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National Academy of Clinical Biochemistry Standards of Laboratory Practice: Recommendations for the Use of Cardiac Markers in Coronary Artery Diseases

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The Sixth Conference on the "Standards of Laboratory Practice Series", sponsored by the National Academy of Clinical Biochemistry (NACB), was held on August 4–5, 1998, at the Annual Meeting of the American Association for Clinical Chemistry, in Chicago, IL. An expert committee was assembled to write recommendations on the use of cardiac markers in coronary artery diseases. The NACB Committee prepared a preliminary draft of the guidelines, made them available on the World Wide Web (www.nacb.org), and distributed them before the presentations. The recommendations were divided into four areas: the use of markers in the triage of patients with chest pain, acute coronary syndromes, clinical applications other than acute myocardial infarction and research, and assay platforms and markers of acute myocardial infarction. The recommendations were revised and subsequently re-presented in part at the "Biomarkers in Acute Cardiac Syndromes Conference", sponsored by the Jewish Hospital Heart and Lung Institute, Louisville KY, on October 16–17, 1998. This report lists each recommendation, its scientific justification, and a summary of discussions from conference participants and reviewers.

Approximately 100 individuals responded to various versions of these recommendations via direct correspondences, telephone calls to Committee members, electronic mail correspondence to the Committee Chairman, or oral questions and comments raised during one of the two conference presentations. Some of the recommendations were changed to reflect the consensus opinion. In cases in which there was no consensus, the Committee included pertinent discussion without necessarily changing the original recommendations. At times, the

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Although entitled "Standards of Laboratory Practice", the statements made in this document are "recommendations" and not practice standards. These recommendations represent the individual experiences of experts in the field of clinical biochemistry, cardiology, and emergency medicine, and should be examined for appropriateness in individual or unique settings. These recommendations were authored, in part, to provide education and guidance as to the use of these tests. Discussions contained herein may also stimulate new research studies to be conceived. Members of the discussion panels for the two meetings were as follows (alphabetically): Jesse E. Adams III, Jewish Hospital, Louisville, KY; Eugene Braunwald, Harvard Medical School, Boston, MA; Robert H. Christenson, University of Maryland, Baltimore, MD; Paul O. Collinson, Mayday University Hospital, Surrey, UK; Robert C. Hendel, Northwestern University, Chicago, IL; James W. Hoekstra, Ohio State University, Columbus, OH; Allan S. Jaffe, State University of New York, Syracuse, NY; Hugo A. Katus, Medizinische Universitat zu Lubeck, Lubeck, Germany; Jack H. Ladenson, Washington University, St. Louis, MO; E. Magnus Ohman, Duke University, Durham, NC; David B. Sacks, Brigham & Womens Hospital, Boston, MA; and Michael H. Salinger, Evanston Northwestern Healthcare, Evanston, IL.

Mauro Panteghini, Brescia, Italy (Chair) and Francesco Dati, DiaSys Diagnostics, Holzheim, Germany (Committee member) also participated in discussions of these recommendations as members of the International Federation of Clinical Chemistry Committee for the Standardization of Markers of Cardiac Damage. A list of conference participants, reviewers, and corporate sponsors will be available with the National Academy of Clinical Biochemistry monograph.

Committee members felt that although a particular recommendation might not be the current standard of care today, they anticipate that it likely will be adopted in the near future.

Session I. Recommendations for Markers in the Triage of Patients with Chest Pain

RECOMMENDATION 1

The triage of patients with chest pain from the emergency department (ED)[7] is one of the most difficult challenges that face ED physicians today. Admission of patients with a low probability of acute coronary artery disease often leads to excessive hospital costs *(1)*. A strategy that is too liberal with regard to ED discharges may lead to higher numbers of patients released with acute myocardial infarction (AMI). Inappropriate discharge of ED patients who have AMI has been estimated to occur in 2–5% of patients and is the single most common cause of malpractice lawsuits against ED physicians today *(2, 3)*.

> Recommendation: Members of emergency departments, divisions of cardiology, hospital administrations, and clinical laboratories should work collectively to develop an accelerated protocol for the use of biochemical markers in the evaluation of patients with possible acute coronary syndromes.
> **Strength/consensus of recommendation:** Class I.[8]
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> For simplicity, this protocol should apply to either the facilitated diagnosis or the rule-out of AMI in the ED or to routine diagnosis from other areas of the hospital, should a patient develop symptoms consistent with acute coronary syndromes while hospitalized.
> **Strength/consensus of recommendation:** Class II.

Many hospitals today have a dedicated area within the ED for the rapid rule-out of AMI. These areas have been designated as "chest pain centers", "heart emergency rooms", or some other terms to indicate that the efficient triage of chest pain patients is a major objective of that center. Essential for early AMI rule-out is frequent electrocardiographic testing and blood collections for the measurement of cardiac markers. Patients with negative results for these tests most likely do not have an AMI. They may, however, have unstable angina or other forms of acute cardiovascular disease. For these patients, it is appropriate to perform additional studies such as a stress test, echocardiogram, or radionuclide ventriculogram for risk stratification. Establishment of a clinical practice guideline for the evaluation of patients with chest pain will reduce the variability of practices among physicians and institutions, at the same time improving the accuracy of triaging decisions *(5)*. The NACB Committee felt that for "routine AMI diagnosis" of patients who are already hospitalized for other reasons, the same criteria should apply as are used in the ED.

Discussion. Although the recommendation that laboratorians should work with ED physicians, cardiologists, and hospital administration may appear obvious, in actual practice, decisions on testing protocols are often made without input from the laboratory. Laboratory directors must be aggressive in requesting that qualified personnel be part of organizational and operating committees when such discussions are being conducted, or should initiate the discussions themselves. Understanding the expanded role that the laboratory will play in creating these rule-out centers will enable justification to hospital administrators for the additional laboratory expenses that will be required. This argument will be particularly effective if the overall objective of reducing in-hospital lengths of stay and the numbers of unnecessary admissions or wrongful discharges from the ED can be demonstrated.

The diagnosis of AMI is not always made in the ED. Sometimes patients admitted for other reasons develop symptoms for AMI while in the hospital. Some physicians or administrators may believe that rapid AMI rule-out of hospitalized patients may not be as important as triage for ED patients. Nevertheless, the NACB Committee felt that the same protocol used in the ED is appropriate for routine AMI diagnosis because new therapies for acute coronary syndromes are available, and, when appropriate, should be delivered rapidly. The use of a rapid AMI rule-out protocol will simplify the steps needed from the laboratory's perspective and provide clinicians optimum diagnostic measures for all patients.

RECOMMENDATION 2

Although the time of onset of chest pain for AMI patients is often known, this information often is less available or reliable for those with unstable angina and other cardiac diseases. It is not uncommon for these patients to report multiple episodes of chest pain over the hours and days before ED presentation. Intermittent closure and spontaneous reperfusion of coronary arteries with ruptured atherosclerotic plaques reflect the dynamic nature of acute

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[7] Nonstandard abbreviations: NACB, National Academy of Clinical Biochemistry; ED, emergency department; AMI, acute myocardial infarction; CK and CK-MB, creatine kinase and CK MB isoenzyme; cTnT and cTnI, cardiac troponins T and I; POC, point-of-care; TIMI, Thrombolysis in Myocardial Infarction; and TAT, turnaround time.

[8] Listed with each recommendation is the degree of evidence from the literature and/or agreement from the consensus of participants who attended either presentation. Using a modified classification scheme defined by the American College of Cardiology/American Heart Association (AHA/ACC), the NACB Committee defined a Class I recommendation as one for which there is evidence and/or general agreement; a Class II recommendation as one for which there is conflicting evidence and/or a divergence of opinion about its usefulness/efficacy, but where the weight of evidence/opinion is in its favor; and a Class III recommendation as one for which there is evidence and/or general agreement that a procedure is not useful or effective *(4)*.

coronary syndromes. In the elderly or in patients with insulin-dependent diabetes mellitus type I, there may be altered thresholds or a blunted response to pain. Indeed, there are many patients with acute coronary syndromes who experience silent ischemia and infarction (i.e., no pain during occlusive episodes) *(6)*.

> Recommendation: For routine clinical practice, blood collections should be referenced relative to the time of presentation to the ED and (when available) the reported time of chest pain onset.
> **Strength/consensus of recommendation:** Class I.

Discussion. In the early drafts of the Guidelines, the recommendations were that all blood collections should be referenced to the time of ED presentation only. However, many reviewers felt it important to also note the time of onset of chest pain, especially when there is a history of a single chest pain event (and not several events over many days) and when the time of onset as reported by the patient or family is deemed to be reliable. It may also provide an explanation as to why some clinical studies fail to document a consistent rise in the concentration of the marker, e.g., at 6 h, whereas other studies indicate that the markers were increased at this time point in all patients (e.g., when the majority of enrolled patients in the study present beyond 6 h of chest pain).

RECOMMENDATION 3

The ideal biochemical marker is one that has high clinical sensitivity and specificity, appears early after AMI to facilitate early diagnosis, remains abnormal for several days after AMI, and can be assayed with a rapid turnaround time *(7, 8)*. Because there currently is no single marker that meets all of these criteria, a multianalyte approach has the most merit.

Because the interval between the onset of pain and ED presentation is variable from patient to patient, two markers are needed to enable detection of patients who present either early or late. Currently, myoglobin is the marker that most effectively fits the role as an early marker. A rise in myoglobin is detectable in blood as early as 1–2 h after onset and can be highly effective for AMI rule-out (Fig. 1, peak A) *(9)*. Moreover, automated immunoassays for myoglobin are commercially available. Myoglobin is not cardiac specific, and patients with renal failure, skeletal muscle injury, trauma, or disease can have abnormal concentrations in the absence of AMI *(10)*. The creatine kinase MB (CK-MB) isoforms (also termed "subforms") have also been shown to be an early marker for AMI *(11)*. Automated stat CK-MB isoform measurements are being used in some hospitals as an early measure of myocardial injury. Moreover, it may also be possible that troponin can be used as an early marker if a new assays are developed that are more sensitive than current ones *(12)*. In an ED study, qualitative measurement of cardiac troponin T and I (cTnT and cTnI) using point-of-care (POC) devices were reliable for ruling out AMI at 6 h after onset of symptoms *(13)*. These studies, however, were not confirmed by a more recent study of chest pain patients that used quantitative laboratory-based assays for troponin *(14)*. Clearly, more studies are needed to fully address the role of troponin in early diagnosis and the comparison between troponin T and I.

In contrast, cTnT and cTnI are currently the best markers for definitive AMI diagnosis. Troponins appear in the serum relatively early after the onset of symptoms

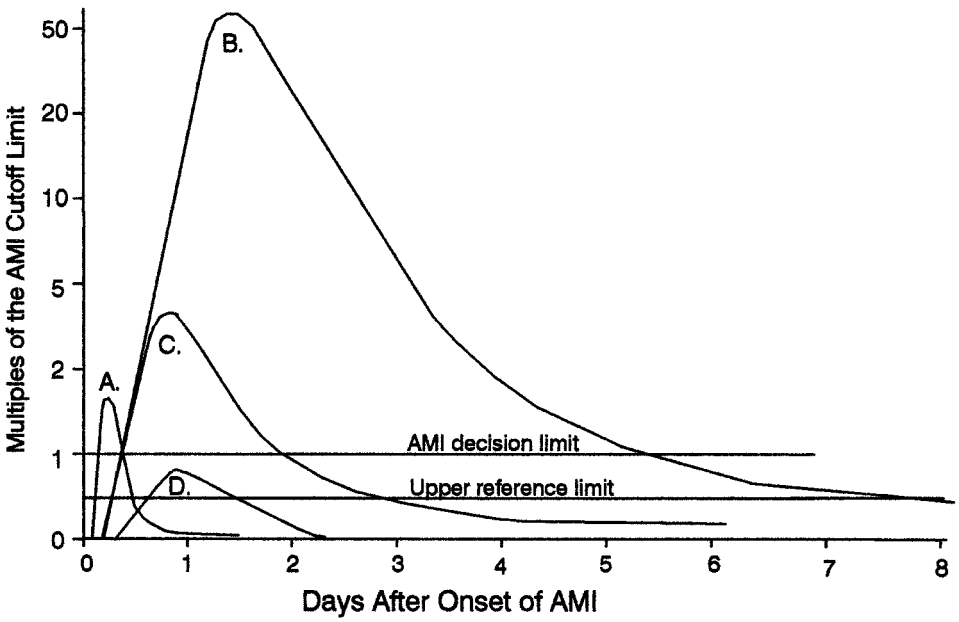

Fig. 1. Plot of the appearance of cardiac markers in blood vs time after onset of symptoms.

Peak A, early release of myoglobin or CK-MB isoforms after AMI; *peak B*, cardiac troponin after AMI; *peak C*, CK-MB after AMI; *peak D*, cardiac troponin after unstable angina. Data are plotted on a relative scale, where 1.0 is set at the AMI cutoff concentration.

(4–12 h) and remain abnormal for 4–10 days (Fig. 1, peak B). Results are not increased in the presence of skeletal muscle troponin *(15, 16)*. Early studies have questioned the clinical specificity of cTnT assays in patients with chronic renal failure *(17, 18)*. With the development of a second-generation ELISA assay for cTnT, the frequency of positive results in these patients is lower than the frequency in the first-generation assay, although still higher than for cTnI *(19, 20)*. Western blot analysis on regenerating human skeletal muscle tissue showed that the cardiac isoforms of troponin T are expressed in pathologic conditions (such as polymyositis and muscular dystrophy) *(21)*. However, subsequent studies have shown that the antibodies used in the Roche commercial assays are specific for myocardial cTnT isoforms, do not detect the cTnT isoforms expressed in diseased skeletal muscle, and therefore, do not produce false-positive cTnT results in renal patients *(22, 23)*. Preliminary outcomes studies have shown that chronic renal failure patients who have high cTnT concentrations in blood have a higher incidence of cardiac death than those with normal concentrations, confirming the notion that troponin is measuring true myocardial injury that is not associated with or classified as an AMI *(24)*. The importance of these findings is not completely known. Are there therapies that can be administered to reduce the short-term mortality of renal failure patients with a positive troponin result? How does risk stratification with troponin compare with other indicators of renal function? One study showed that measurement of the troponins in patients with both acute coronary syndromes and renal insufficiencies reduces the effectiveness for risk stratification of chest pain patients based on cTnT and cTnI monitoring *(25)*. These and other questions will need to be the focus of future studies.

Recommendation: Two biochemical markers should be used for routine AMI diagnosis: an early marker (reliably increased in blood within 6 h after onset of symptoms) and a definitive marker (increased in blood after 6–9 h, but has high sensitivity and specificity for myocardial injury, remaining abnormal for several days after onset).
Strength/consensus of recommendation: Class II.

Discussion. The merits of myoglobin as the early marker have been debated by many reviewers and conference participants. Although there is ample literature suggesting that myoglobin is an early marker *(26–28)*, there are reports that support the view that myoglobin is not any earlier than CK-MB mass assays *(29)*. These reviewers feel that the poor specificity of myoglobin (in the presence of skeletal muscle disease or renal failure) does not justify its routine use as a cardiac marker. However, there is increasing pressure by ED physicians and hospital administrators to rule out AMI sooner. Some chest pain centers have begun to discharge patients within 6 h of ED presentation. CK-MB is not reliably increased at this interval after AMI, and myoglobin may have a role in this situation. As an alternative to myoglobin, a minority of laboratories have begun using CK-MB isoforms as an early AMI marker *(30)*. (In a poll taken during the AACC Annual Meeting, <1% of conference participants indicated that they were currently using isoforms.) Currently, CK-MB isoforms are most effectively measured by high-voltage electrophoresis *(31)*. With improvements in analytical methodologies, the number of laboratories routinely using isoforms might increase. The NACB Committee recognizes the limitations of myoglobin and CK-MB isoforms and encourages continued research into earlier markers, particularly if they are more specific for myocardial necrosis. In the meantime, the NACB Committee believes that myoglobin is an earlier marker than CK-MB mass and is more conveniently measured on automated immunoassay analyzers than CK-MB isoforms.

RECOMMENDATION 4

Large studies in New York and Texas have shown that ~50% of AMI patients will present to the ED with evidence of acute myocardial injury on the electrocardiogram (ECG) *(32)*. Acute intervention with thrombolytic therapy or angioplasty should be considered in those patients who present within 12 h after the onset of symptoms *(33, 34)*. Specific ECG changes are highly diagnostic for AMI when interpreted by well-trained physicians *(35)*.

Recommendation: In patients with a diagnostic ECG on presentation (ST-segment elevations, presence of Q waves or left bundle branch block in two or more contiguous leads), the diagnosis of AMI can be made and acute treatment initiated without results of acute cardiac marker testing.
Strength/consensus of recommendation: Class I.

In AMI patients with diagnostic ECGs, biochemical marker testing at a reduced frequency of blood collection (e.g., twice per day) is valuable for confirmation of diagnosis, to qualitatively estimate the size of the infarction, and to detect the presence of complications such as a reinfarction.
Strength/consensus of recommendation: Class I.

Discussion. The NACB Committee sought advice from ED physicians and cardiologists as to why cardiac markers are still being ordered on patients with ECG-documented AMI, when in many cases, therapy had already been initiated before results of tests were available from the laboratory. Although most physicians recognize that in this context, these tests do not serve a diagnostic role, many felt that biochemical documentation of AMI was

necessary to complete the triad of criteria established by WHO for AMI diagnosis *(36)*. It is also likely that a positive result for a cardiac marker in these patients provided a level of comfort and confidence to the attending staff. Many physicians also felt that knowing the peak concentration of a cardiac marker provided a qualitative estimate of infarct size (without calculating the area under the curve of marker concentration vs time). This information might have a role in the future management of surviving AMI patients.

Many conference participants also felt that continued measurement of markers was helpful in detecting the presence of a reinfarction, estimated to be 17% of AMI patients *(37)*. If the reinfarction occurs before there is complete clearance of the marker from the original infarct, it might not be possible to detect the presence of the reinfarction because the markers released from the second event might be indistinguishable from that released by the initial event. For this reason, the use of cardiac markers that return to baseline concentrations early may have an advantage over the use of markers that are slow to clear from the circulation. For example, myoglobin and CK-MB isoforms return to reference values typically within 24 h after AMI (Fig. 1, peak A). If a reinfarction were to occur after this time, increases in the concentration or activity of these proteins would enable detection of a second necrotic event. CK-MB mass can also be considered as a reinfarction marker that returns to baseline concentration reasonably early (but not as early as myoglobin). Many reinfarctions occur between 7 and 14 days after the initial event. Because CK-MB remains abnormal for 3–4 days (Fig. 1, peak C), CK-MB may be useful to detect a reinfarction even if the event is not immediately suspected by the medical staff. CK-MB mass would show a secondary increase, whereas myoglobin and CK-MB isoforms could have returned to baseline concentrations (Fig. 1, peak A). Alternatively, one could request that the laboratory retrieve a stored specimen for myoglobin or isoform testing if available because serum myoglobin is stable for several days if refrigerated *(38)*, and isoforms are stable when collected with EDTA *(39)*.

RECOMMENDATION 5

For AMI rule-out of patients who have equivocal ECG changes, cardiac markers play an essential diagnostic role in non-Q-wave AMIs. Unfortunately, there is great variability between hospitals in the frequency of blood collections. In 1986, the American College of Physicians recommended a conservative testing guideline based on total CK and CK-MB for blood collected on admission and at 12 and 24 h after admission, and the use of lactate dehydrogenase isoenzymes when admission is >24 h after onset *(40)*. The NACB Committee believes that this strategy is no longer adequate to meet the current triaging needs.

Rule-out of AMI requires serial collection and testing of blood for cardiac markers. When an early marker such as myoglobin is used, acute myocardial necrosis can be effectively ruled out within 6–9 h after ED presentation *(41, 42)*, and a decision to discharge the patient to home or a to low care level bed can be considered. On the other hand, for AMI rule-in, a single positive result for either troponin T or I would trigger a diagnosis of AMI and triage of the patient to the appropriate level of care *(13)*, without the need for necessarily completing this algorithm *(43, 44)*. This recommendation was made because, unlike myoglobin, CK, CK-MB, and lactate dehydrogenase, positive results for cTnT and cTnI are highly indicative of myocardial damage, with no release of these proteins from skeletal muscles or other tissues *(45, 46)*.

Recommendation: For detection of AMI by enzyme or protein markers, in the absence of definitive ECGs, the following sampling frequency is recommended:

Marker	Admission	2–4 h	6–9 h	12–24 h
Early (<6 h)	x	x	x	(x)
Late (>6 h)	x	x	x	(x)

(x) indicates optional determinations.

Strength/consensus of recommendation: Class II.

Discussion. The need to perform the 2–4 h blood collection for the late marker can be questioned. In particular, negative results at admission and at 2–4 h after admission for myoglobin, and a negative result for cardiac troponin at admission would obviate the need for measuring troponin in the 2–4 h sample. The NACB Committee felt that most laboratories do not currently have a mechanism for automatic "reflex testing" (i.e., testing that involves the ordering or cancellation of follow-up tests on a given sample based on results of preliminary tests). Therefore, it is more convenient for the laboratory to perform testing for both markers on all samples, rather than to hold specimens until results of preliminary tests (i.e., the early markers) are known.

Among chest pain centers, there are many variations to the protocol for blood sampling and the total number of samples needed for AMI rule-out. Some centers use intervals of every 3 h, whereas others use every 4 h. In one study, chest pain patients were triaged on the basis of only two samples collected: one at admission and one at 4 h *(13)*, with a third sample collected only on patients presenting with <2 h history of chest pain. Because of the unreliability of the chest pain history, the NACB Committee has taken a more conservative approach of recommending the collection of at least three blood samples during the early triage period. A blood collection at 12–24 h may be useful for the detection of reinfarction or myocardial extension or for risk stratification of patients with unstable angina. Investigators have found that a 16-h

blood sample adds additional value for risk stratification over the initial blood sample *(47)*.

RECOMMENDATION 6

Some EDs are slow to develop a rapid rule-out chest pain center because of financial limitations, space, and/or a lack of knowledge of the potential benefits. In these centers, the extra laboratory tests bring additional costs without benefits in terms of reduced hospital lengths of stay or frequency of inappropriate discharges of patients with AMI.

> Recommendation: For those EDs in which patient triage decisions are not made within the first few hours after ED presentation, the use of an early marker such as myoglobin may be unnecessary. In this case, only one definitive marker such as cardiac troponin is needed. The frequency of blood collection should also be reduced.
> **Strength/consensus of recommendation:** Class I.

Session II. Recommendations for Markers in Acute Coronary Syndromes

RECOMMENDATION 1

The acute coronary syndrome is a pathophysiologic continuum that results from rupture of an atherosclerotic plaque, with subsequent platelet aggregation and thrombus formation *(48, 49)*. It can lead to clinical presentations ranging from entirely asymptomatic to unstable angina to AMI to sudden cardiac death attributable to arrhythmias. There have been major improvements in the specificity of new cardiac markers (such as cardiac troponin) and increases in analytical sensitivity for older markers such as CK-MB. When improved markers are compared to accepted standard markers, such as CK-MB, results that are discordant to each other can occur. For example, what does a positive troponin in a chest pain patient suggest when CK-MB is within the health-related reference interval? With improvements in the analytical sensitivity of these assays, it is now evident that small increases in sensitive markers such as cardiac troponin provide additional clinical information that is not evident with conventional enzyme markers.

Original validation studies for cardiac troponin assays have compared results against CK-MB for the diagnosis of AMI. When the upper limit of normal is used as the cutoff concentration, clinical studies have shown that cardiac troponin was less specific for AMI diagnosis than CK-MB mass *(50)* when the classical WHO definition of AMI was used *(36)*. This was because assays for cardiac troponin were detecting myocardial injury in some cardiac patients (e.g., those with unstable angina) with CK-MB below the cutoff (Fig. 1, peak C), and the extent of damage was insufficient to produce ECG patterns that were indicative of AMI. A higher cutoff concentration could be used to mimic the clinical specificity of CK-MB for AMI. However, this will lead to the loss of clinically useful information because the importance of detecting myocardial injury (Fig. 1, peak D) has been demonstrated in retrospective outcomes studies in patients with abnormal concentrations of cTnT *(51–53)* or cTnI *(54–56)*. These studies define a population that is at high short-term risk (<6 weeks) for adverse events (AMI and cardiac death). Cumulative metaanalyses suggest that the odds ratio for adverse events of a high troponin in unstable angina are 5:1 relative to a cohort of chest pain patients with normal troponin results *(57)*. The risk is additive: the higher the cTnT and cTnI concentrations in blood, the higher the prospective risk *(56, 58)*. Thus, the detection of a low degree of myocardial injury is possible with the use of a low cutoff concentration for cardiac troponin (e.g., the upper limit of the reference interval), a strategy that is less applicable for nonspecific markers such as CK-MB.

The methodology for assignment of the low and high cutoff concentrations for cardiac troponin or any other cardiac marker is discussed in *Session III* under "Recommendation 5".

> Recommendation: Two decision limits are needed for the optimum use of sensitive and specific cardiac markers such as cTnT or cTnI. A low abnormal value establishes the first presence of true myocardial injury, and a higher value is suggestive of injury to the extent that it qualifies as AMI, as defined previously by WHO *(36)*.
> **Strength/consensus of recommendation:** Class II.

Discussion. The concept of two decision limits for cardiac troponin was highly debated during the presentation of the Guidelines. A survey indicated that slightly more participants would prefer the use of a single cutoff concentration set at the lower of the two decision limits, rather than define two separate limits. No one suggested the use of a single cardiac troponin decision limit set at the AMI cutoff concentration. Many felt that the use of two limits overly complicates the situation and would require a substantial amount of physician education. Others felt that the therapeutic approaches for patients with unstable angina and non-Q-wave AMI are identical and that a differentiation between these two groups is, therefore, unnecessary.

The NACB Committee agreed with the consensus that detection of any myocardial injury was important *(51)*, thereby justifying the use of a single low cutoff concentration for cardiac troponin. However, the Committee felt that use of a more sensitive cardiac marker (in a patient with a positive history of chest pain) would double the number cases of AMI compared with using the existing WHO criteria, which are based on the use of enzyme

markers. It is important to not classify these patients as AMI, because they may be disadvantaged from a social, psychological, and socioeconomic standpoint *(59)*. It may also affect how the hospital gets reimbursed for these services. Until the criteria for diagnosis of AMI are redefined by WHO or other clinical groups such as the American Heart Association or the American College of Cardiology, the NACB Committee recommends a two-cutoff designation for cardiac troponin; a low limit that detects a small amount of myocardial injury but classifies those patients at high risk, and a higher limit with the amount of injury present is to the extent that it conforms with a WHO-defined AMI.

RECOMMENDATION 2

In the past, CK-MB results between the upper limit of normal and the AMI decision limits had been termed a "gray zone". This practice was appropriate because CK-MB was not specific for the heart, and there were healthy subjects who had measurable CK-MB concentrations from skeletal muscle release within this range. The use of a low CK-MB cutoff would cause many of these patients to be incorrectly classified as having high cardiac risk. For cTnT and cTnI, the term gray zone should not be used because it connotes uncertainty in clinical interpretation.

> Recommendation: Chest pain patients with laboratory results for cTnT and cTnI between the upper limit of the reference interval and the decision limit for AMI should be labeled as having "myocardial injury". These patients should be admitted and acutely treated to reduce the risks associated with this injury *(60, 61)*.
> **Strength/consensus of recommendation:** Class I.

Discussion. In the original draft of these Recommendations and in some early literature reports on cardiac troponin [e.g., Ref. *(62)*], abnormal troponin results occurring in some non-AMI patients with CK-MB within the reference interval were designated as having "minor myocardial injury or damage". The descriptive term, "minor" meant that the amount of tissue damage occurring to the heart was significantly less than that which occurs in patients with AMI. However, many conference participants felt that use of this term might be interpreted by physicians as minor risk for future untoward cardiac events, which is not true. In fact, unstable angina patients with abnormal concentrations of troponin may be at greater risk than surviving AMI patients because therapeutic options such as intravenous thrombolytic therapy are not available for the non-AMI patient. Other terms have been suggested that might better describe the clinical importance of this finding, such as "microinfarct" or "infarctlet", or suggest that these patients have suffered a non-Q-wave AMI *(63)*. Perhaps in some future clinical guideline, the term "acute myocardial infarction" can be eliminated entirely and replaced with "acute coronary syndromes". In this way, a single cutoff concentration for a cardiac marker such as troponin can be justified. This would reflect the incremental risks associated with increasing concentrations of the marker, consistent with the continuous injury concept of acute coronary syndromes.

In the current version of these Guidelines, the term minor has been removed. Excluding situations where the cardiac troponin was increased because of a problem with the assay's analytical specificity, all patients with an abnormal concentration of troponin have myocardial injury and should be viewed as having cardiovascular risk. It is the responsibility of the ordering physician to use this information in the context of other data in making the appropriate management decision.

It is also important to recognize that because troponin is increased for many days after AMI, it may be possible that without a full clinical history, small increases in troponin with a negative CK-MB might simply reflect an AMI in which CK-MB had returned to normal. Because of this fact, some might advocate keeping CK-MB mass assays available for this purpose. However, myoglobin could also fulfill this need because it would be normal in these late-presenting AMI patients. Myoglobin would might be available if the recommendations for two cardiac markers for ED triaging were followed by an institution.

RECOMMENDATION 3

WHO has defined the diagnosis of AMI as a triad *(36)*. Two of which must be present for diagnosis:

(*a*) The history is typical if severe and prolonged chest pain is present;
(*b*) Unequivocal ECG changes that are the development of abnormal, persistent Q or QS waves, and evolving injury lasting longer than 1 day; and
(*c*) Unequivocal change consisting of serial enzyme changes, or initial rise and subsequent fall. The changes must be properly related to the particular enzyme and to the delay time between the onset of symptoms and blood sampling.

With the development of biochemical markers that are not themselves enzymes, such as cTnT, cTnI, and myoglobin, the third criterion of the WHO triad should be revised.

> Recommendation: The WHO definition of AMI should be expanded to include the use of serial biochemical markers and not be limited to enzyme changes. It should be emphasized that rule-out of AMI cannot be made on the basis of data from a single blood collection. However, when very specific cardiac markers are used, the presence of an abnormal concentration from a single specimen can be highly diagnostic of myocardial injury.
> **Strength/consensus of recommendation:** Class I.

Discussion. The NACB Committee recognizes that clinical groups will have to lobby WHO to make substantive changes to their criteria for AMI diagnosis. This will require an international effort by cardiologists, emergency physicians, and laboratorians. Thus, the above recommendation is included to justify the use of myoglobin and cardiac troponin, and perhaps future non-enzyme protein markers that will have been shown to have value in the diagnosis of AMI.

RECOMMENDATION 4

The analysis of blood for lipids such as cholesterol and lipoproteins such as LDL and HDL is well established in the assessment of coronary artery disease risk *(64)*. As such, these markers are being used to screen asymptomatic individuals. Because sensitive cardiac markers have also been shown to provide information on risk stratification, there may be an impetus to use these markers as part of a biochemical panel for routine health screening to detect the presence of silent ischemia, or after exercise stress testing to detect presence of ischemic injury.

Studies of biochemical markers before and after nuclear ventriculography of chest pain patients have shown that neither cTnT or cTnI is increased after stress testing, even in patients with documented evidence of flow defects *(65)*.

Recommendation: At this time, there are no data available to recommend use of cardiac markers such as cTnT or cTnI for screening asymptomatic patients for the presence of acute coronary syndromes. The likelihood of detecting silent ischemia is extremely low and cannot justify the costs of screening programs. Additionally, there is no evidence that cardiac marker analysis of blood following stress testing can indicate the presence of coronary artery disease.
Strength/consensus of recommendation: Class III (for use of cardiac markers for screening).

Session III. Recommendations for Markers in Clinical Applications Other than AMI and Research

RECOMMENDATION 1

Acute revascularization is now standard practice for patients with ST-segment-elevation AMI. The objectives for thrombolytic therapy and/or emergent percutaneous transluminal coronary angioplasty are to recanalize occluded arteries and to reduce mortality. Cardiac markers can be used to assess the success or failure of such therapy. AMI patients who develop patent coronary circulation will release a bolus amount of enzymes and proteins into the circulation ("washout phenomenon") when compared with AMI patients with permanent occlusions *(66)*. The accepted standard measurement of reperfusion status is coronary angiography. Blood flow is assessed according to a scale determined by the Thrombolysis in Myocardial Infarction (TIMI) investigators *(33)*. TIMI grades 0–2 indicate various stages of occluded blood flow, whereas TIMI grade 3 indicates reperfusion. The time interval of collection of samples is important for the proper interpretation of results. Methods to predict reperfusion, such as chest pain and ECG resolution, reperfusion arrhythmias, and other criteria, have been shown to be unreliable *(67)*.

When reperfusion is successful, it is produced in the majority of cases within 90 min after the initiation of therapy *(68–70)*. Sampling blood at 60 after the initiation of therapy may be helpful in the early determination of successful reperfusion, but cases of late recanalization could be missed. Some investigators have suggested a 120-min sample *(71)*. Although this time interval is also acceptable, it could delay any subsequent management decision. Other investigators have used the time to peak marker concentration as the discriminating factor. This is not recommended because it requires more blood sampling and could produce further delays in interpreting results. This is particularly true for patients who have permanent occlusions.

Recommendation: For assessment of reperfusion status following thrombolytic therapy, at least two blood samples are collected and marker concentrations compared: time = 0, defined as just before initiation of therapy, and time = 1, defined as 90 min after the start. From these values, the determination of the (*a*) slope value [$(\text{marker}_{t=90} - \text{marker}_{t=0})/90$ min]; (*b*) absolute value of $\text{marker}_{t=90}$, in minutes; or (*c*) the ratio of $\text{marker}_{t=90}/\text{marker}_{t=0}$ can be used as the discriminating factor between successful and unsuccessful reperfusion. However, monitoring with biochemical marker strategies has not been successful in distinguishing between TIMI grade 3 and TIMI grade 2 flow patients, rendering the utility of these measurements clinically problematic for determining complete reperfusion.
Strength/consensus of recommendation: Class II.

RECOMMENDATION 2

Cardiac markers have also been used to detect the presence of perioperative AMI in patients undergoing surgical procedures *(72)*. The use of nonspecific cardiac markers such as CK, CK-MB, myoglobin, and lactate dehydrogenase have limited usefulness because they are released from noncardiac tissues as a consequence of the procedure itself *(73)*.

The performance of cardiac troponin for the detection of perioperative AMI has been shown to be superior to other cardiac markers such as CK-MB *(74, 75)*. However, a protocol for the frequency of blood collection and interpretation of results will require more clinical studies before specific recommendations can be made as to the appropriate decision limit for perioperative AMI. These studies should answer several questions. Can the existing AMI decision limits be used? If the surgical procedure involves the heart, e.g., coronary artery bypass graft, some injury to the myocardium itself is expected. Should a higher AMI decision limit be used in open heart surgeries? It has been shown, for example, that a cTnT concentration of 0.6 μg/L (sixfold higher than the recommended 97.5% upper reference limit cutoff) had a positive predictive value for an adverse outcome of 87.5%, with a negative value of 98% *(76)*. More studies in which cutoff concentrations are optimized to outcomes are needed.

Recommendation: cTnT or cTnI should be used for the detection of perioperative AMI in patients undergoing noncardiac surgical procedures. The same AMI decision limit should be used.
Strength/consensus of recommendation: Class I.

RECOMMENDATION 3

Cardiac markers have been used in other monitoring roles, such as myocardial infarct sizing. Infarct sizing involves serial collection of cardiac markers and integrating the area under the curve of a plot of enzyme activity or protein concentration vs time. Such calculations produce an estimate of the quantity of infarcted tissue that correlates to anatomic estimates of infarct size made at autopsy *(77)*. For cardiac markers that exhibit the washout phenomenon, infarct-sizing estimates are inaccurate when reperfusion of occluded coronary arteries is successful *(78)*. Other markers that are not sensitive to reperfusion status, such as myosin heavy chains *(79)*, may provide more accurate infarct-sizing estimates. However, commercial assays are not readily available for myosin light chains.

Assessment of infarct sizing, however, may be useful as a research tool in clinical trials of new drugs (e.g., intravenous thrombolytic therapy, thrombin inhibitors, and glycoprotein IIb/IIIa inhibitors) or procedures (e.g., angioplasty) designed to limit the extent of myocardial injury, or in studies involving the injury that occurs when an occluded artery is suddenly reperfused *(80)*.

Recommendation: Cardiac markers should not be routinely used for infarct sizing because the existing markers are inaccurate in the presence of spontaneous, pharmacologic, or surgical reperfusion.
Strength/consensus of recommendation: Class III (for use of markers in infarct sizing).

RECOMMENDATION 4

New markers will continue to be developed and examined for patients with acute coronary syndromes. When a marker such as cardiac troponin demonstrates major advantages over existing markers, there is an urgency of manufacturers to develop and market commercial assays. In the specific cases of CK-MB mass and cTnI assays, there were no cooperative attempts to develop reference materials or to standardize results.

The NACB Committee acknowledges that the exclusive release of new markers may be in the manufacturer's best interests in terms of profitability, and therefore, they may be reluctant to share ideas and needs with their colleagues. Nevertheless, the implementation of new tests is more easily integrated into the laboratory when these markers are available on a wide spectrum of analyzers, and it is in the best interests of the medical community and the in vitro diagnostic industry that assays correlate to one another.

Recommendation: Early in the process, manufacturers should seek assistance and provide support to professional organizations such as the AACC or IFCC to develop committees for the standardization of new analytes. These organizations will determine the need for analyte standardization based on the potential clinical importance of the marker and gather the necessary scientific expertise for the formation of a standardization committee.
Strength/consensus of recommendation: Class I.

Discussion. The IFCC has established the Committee on Standardization of Markers of Cardiac Damage to coordinate the ongoing worldwide activities in this area. This Committee will be working with national clinical chemistry societies, such as the AACC and the German Society for Clinical Chemistry, in their efforts to standardize cTnI and myoglobin, respectively. cTnT is only available from one manufacturer, and standardization is not now an important issue.

RECOMMENDATION 5

Utilization of a new test requires the establishment of a reference interval. This is achieved by measuring the concentration of the marker in a cohort of apparently healthy subjects. For cardiac markers, a separate "decision limit" is used to differentiate between AMI and non-AMI diagnoses. The decision limit is typically higher than the upper reference limit. Establishment of these limits is essential for the proper interpretation of results.

For cardiac markers, only the upper limit of the reference interval is needed because there is no significance for results that are below the lower reference limit. The first lower decision limit is defined as the upper 2.5 percentile (one-tail test) of results from a healthy population *(81)*. This statistical approach is commonly used to assign reference interval concentrations *(82)*. For nonspecific markers such as CK, CK-MB, or myoglobin, the reference interval is for reference only and is not used for clinical decisions. For specific marker such as cardiac troponin, the upper reference limit is used to establish the presence of cardiac injury (see *Session II*, "Recommendations 1 and 2").

The AMI cutoff concentration is determined by ROC analysis of results from marker concentrations collected within the established diagnostic window on a population of consecutive chest pain patients presenting to the ED for AMI rule-out. The patients must be diagnosed as having an AMI independent of the experimental cardiac marker being tested, by accepted and rigorously applied criteria (e.g., WHO). However, as part of the AMI diagnosis criteria, one cannot avoid use of accepted cardiac markers (such as CK-MB) that are in routine use at the facility. Recommendations for the standardization of ROC curves have been published *(83)*. These published guidelines suggest that decision thresholds be printed on the ROC curve, the determination of the area under the ROC curve (including standard error and the confidence interval) and calculation of P (or z) when two or more markers are compared on the same ROC plot. Decision limits provided by reagent manufacturers that are not rigorously determined according to the above recommendation should be considered as guidelines and should not substitute for ROC analysis.

Recommendation: Reference intervals are established for each marker on a population of healthy individuals, using the 97.5 percentile (one-tail) of results. Separate cutoff concentrations for results indicative of AMI are also necessary for all cardiac markers. Standardized ROC curves should be used to establish AMI decision limits, using carefully selected and diagnosed patient populations.
Strength/consensus of recommendation: Class I.

Discussion. There was substantial discussion as to how the first troponin cutoff concentration for the detection of myocardial injury should be established. Ideally, this cutoff should be determined empirically with a retrospective analysis of patients with acute coronary syndromes in which the clinical outcomes of these patients are assessed after 4–6 weeks. Using logistic analysis, the value that produces the highest odds ratio for predicting short-term outcomes would be selected as the cutoff concentration. Because such a study is impractical for most hospital laboratories, the upper 2.5 percentile recommendation was made. Other reviewers felt that any detectable troponin indicates cardiac injury, and therefore, the detection limit should be used as the lower cutoff. This might have been acceptable for insensitive assays in which all healthy subjects are below the detection limit. However, improved cardiac troponin assays are being developed that are more sensitive than previous versions, and these assays enable detection of baseline concentrations of cardiac troponin in healthy subjects. Residual troponin concentrations in these subjects represent normal apoptotic turnover of myocardial tissue and not true ischemic myocardial damage *(84)*. Setting the cutoff at the upper 2.5% of the reference population will be directly applicable when more sensitive become available.

RECOMMENDATION 6

Much of the focus for new markers has been on the discovery and evaluation of markers that can detect the initial pathophysiologic events of acute coronary syndromes, such as inflammation, thrombus formation, platelet aggregation, and reversible ischemia. Some of the markers examined for these processes include C-reactive protein *(85)* amyloid protein A *(86)*, thrombus precursor protein *(87)*, p-selectin *(88)*, and glycogen phosphorylase isoenzyme BB *(89)*. Other markers that may be used in place of or to improve the specificity of myoglobin

Recommendation: For research studies involving the kinetics of release and appearance of new biochemical markers, the time course of release and appearance in blood must be defined relative to the onset of clinical symptoms.
Strength/consensus of recommendation: Class I

The diagnostic accuracy of these new markers may be compromised if the diagnosis of AMI for study patients is based on standard enzyme markers that themselves have sensitivity and/or specificity limitations (e.g., total CK and CK-MB). Therefore, AMI diagnosis should be defined by WHO criteria, but with the substitution of "unequivocal serial changes of cTnT or cTnI" as the principal biochemical marker, in place of the current WHO criteria of "unequivocal serial enzyme changes".
Strength/consensus of recommendation: Class II.

include heart fatty acid-binding protein *(90)* and carbonic anhydrase III isoenzyme *(91)*. For research studies involving these new markers, the time of admission is not useful when the results are compared with conventional markers such as myoglobin, CK-MB, and cardiac troponin because the interval between the onset of clinical symptoms and ED admission is variable from institution to institution *(92)*.

Session IV. Recommendations for Assay Platforms and Markers of Acute Myocardial Infarction

RECOMMENDATION 1

CK-MB has long been considered the biochemical standard for the laboratory diagnosis of AMI *(93)*. The development, characterization, and clinical interpretation of cTnT and cTnI seriously challenge the role of CK-MB. cTnT and cTnI appear in the blood at or near the same time as CK-MB, but remain abnormal for 4–10 days (Fig. 1, peak C).

The use of CK-MB should be phased out over the ensuing years as more cTnT and cTnI assays become available and the cost for such assays becomes competitive with CK-MB mass assays *(94)*. If a hospital is already using cTnT or cTnI, the NACB Committee felt that the measurement of lactate dehydrogenase isoenzymes and β-hydroxybutyric dehydrogenase should be discontinued immediately *(16, 95)* No recommendation is being made as to the discontinuance of assays for total CK. This marker is inexpensive and readily available in clinical laboratories, and it can be very useful for the detection of skeletal muscle injury or disease *(96)*.

Recommendation: Cardiac troponin (T or I) is the new standard for diagnosis of myocardial infarction and detection of myocardial cell damage, replacing CK-MB.
Strength/consensus of recommendation: Class II.

There is no longer a role for lactate dehydrogenase and its isoenzymes in the diagnosis of cardiac diseases.
Strength/consensus of recommendation: Class I.

Discussion. There was considerable discussion as to whether cardiac troponins can now replace total CK and/or CK-MB. As summarized in Table 1, there are several ongoing analytical issues that have inhibited a more rapid conversion toward cardiac troponin. For cTnT, the first-generation assay had a problem with nonspecific binding of skeletal muscle troponin (corrected with the subsequent generation of assays). For cTnI, a major issue is the lack of standardization. Results from different manufacturers produce cTnI values that differ by a factor of 20 or more *(97)*. Within-run and total imprecision also are not uniform between commercial assays *(98)*. In many assays for cardiac troponin, the presence of fibrin clots and heterophile antibodies can produce false-positive results *(99)*. False-positive cardiac troponin results have led to cardiologists performing unnecessary cardiac catheterizations (personal observations of NACB Committee members). These problems have prompted manufacturers of troponin assays to produce new generation kits to improve assay sensitivity and specificity.

Table 1. Continuing analytical issues for implementation of cardiac troponin.

Lack of assay standardization for cTnI
Lack of standardization between laboratory-based and POC testing platforms
Lack of good analytical correlation (e.g., $r > 0.950$) among commercial cTnI assays for clinical specimens
Variability in imprecision for all cardiac troponin assays
Variability in acceptable blood collection tubes
Appropriate cutoff concentrations not documented
Potential for false-positive results because of the presence of fibrin, human anti-mouse antibodies, and rheumatoid factor

Cardiologists have also expressed concerns about totally replacing CK-MB. Although quantitative calculations using the area under the CK-MB vs time curve are seldom made, many physicians use peak CK-MB to get a qualitative impression as to the size of a myocardial infarction. Others have questioned whether serial troponin measurements can be used for reinfarction (because of the prolonged release pattern) and suggest a continuing role for CK-MB for this purpose. Still others feel that there has not been enough peer-reviewed publications on various troponin assays (particularly cTnI) or day-to-day experience by practicing cardiologists to warrant a change at this time. The NACB Committee felt that over the ensuing years, most of these issues will be resolved. Therefore, despite the existence of these limitations, hospitals should begin considering the replacement of CK-MB at their institutions.

An important issue that must be resolved at each institution is reimbursement for these tests. Recently, the Health Care Finance Administration announced that "it is not necessary to use troponin in addition to creatine kinase (CPT codes 82550-82554) (which includes the MB isoenzyme) in the management of patients with myocardial infarctions", suggesting that reimbursement will not be given when both tests are ordered *(100)*. Private insurance companies may also limit reimbursements for cardiac markers (e.g., Blue Cross/Blue Shield of Michigan does not reimburse for cardiac troponin). Although the Guidelines recommend the use of troponin as the new standard for myocardial injury, the NACB Committee recognizes that it is unrealistic for a hospital or medical center to completely change over to cardiac troponin

without a "transition period", during which both CK-MB and cardiac troponin assays are offered. The length of the transition period could be 3–6 months, depending on the acceptance and understanding of the use cardiac troponin results by the medical staff and the degree of continuing education available. After the trial period, the data should be reviewed and a decision made as to whether to (*a*) continue the trial period, (*b*) keep CK-MB, (*c*) replace it with one of the cardiac troponins, or (*d*) make routine use of both CK-MB and cardiac troponin.

During the presentations, the NACB Committee took a poll as to whether a recommendation can be made now to retire CK-MB. The majority felt that CK-MB still had a role. However, when the conference participants were asked about the future (5 years) use for CK-MB, essentially all felt that CK-MB would eventually be abandoned. The NACB Committee has retained this recommendation because the NACB believes that it should take a leadership role in recommending future clinical laboratory practices. The publication of the recommendation as written may provide documentation and assist laboratory directors and administrators to make changes in testing policies sooner. If laboratories are to retain CK-MB, the NACB Committee recommends the use of mass assays, which have been shown to be superior to activity-based assays (such as immunoinhibition or electrophoresis) *(29, 101)*. The calculation of the percent relative index [CK-MB (in μg/L)/total CK (in U/L) $\times$ 100] may assist in the differentiation between myocardial and skeletal muscle causes of increased total CK *(102, 103)*. Other investigators have concluded that the relative index unacceptably degrades the sensitivity of CK-MB and should be abandoned *(104, 105)*.

RECOMMENDATION 2

AMI patients with ST-segment elevations on the ECG can be effectively treated with thrombolytic therapy, particularly if therapy is initiated within 12 h after the onset of chest pain. Delays in implementation will reduce the success of this treatment. As such, the National Heart Attack Alert Program has made a recommendation to physicians to treat all AMI patients within 60 min of their arrival in the ED *(106)*. Results for serum cardiac markers are not needed in making this therapeutic decision. However, rapid testing and reporting of cardiac marker concentrations may produce other benefits for cardiac patients. Two outcome studies have shown that testing cardiac markers on a continuous random-access basis decreased the length of stay and overall laboratory costs compared with testing on a batched basis *(107, 108)*. It is presumed that providing stat testing will lead to more time-efficient decisions for triage and discharge.

The factors that affect TATs include the delay in the delivery of the sample to the laboratory, the preanalytical steps necessary to prepare the sample, the analysis time itself, and the effort it takes to deliver results to the ordering physician. The NACB Committee understands that the time taken for the delivery of samples to the laboratory is not always under the control of the laboratory. Nevertheless, laboratory personnel should work closely with hospital administrators and nursing staffs to minimize delays. TATs can be improved with the implementation of pneumatic tubes that deliver samples directly and rapidly to the central laboratory. The use of satellite laboratories is another mechanism to reduce delivery and, therefore, reporting turnaround times. Fig. 2 summarizes the steps necessary for reporting a laboratory result for cardiac markers.

> Recommendation: The laboratory should perform stat cardiac marker testing on a continuous random-access basis, with a target turnaround time (TAT) of 1 h or less. The TAT is defined as the time from blood collection to the reporting of results.
> **Strength/consensus of recommendation:** Class II.

Discussion. There was considerable discussion on the issue of TAT. There was some support for further reducing

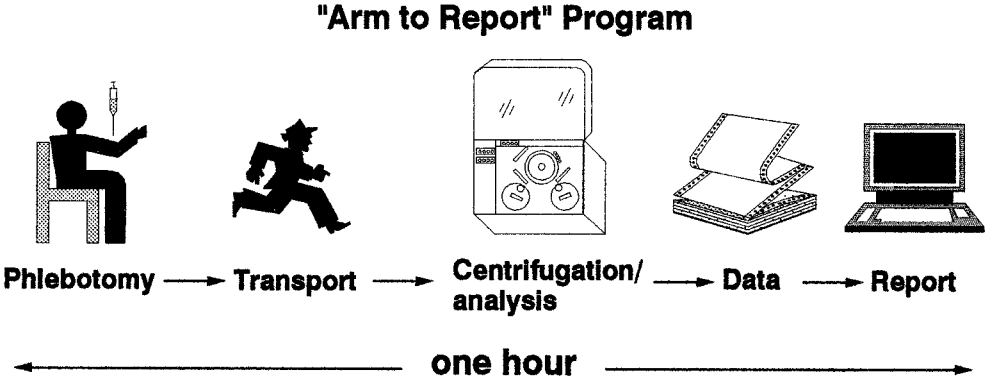

Fig. 2. NACB "Arm to Report" recommendation for a 1-h TAT for collection, transportation, analysis, and delivery of results for acute cardiac marker testing.

TATs. When questioned during the plenary lecture, Dr.Eugene Braunwald responded that 40 min was a target for ED TAT. One reviewer stated that new technologies for sample delivery, bar-coding, and rapid centrifugation will enable laboratories to consistently meet this goal and that the NACB should begin to set very high standards. Decreasing TATs would invariably be received positively by the ED staff if they themselves were not responsible for the testing. On the other hand, other individuals felt that although the technology for rapid TATs exists, many hospitals have limitations in human resources. Thus, if a sample sent from the ED for cardiac markers is accompanied by a request for a complete blood count, blood gases, electrolyte profile, gram stains, and other tests, the bench technologist must prioritize which test to perform first. When a choice is presented to the ED staff as to which stat analytes should be tested first, a cardiac marker panel might not have the highest priority. Because of the lack of consensus, the NACB Committee has retained the recommendation of a 1-h TAT objective. It is unlikely that a laboratory will be able to consistently (>90%) deliver stat cardiac marker results in <30 min, using laboratory-based serum or plasma assays. Results of stat cardiac marker testing will not be used to determine the need for thrombolytic therapy. Moreover, rule-out of AMI from the ED does require results of serial sampling, which further diminishes the need for a very rapid TAT on any single sample.

RECOMMENDATION 3

Some laboratories do not have automated immunoassay analyzers, rapid tube delivery systems, or staffing to deliver results within 1 h on a continuous basis.

Qualitative as well as quantitative POC testing devices are now available for myoglobin, CK-MB, cTnT, and cTnI *(109–112)*. These assays make use of anticoagulated whole blood, and have TATs of <20 min. Eliminating the need to deliver samples to the central laboratory and centrifugation enables TATs of <30 min. In a recent randomized study, results obtained with POC testing were compared with results obtained in a central laboratory for consecutive admissions to a coronary care unit *(113)*. The POC testing group was associated with a shorter assay TAT (5 min vs 69 min) and coronary care unit length of stay (1.94 vs 2.51 days) compared with testing performed in the central laboratory. (Because of the small number of subjects, the difference in coronary care unit length of stay did not reach statistical significance.) Recently, multipanel quantitative POC testing devices have been approved by the Food and Drug Administration for combinations of myoglobin, CK-MB, and cTnI. Quantitative assays may ultimately be more useful than qualitative POC devices. However, because ofthe newness of quantitative POC assays, there have been no studies to compare the effectiveness of qualitative vs quantitative POC testing in the ED. Therefore, the NACBCommittee was unable to formulate a recommendation at this time. In some qualitative and quantitative POC testing devices, the total number of analytes measured is fixed. Despite this, the NACB Committee endorses the use of only two: an early (myoglobin or CK-MB mass) and a definitive (cardiac troponin).

Although outcome studies have shown that stat testing and reporting of results for cardiac markers reduces hospital length of stay and laboratory costs for cardiac patients *(107, 108)*, there are no outcome studies to validate the specific need for a 1-h TAT. It is clear, however, that early treatment of Q-wave AMI patients with thrombolytic therapy is important for success in terms of reducing mortality and increasing the rate of coronary artery patency. With the development of new therapeutic strategies for unstable angina and non-Q-wave AMI, the NACB Committee anticipates that early detection of any myocardial injury will also be beneficial in the management of these patients. For those patients who are ruled out for acute coronary syndromes, it is expected that fast TATs for laboratory data will lead to faster patient discharges and a reduction in overall hospital costs. The NACB Committee encourages prospective outcome studies to examine the putative advantage of reporting TATs within 1 h.

Recommendations: Institutions that cannot consistently deliver cardiac marker TATs of ~1 h should implement POC testing devices. The cutoff concentrations of these devices should be set at the 97.5% upper reference limits so that the devices can detect the first presence of true myocardial injury.

Strength/consensus of recommendation: Class I.

RECOMMENDATION 4

POC devices are designed for testing to be performed at or near the bedside by the primary caregivers. However, the responsibility for this testing must reside with the laboratory. The success of POC testing programs will depend on cooperation and the acknowledgment of the laboratory's responsibility by hospital administrations, nursing staffs, and the appropriate units within the hospital (e.g., the ED).

When the laboratory staff recognizes a situation of noncompliance, they should have the authority to remove POC testing devices and suspend testing from the area of the hospital where the testing was conducted until the deficiencies have been satisfactorily corrected.

Recommendation: Among other tasks, laboratory personnel must be involved in the selection of devices, the training of individuals to perform the analysis, the maintenance of POC equipment, the verification of the proficiency of operators on a regular basis, and the compliance of documentation with requirements by regulatory agencies such as the Health Care Finance Administration and the Clinical Laboratory Improvement Act of 1988. In meeting these requirements, quality-assurance and quality-control programs must be instituted and fully documented on a regular basis.
Strength/consensus of recommendation: Class I.

RECOMMENDATION 5

Assays for cardiac markers for early diagnosis, rule-out, triaging of patients from the ED, or for determination of successful reperfusion require markers that have a short assay TAT. Irrespective of how the testing is performed (i.e., laboratory-based or POC testing), assays must meet minimum precision requirements. Imprecise assays at or near cutoff concentrations will adversely affect the clinical performance of the test.

The NACB Committee understands the importance of establishing objective analytical goals for assays for new cardiac markers. This will assist manufacturers in the construction of new assays. The total precision required for a particular assay is dependent on the biological variation of the analyte. The biologic variation has been established at <5.6% for myoglobin *(116)* and <9.3% for CK-MB *(117)*. The biologic variation for cardiac troponin has not been established. As such, this recommendation for total precision was arbitrarily set at 10% without a prior scientific basis.

Recommendation: Assays for cardiac markers should have an imprecision (CV) <10% at the AMI decision limits and an assay TAT of <30 min. Before launch, assays must be characterized with respect to potentially interfering substances [e.g., other related proteins, human anti-mouse antibodies *(114, 115)*, and other interferences].
Strength/consensus of recommendation: Class II.

RECOMMENDATION 6

Most patients with cardiac diseases are heparinized while hospitalized. When serum is collected from these patients, full clot retraction from tubes without preservatives can take 10–15 min or more. Clots can continue to form even after the sample has been centrifuged and the serum placed onto immunoassay analyzers. When this occurs, instrument probes can be blocked by fibrinous material. For automated immunoassay analysis, the use of plasma will eliminate the extra time needed for clotting, thereby reducing the overall preanalytical TATs. Manufacturers should target their assays for use in plasma. Results for serum and plasma are not interchangeable for all assays and markers, particularly for cTnI. Therefore, for cardiac troponin, NACB cannot recommend that laboratories intermix different types of blood collection tubes at the same facility.

Although whole blood testing is not an option for most automated immunoassay analyzers, it is available for POC testing. The use of whole blood can reduce assay and reporting TATs. Currently, the assay TATs for myoglobin, CK-MB, and troponin are 10–20 min. For some samples, dilutions will be necessary to report quantitative results that are within the limits of the reportable range. Electronic transmission of results will be essential for efficient delivery of results.

Recommendation: Plasma or anticoagulated whole blood are the specimens of choice for the stat analysis of cardiac markers.
Strength/consensus of recommendation: Class I.

Discussion. In the original draft of the Guidelines, the recommendation stated that heparinized plasma is the specimen of choice for troponin measurements. However, some reviewers, particularly those in Europe, suggested that the Guidelines be expanded to included all forms of plasma collection tubes (such as EDTA or citrated collection tubes). Laboratories that choose to use these collection types must proceed with caution. With EDTA tubes, troponin released as a ternary (cTnT-I-C) or binary (cTnI-C) complex will degrade to free subunits because ionized calcium is needed to maintain this complex and is removed by chelation of the metal ions *(118)* Troponin assays that do not exhibit an equimolar response between complexed and free subunits will produce significant biases between serum and EDTA plasma *(97)*. Heparin does not disrupt complexes; therefore, no change in results between serum and plasmas are expected. The laboratory must follow the recommendations for accept-

able specimen types listed in manufacturers' package inserts and should use a reference interval specific to the specimen type.

General Discussion

One reviewer expressed concern that if these guidelines are enacted, laboratories that choose not to enact one or more of the recommendations may be open to liability if a cardiac patient suffers an unfavorable outcome and a lawsuit is filed. This is an important issue for all clinical practice guidelines committees and expert panels. It is important to recognize that to successfully win a malpractice lawsuit, the plaintiff must prove that the victim "was injured by medical management that failed to reach the standard reasonably expected of the medical practitioner" *(119)*. Thus, if a laboratory fails to use cardiac troponin, but instead uses CK-MB in a patient with chest pain, there will be no liability because this practice is acceptable and well documented in the literature (irrespective of recommendations made in these Guidelines). If on the other hand, the physician fails to order or the laboratory fails to make available results of any cardiac marker test, either may suffer liability because this is not standard practice. Although these guidelines recommend the use of two cutoff limits for cardiac troponin, there is ample scientific evidence and widespread clinical practice for the use of a single cutoff to defend laboratories who choose this approach.

The objective of the NACB Committee was not to make recommendations as to how cardiac markers are to be used with other diagnostic modalities (e.g., electrocardiography, echocardiography, and nuclear imaging ventriculography) or how results should be used to select specific therapies. Organizations such as the National Heart Attack Alert Program Committee and the Agency for Health Care Policy Research have been developed to address such issues.

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