky-Birnbaum Ischemia Grading (SB-IG) algorithm represents three grades of ischemia, based on the relation between the acute appearances of the T wave, the ST segment, and the QRS complex.

The SB-IG has been validated in various clinical trials, investigating both anterior and inferior acute myocardial infarction. These studies have shown that the differentiation between Grade II and Grade III of ischemia is associated with a history of pre-infarct angina, influenced by the presence of collateral circulation, and predictive of final acute myocardial infarction size, morbidity, and mortality (7–12). Patients presenting with the most severe grade of ischemia (Grade III) have a lower incidence of pre-infarct angina (8,10) and more limited collateral circulation (11), and subsequent higher mortality, larger final infarct size, and a greater risk of reinfarction independent of therapy (7–10). In contrast, patients classified as having a higher level of ischemic protection (Grade II) have higher incidence of TIMI (Thrombolysis In Myocardial Infarction) 3 flow following rescue percutaneous coronary intervention (12), higher predischARGE left ventricular ejection fraction, and lower incidence of chronic heart failure (11). However, in most of the above-mentioned studies, the Sclarovsky-Birnbaum Ischemia Grading System has only been applied by one of the 2 principal developers.

The hypothesis of the present study is that a more detailed description of the Sclarovsky-Birnbaum Ischemia Grading System for refinement of the algorithm will facilitate attainment of the high level of interobserver agreement required for its general implementation. An additional purpose is to identify areas of disagreement where clarification is needed.

Methods

Study Population

Presenting electrocardiograms from 22 anterior and 24 inferior acute myocardial infarction events

were randomly selected from an acute myocardial-infarction database at the Mayo Clinic, Rochester, MN. These electrocardiograms were selected to serve as a training population for developing a refined algorithm for applying the Sclarovsky-Birnbaum Ischemia Grading System. Eight observers individually evaluated these electrocardiograms based on the published description of the Sclarovsky-Birnbaum Ischemia Grading System (13); and the primary developer (YB) then provided suggestions for the more detailed description required to refine the algorithm.

To compile a test population for the interobserver-agreement study, electrocardiograms with an equal distribution both between Grades II and III of ischemia and the two most common infarct locations (anterior and inferior) were selected. This test population was evaluated independently by five observers. A sample size of 50 patients was considered sufficient for demonstrating statistical significance, since the inclusion of 5 readers made 500 comparisons possible.

The final test population (37 males and 13 females, mean age 62 ± 10 years, range 38–87 years) was selected by the primary developer from the Mayo Clinic database supplemented by the Duke ECG Core Lab database. The remaining observers were blinded to this selection.

The sole inclusion criterion was an electrocardiographically established presence of single acute myocardial infarction (transient ≥ 1 mm ST-segment elevation in at least two contiguous leads). Patients were excluded from the study if the presenting electrocardiogram showed left/right bundle branch block, left posterior fascicular block, left ventricular hypertrophy, pre-excitation or ventricular rhythm. Electrocardiograms with left anterior fascicular block were included, but evaluated according to separate criteria, as shown in Appendix 1.

Development of the “Refined” Sclarovsky-Birnbaum Ischemia Grading Algorithm

The training set of 46 acute electrocardiograms was evaluated by the observers according to the published description of the Sclarovsky-Birnbaum Ischemia Grading System and the resulting compiled suggestions for additions and changes were used for further algorithm refinement. The refined Sclarovsky-Birnbaum Ischemia Grading System is presented in Appendix 1. The modifications were intended to make the system implementable by experienced electrocardiographers for various kinds

of acute ischemic changes. Criteria refinements included:

1. The exclusion of non-supraventricular-paced beats, leads with a peak-to-peak amplitude of <0.4 mV, and electrocardiograms showing either terminal (biphasic T wave with terminal negativity) or total T-wave inversion.
2. Addition of a definition for tall T waves in each lead based on the study of T-wave amplitudes in a normal population by Gambill et al (14).
3. Definition of an ECG baseline for correct amplitude measures and a clarification of the evaluation of indistinct R-wave ending.
4. A detailed definition of criteria employment with respect to different QRS morphology.

Following acute occlusion of a coronary artery, various electrocardiogram manifestations are detected: the T waves are tall, symmetrical and peaked (Grade I ischemia), the ST-segments are elevated (Grade II ischemia), and the terminal portion of the QRS complex is distorted (Grade III ischemia) (15–17). These changes include decreased amplitude of the terminal R wave to no greater than twice the ST elevation in leads with typically a qR configuration (leads I, II, III, aVL, aVF, and V4–V6); and disappearance of S waves in leads with typically an Rs configuration (leads V1–V3).

The changes in the terminal portion of the QRS are presumably caused by prolongation of the electrical conduction in the ischemic region (18–19). This delayed conduction changes the time of activation of the involved myocardial regions, impacting the configuration of the terminal waveforms in the QRS complex (18–22).

Absence of distortion of the terminal portion of the QRS during thrombosis-induced transmural ischemia may be a sign of myocardial protection via persistent myocardial flow from collateral circulation (11) and/or myocardial preconditioning caused by preceding brief ischemic episodes (10). Disappearance of S waves below the PR baseline in leads with an Rs configuration is quite easy to detect, but evaluation of R-wave diminution is only possible if pre-occlusion recordings are available. Hence, an alternate criterion for leads with qR configuration was developed. This criterion relates the R-wave amplitude to the level of the J point of the ST segment (15,17). Although the transition between the grades of ischemia is gradual and continuous, for practical clinical purposes, it was convenient to define Grade II as ST elevation without distortion of the terminal portion of the QRS, and Grade III as ST elevation with distortion of the terminal portion of

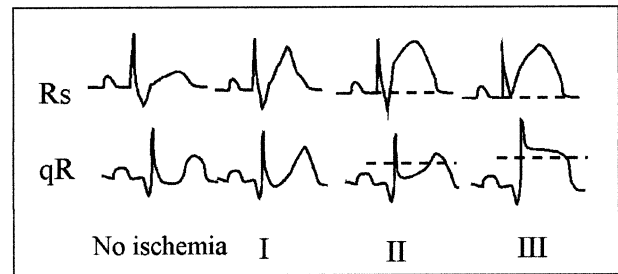


Fig. 1. Description of the different grades of ischemia, for qR and Rs leads, respectively.

the QRS. The latter is defined in the original description of the SB-IGS as disappearance of the S wave below the PR baseline in leads with an Rs configuration or emergence of the J point at ≥ 0.5 of the R-wave amplitude in leads with qR configuration (5,7–9,15, 23) (Fig. 1). This system is limited to the most acute phase of acute myocardial infarction and therefore, patients with electrocardiographic evidence of reperfusion or a more advanced stage of infarction (inversion of T waves) are excluded.

The more detailed description of the Sclarovsky-Birnbaum Ischemia Grading System is included as Appendix 1 below.

Selection of Observers

The 5 electrocardiogram observers, who evaluated the test population, were included because of their interest and commitment to the development and definition of the algorithm. They are all experienced electrocardiogram readers and have been active investigators during the progressive evolution of the Sclarovsky-Birnbaum Ischemia Grading System.

Implementation of the Interobserver-Agreement Algorithm. The interobserver agreement of implementation of the refined Sclarovsky-Birnbaum Ischemia Grading System was determined using the test population of 50 acute event electrocardiograms, as described above. These 50 test ECGs were different from the initial 46 training ECGs. Unlabeled photocopies of the electrocardiograms, a short methods description, and simplified grading sheets were distributed to each of the observers. The results from this investigation were used as a basis for calculating the interobserver agreement for the refined algorithm.

Table 1. Distribution of Grades among the Observers

Ischemia Grade	Observer				
	1	2	3	4	5
II	26	26	25	23	28
III	21	24	22	24	20
none	3	0	3	3	2

Statistics

The percent agreement between pairs of readers ($n = 50$) was calculated, and kappa statistics (24) were used to measure the level of agreement among the readers. Similar measures were calculated for all paired comparisons ($n = 500$).

Results

The refined algorithm was employed on the electrocardiograms of the 50 test patients in the interobserver agreement evaluation. Out of the "5 times 50" electrocardiograms evaluated, 128 (26 ± 2 per observer) were classified as Grade II ischemia, 111 (22 ± 2 per observer) were classified Grade III ischemia, and 11 (2 ± 1 per observer) were classified as "ungradable" because of inverted T waves. The distribution between different ischemia grades among the 5 observers is reported in Table 1.

An overall interobserver agreement of $94 \pm 2.3\%$ ($K = 0.89$, 95% confidence interval 0.86-0.93) was attained for the refined Sclarovsky-Birnbaum Ischemia Grading System. Table 2 shows the specific agreement regarding the 50 acute event electrocardiograms among each of the 5 observers.

Of 50 electrocardiograms evaluated there was total agreement on 40 (80%), 1 reader disagreed with the remaining 4 on 7 (14%), and 2 readers disagreed with the other 3 on 3 (6%). Three of the 10 disagreements were due to oversight of exclusion of inverted T waves, and the other 7 were due to different opinions regarding designation of Grade II and Grade III ischemia. Examples of the electrocardiograms resulting in disagreements are presented in Figure 2. Failure to consider the terminal T-wave inversion (2a) caused misclassification as Grade III, rather than correct exclusion of this electrocardiogram as "ungradable". The assignment as either having a qR or an Rs configuration in leads III and aVF (2b) led to split opinions between Grade II and III. In both leads II and aVF, a terminal R wave is visible, indicating that the correct classifi-

cation is Grade III ($STJ > 0.5 \times R$ -wave amplitude) rather than Grade II (persistence of S waves).

Discussion

The standard 12-lead electrocardiogram remains the most widely available and cost-effective method for evaluation of acute ischemic heart disease. The possibility to utilize the presenting electrocardiogram in patients with acute myocardial infarction for prediction of myocardial salvageability, and thus the prognosis of the patient, would enhance the clinical power of the presenting electrocardiogram. Currently, no method can reliably detect the severity of ischemia in the acute situation. Myocardial scintigraphy using Technetium-99m-sestamibi (25) or contrast echocardiography (26) may give an estimation of collateral flow, but this procedure is not realistic to perform prior to initiating reperfusion therapy on a routine basis and does not incorporate any information on metabolic adaptation, such as myocardial ischemic preconditioning. An estimation of the combined information of ischemic protection by collateral flow and ischemic preconditioning may be found in the presenting electrocardiogram. An algorithm to identify patients with a more severe grade of ischemia, and thus more rapidly evolving infarction is potentially useful for the clinical triage of patients toward either immediate initiation of intravenous thrombolysis or acute percutaneous coronary intervention.

In this study our purposes were to refine the description of the Sclarovsky-Birnbaum Ischemia Grading System, to investigate the level of interobserver agreement of the refined algorithm, and to identify specific areas of disagreement, where further clarification is needed.

Table 2. Interobserver Comparisons ($n = 50$)

Comparison	% Agreement	Kappa	95% CI	P value
1 vs. 2	94	0.89	0.77-1.01	<.0001
1 vs. 3	98	0.96	0.89-1.03	<.0001
1 vs. 4	94	0.89	0.77-1.01	<.0001
1 vs. 5	92	0.85	0.71-0.99	<.0001
2 vs. 3	96	0.93	0.83-1.03	<.0001
2 vs. 4	96	0.93	0.83-1.03	<.0001
2 vs. 5	94	0.89	0.77-1.01	<.0001
3 vs. 4	96	0.93	0.83-1.03	<.0001
3 vs. 5	94	0.89	0.77-1.01	<.0001
4 vs. 5	90	0.82	0.67-0.97	<.0001
All readers ($n = 500$)	94	0.89	0.86-0.93	<.0001

CI, confidence interval.

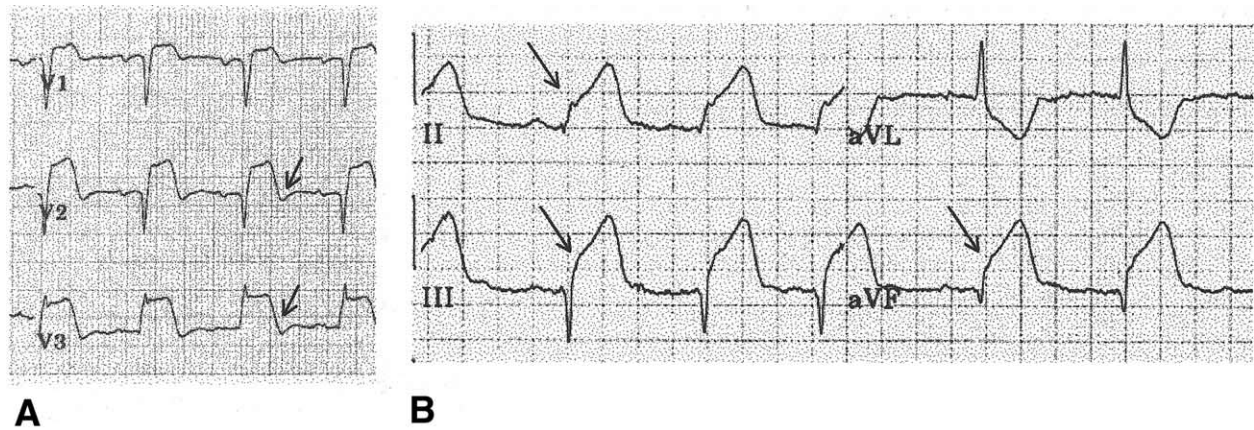


Fig. 2. Examples of ECG leads, where disagreement occurred among the observers. (A) A terminal T-wave inversion (arrows) was overlooked, which resulted in misclassification as Grade III, rather than correct exclusion of the ECG. (B) Variability in classification of the QRS complexes with an Rs or qR configuration. In both leads II and aVF there is qR pattern (arrows), indicating that the correct classification is Grade III ($STJ > 0.5 \times R$ -wave amplitude) rather than Grade II (persistence of S waves). Furthermore, the peak of the R wave (arrow) in lead II is more easily determined and may be utilized for alignment with the remaining leads.

To accomplish the study, ECGs from the Mayo Clinic database were used. They contained sufficient evidence of acute myocardial infarction, were readily available, of good quality and represented to a population of patients presenting with chest pain, later also confirmed as acute myocardial infarction by scintigraphy.

The overall agreement among the observers was very good, $94 \pm 2.3\%$, with a kappa value of 0.89. These results were accomplished using a well-experienced observer population, but they are nonetheless valid as support for the assumption that the system is ready for further refinement and validation, and as the next step, dissemination into general electrocardiographic practice.

Areas of Disagreement

The most common reason for observer variability was the terminal negative T wave (Fig. 2A). The developers of the Sclarovsky-Birnbaum Ischemia Grading System included this consideration because inversion of the terminal aspect of the T wave has been considered indicative of a later phase in acute myocardial infarction evolution (27), for example a sign of reperfusion or the "sub-acute phase" of infarction.

This algorithm is only clinically applicable in the "acute phase." Further studies are required to determine if assignment of ischemia grade should be influenced by "terminal T negativity." Its inclusion

may complicate automated application of the refined Sclarovsky-Birnbaum Ischemia Grading System, since such a biphasic T wave is difficult to define. Comparative validation of this method with and without consideration of the "terminal T negativity" is required.

Another difficulty is the ability of the observers to correctly determine whether a qR or an Rs configuration of the QRS complex is present in a particular lead. The determination considerably impacts the final grade assigned, which is illustrated above in Figure 2b. When a lead is assigned as showing an Rs pattern, the presence of S waves assigns it to Grade II of ischemia. Accordingly, it is very important not to neglect a small, but detectable initial R wave before the negative deflection. This difficulty may be even greater in patients with leftward axis deviation, where the leads oriented vertically (primarily III and aVF) that typically display qR configuration have the decreased R-wave amplitude and increased S-wave depth that produces an Rs configuration.

Limitations

This ischemia grading system was initially created as a clinical tool, rather than a research-based method, and the distribution of grades in a typical infarct population is uneven. Patients with Grade I of ischemia are rarely identified, which makes the system dichotomous. Hence, the current

Sclarovsky-Birnbaum Ischemia Grading System is primarily based on two general grades. A continuous, quantitative system for estimating the level of myocardial protection would be of greater clinical value, allowing better discrimination among the wide variety of electrocardiogram-waveform appearances during the evolution of acute myocardial infarction. An argument to further strengthen the suggested development of the algorithm is that patients presenting with chest pain and complete or tendency to T-wave inversion in the ECG will be excluded. The current system only applies for the "hyperacute" phase of an acute myocardial infarction and an inverted or biphasic T wave is, as mentioned above, seen as a sign of reperfusion or indicative of a later phase of infarction.

In this particular study, only electrocardiogram readers who were familiar with the original algorithm were included as observers. Further studies with completely "uninitiated" investigators should now be performed to eliminate the possibility of an overestimation of the agreeability among these "initiated" observers.

The Sclarovsky-Birnbaum method of classifying QRS distortion by an STJ/R-wave ratio does not reflect the appearance of the QRS complex before the acute event. For example, the R wave may just be "pulled up" by the injury current and may therefore not be equivalent to "real" QRS distortion (20). A more representative and independent measure of QRS distortion may have to be developed.

Furthermore, only 11 electrocardiographic leads are considered. Since at least two contiguous leads are required to assign a patient to Grade III of ischemia, this might lead to underestimation of Grade III of ischemia infarcts in a typical acute myocardial infarction population. This is obvious especially for inferior infarcts, where the acute changes primarily take place in leads II, aVF and III. If the system were expanded to also consider the negative aspects of the standard leads, ie, as a 24-lead concept (28–29), changes in leads –aVR and –aVL would, for example, expand the range of consideration for inferior infarcts.

Future Considerations

The specific areas as those depicted above, where difficulties were identified, may need further clarification before the refined Sclarovsky-Birnbaum Ischemia Grading System should be used in routine practice. Several future aims may be seen for the Sclarovsky-Birnbaum Ischemia Grading System.

One goal would be to develop the system as an electrocardiographic parameter of myocardial protection for research purposes, and another would be for use in clinical electrocardiographic practice. The ultimate aim would be to generate a computer algorithm, capable of being used in commercially available electrocardiogram devices. Given the complexity of the system, the possibility of having access to the written criteria may be required for accurate clinical utilization of the system.

Conclusion

The refined Sclarovsky-Birnbaum Ischemia Grading System can be applied manually with a very good level of interobserver agreement. It has potential for support of the acute myocardial infarction triage decision in general clinical practice as an electrocardiographic method for evaluating the level of ischemic protection at the time of either pre-hospital or emergency-department presentation.

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Appendix 1

THE REFINED SCLAROVSKY-BIRNBAUM ISCHEMIA GRADING SYSTEM

- A. Consider only ECGs with:
 1. no complete RBBB or LBBB
 2. no LVH
 3. no WPW
 4. no ventricular paced or ventricular rhythm
- B. Consider only leads with:
 1. Total peak-to-peak QRS amplitude ≥ 0.4 mV
 2. ST elevation (rounded up to ≥ 0.1 mV) and entirely positive T waves and/or tall positive T waves by Gambill criteria:
 1. III and aVL ≥ 0.25 mV
 2. I, II, aVF, V1 and V6 ≥ 0.5 mV
 3. V₅ ≥ 0.75 mV
 4. V2, V3 and V4 ≥ 1.0 mV
- C. Consider only beats with supraventricular QRS morphology.

- D. Measure all waveforms from the PR baseline. If there is apparent PR depression consider the TP baseline.
- E. Assign Grades I, II, or III, to all considered leads meeting the stated criteria. In leads where it is difficult to identify the end of the R wave, use an adjacent lead with a well defined QRS complex as a reference for the QRS duration.

For leads I, II, III, aVL, aVF, V4, V5 and V6

1. Leads with a QR configuration (i.e. R only or QR):
 - a. Grade I tall positive T wave, no ST elevation
 - b. Grade II positive T wave, J point/R wave amplitude ratio <0.5
 - c. Grade III positive T wave, J point/R wave amplitude ratio ≥ 0.5
2. Leads with an RS or RSR' configuration (i.e. RSR' or QSR'): In leads with a terminal S configuration and ST elevation; grade II should always be assigned because of the presence of S waves.

3. Leads V4 and V5 in presence of left axis deviation:

- a. In cases with left axis deviation ($\leq -30^\circ$) and with S waves present in lead V5: If there is ST elevation without an S wave present in lead V4, assume that on the pre-event ECG, there were also S waves in V4; therefore assign the lead as Grade III.
- b. In cases with left axis deviation ($\leq -30^\circ$) and with S waves present in lead V6: If there is ST elevation without an S wave present in lead V5, assume that on the pre-event ECG, there were also S waves in V5; therefore assign the lead as Grade III.

For leads V1, V2 and V3

Regardless QRS configuration

1. Grade I tall, positive T wave, no ST elevation.
2. Grade II positive T wave, ST elevation with an S wave below the isoelectric line.
3. Grade III positive T wave, ST elevation without an S wave below the isoelectric line.