American Journal of Emergency Medicine (2012) xx, xxx–xxx

The American Journal of Emergency Medicine

www.elsevier.com/locate/ajem

Review

# Cardiac troponin: a critical review of the case for point-of-care testing in the ED

Roland Bingisser MD[a], Charles Cairns MD[b], Michael Christ MD[c], Pierre Hausfater MD, PhD[d], Bertil Lindahl MD, PhD[e], Johannes Mair MD[f], Mauro Panteghini MD[g], Christopher Price PhD[h], Per Venge MD, PhD[i,*]

[a]*Universitätsspital, 4031 Basel, Switzerland*
[b]*University of North Carolina, Chapel Hill, NC 27599, USA*
[c]*Community Hospital Nuremberg, 90419 Nuremberg, Germany*
[d]*Hôpital Pitié-Salpêtrière et Université Pierre et Marie Curie, 75005 Paris, France*
[e]*Uppsala Clinical Research Center, 75185 Uppsala, Sweden*
[f]*Innsbruck Medical University, 6020 Innsbruck, Austria*
[g]*Department of Clinical Sciences "Luigi Sacco," University of Milano, 20157 Milan, Italy*
[h]*University of Oxford, OX1 2JD Oxford, UK*
[i]*University of Uppsala, 75183 Uppsala, Sweden*

Received 9 February 2012; accepted 5 March 2012

**Abstract** The measurement of cardiac troponin concentrations in the blood is a key element in the evaluation of patients with suspected acute coronary syndromes, according to current guidelines, and contributes importantly to the ruling in or ruling out of acute myocardial infarction. The introduction of point-of-care testing for cardiac troponin has the potential to reduce turnaround time for assay results, compared with central laboratory testing, optimizing resource use. Although, in general, many point-of-care cardiac troponin tests are less sensitive than cardiac troponin tests developed for central laboratory–automated analyzers, point-of-care systems have been used successfully within accelerated protocols for the reliable ruling out of acute coronary syndromes, without increasing subsequent readmission rates for this condition. The impact of shortened assay turnaround times with point-of-care technology on length of stay in the emergency department has been limited to date, with most randomized evaluations of this technology having demonstrated little or no reduction in this outcome parameter. Accordingly, the point-of-care approach has not been shown to be cost-effective relative to central laboratory testing. Modeling studies suggest, however, that reengineering overall procedures within the emergency department setting, to take full advantage of reduced therapeutic turnaround time, has the potential to improve the flow of patients through the emergency department, to shorten discharge times, and to reduce cost. To properly evaluate the potential contribution of point-of-care technology in the emergency department, including its cost-

* Corresponding author. Department of Medical Sciences, University Hospital, SE-751 85 Uppsala, Sweden. Tel.: +46 705349646; fax: +46 186113703.
*E-mail address:* per.venge@medsci.uu.se (P. Venge).

0735-6757/$ – see front matter 
doi:10.1016/j.ajem.2012.03.004

effectiveness, future evaluations of point-of-care platforms will need to be embedded completely within a local decision-making structure designed for its use.


## 1. Introduction

The management of patients presenting with chest pain accounts for a substantial proportion of emergency care resources [1]. Nevertheless, evaluating patients with acute chest pain in the emergency department remains challenging, despite an exponential recent growth in the volume of published research on the diagnosis and management of these patients. Patients with acute coronary syndromes including acute myocardial infarction or other high-risk conditions should be effectively identified by the emergency physician in a timely manner to initiate specific clinical actions. Conversely, patients who do not have acute coronary syndromes (most patients admitted with chest pain [2]) or alternative high-risk conditions should be discharged safely and promptly. Achieving these outcomes benefits both the patient (perhaps by facilitating the diagnosis of another serious condition) and the emergency department, in terms of increased efficiency and throughput and reduced overcrowding.

Current recommendations identify the measurement of cardiac markers, especially cardiac troponin, as an important part of the diagnosis of acute myocardial infarction, alongside other testing modalities such as electrocardiogram (ECG) measurement and cardiac angiography [3-7]. In a number of institutions, however, the central laboratory is unable to meet the requirements for a rapid turnaround time for cardiac biomarker measurement, with the recommended time from blood draw to test result reporting of 60 minutes or less [8-10]. Then, measurement at the point of care is a potential strategy for reducing the turnaround time for cardiac troponin testing in the emergency setting [11]. Here, we review systematically the rationale for and the current status of point-of-care testing in the emergency department setting, with regard to its evidence base, limitations, advantages, and barriers, and, in respect of a series of key questions, its impact on length of stay, patient management, outcomes, and resource use.

## 2. Methods

PubMed was searched for "troponin AND ('point-of-care' OR 'point of care' OR POCT) AND ('myocardial infarction' OR 'acute coronary syndrome' OR 'acute coronary syndromes')." Further materials came from the reference lists from publications or from the experience of the authors. Preference was given to randomized, controlled trials, where available, although other types of studies were considered where data from randomized trials were lacking.

## 3. What is the state of the art for the evaluation of patients presenting with chest pain to an emergency department?

### 3.1. Elevated cardiac troponin and cardiac risk

An increasing level of cardiac troponin in the bloodstream signifies severe and, probably, irreversible damage to the myocardium, and it is central in the diagnostic definition of an evolving acute myocardial infarction (see below) [3,4]. The clinically important troponins are troponin I and troponin T: separate genes regulate their expressions in the heart and skeletal muscle. Expression of cardiac isoforms of troponins has not been reported outside the heart in adult humans. Accordingly, the detection in the blood of troponin isoforms of cardiac origin can be achieved using specific monoclonal antibodies. The detection of circulating cardiac troponin is currently the most sensitive and specific biochemical marker of irreversible myocardial injury (necrosis) that is available to the physician in clinical settings including the emergency department [12].

No single diagnostic instrument consistently identifies or rules out the presence of an acute coronary syndrome at presentation to the emergency department, and relying on signs and symptoms alone can be misleading because a substantial proportion of patients present with nonspecific symptoms [13,14]. Several approaches have been used to incorporate measurements of cardiac biomarkers, including cardiac troponin, alongside ECG measurement, patients history, and so on, during the diagnostic workup of patients with chest pain in the emergency setting. For example, elevated cardiac troponin, along with ST-segment changes, has been used to stratify patients for risk of adverse cardiac outcome using a risk score derived from the Thrombolysis in Myocardial Infarction trial [15,16]. Lower cardiac troponin concentrations than those traditionally required for diagnosis of acute myocardial infarction (see below) have also been shown to predict adverse prognosis, and we may need to reassess the clinical importance of minor increases in cardiac troponin with respect to therapeutic intervention [17,18], especially as cardiac troponin assays become more sensitive and more widely used in routine clinical practice [19].

### 3.2. Cardiac troponin and diagnosis of acute coronary syndromes: recommendations, consensus statements, and guidelines

Fig. 1 summarizes key steps in the triage and management of patients presenting with suspected acute coronary syndromes [20]. The initial triage of a patient presenting to an

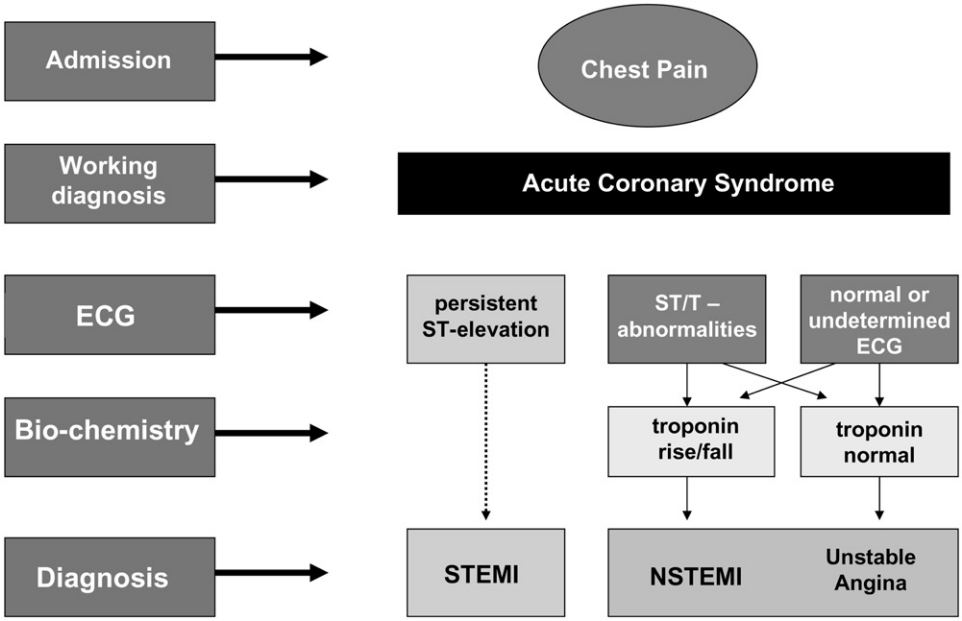


**Fig. 1** Algorithm for triage and evaluation of a patient presenting with chest pain suggestive of a possible acute coronary syndrome. Reproduced from Hamm et al [20], with the permission of Oxford University Press.

emergency department with acute chest pain and ST-segment elevation in the 12-lead ECG is usually straightforward. Patients with non–ST-elevation acute coronary syndromes must be assessed using a combination of 3 key factors: clinical presentation, 12-lead ECG findings, and measurement of cardiac biomarkers (principally, cardiac troponin [12]; see also Fig. 1), incorporating formal risk stratification using risk assessment tools such as the Thrombolysis in Myocardial Infarction, Platelet glycoprotein IIb/IIIa in Unstable angina: Receptor Suppression Using Integrilin Therapy (PURSUIT), or Global Registry of Acute Cardiac Events (GRACE) risk scores (reviewed elsewhere [21]). The Universal Definition of Myocardial Infarction, a collaborative consensus proposed jointly by European, American, and international expert societies in 2007, considered that a change in the blood concentrations of cardiac troponin, with at least 1 value above the 99th percentile limit of the distribution of reference values, can be used to diagnose acute myocardial infarction when accompanied by other signs of ischemia (symptoms or ECG changes) [3,4]. Further recommendations proposed by the International Federation of Clinical Chemistry and Laboratory Medicine and the National Academy of Clinical Biochemistry (NACB) also proposed a diagnostic cutoff for cardiac troponin (cardiac troponin I or cardiac troponin T) corresponding to the 99th percentile limit [5,6].

In some cases, cardiac troponin measurements made soon after the presentation and alongside ECG measurements may contribute to accelerated patient management decisions. Recent recommendations have noted that currently available cardiac troponin assays can contribute to rule-out protocols for myocardial infarction within 3 hours of arrival at the emergency department [7,20] (a useful guide to the characteristics of such assays has been published recently) [22]. One additional study from the United States showed that measurement of myoglobin and creatine kinase (CK) MB did not add to the value of a sensitive cardiac troponin assay for achieving the diagnosis of non–ST-elevation myocardial infarction (NSTEMI) within 2 hours [23].

Other diagnostic modalities such as imaging techniques may assist in the ruling in or ruling out other potentially life-threatening conditions such as pulmonary embolism or aortic dissection. Using the data assembled during this process, the emergency department physician must either refer the patient to one of the following: immediate revascularization, intensive care unit, coronary care unit, other wards, or ambulatory care, usually with a coronary stress test.

### 3.3. Availability of biomarker test results in the emergency department

The core principle underlying point-of-care measurement has been described as reducing turnaround time without compromising the quality of information on which clinical decisions for patients are based [24]. In the United States, the NACB noted that patients with ST-elevation myocardial infarction (STEMI) should receive treatment within 60 minutes of admission without the use of cardiac biomarkers (the European Society of Cardiology provided a similar recommendation [20,25]). The NACB further recommended an accelerated protocol involving the use of cardiac biomarkers in the diagnosis of acute coronary syndrome, which would be of benefit to patients with NSTEMI [10]. Specifically, a turnaround time of less than 1 hour should be achieved, and it can be observed that the availability of point-of-care testing can reduce this to less than 30 minutes. The 2011 guideline for

management of non–ST-elevation acute coronary syndromes noted that a rapid (2-hour) rule-out protocol for acute coronary syndromes using point-of-care biomarker testing, ECG, and risk scoring was found to be safe [20,26].

It should also be noted that a turnaround time of 20 to 30 minutes would provide results during the initial examination by the physician, although a longer turnaround time (45-60 minutes) would often provide results when the physician was attending to another patient. Accordingly, institutions that cannot consistently deliver turnaround of cardiac biomarker results within 1 hour should consider the introduction of point-of-care cardiac troponin testing to address this issue [5].

### 3.4. Point-of-care technology and platforms for cardiac troponin

Point-of-care systems should provide quantitative measurement of cardiac troponin to support or rule out a diagnosis of acute myocardial infarction. In addition, the sensitivity of the assay system should not differ from that provided by automatic platforms in the central laboratory. The imprecision of the measurement at the 99th percentile concentration (the consensus diagnostic threshold for acute myocardial infarction, as described above) has been highlighted as important in the current management recommendations relating to the cardiac troponin measurement [4]. Specifically, imprecision (as coefficient of variation) of 10% or less at the 99th percentile limit is desirable, and routine use of cardiac troponin assays with imprecision greater than 20% is no longer recommended.

There are 2 main types of point-of-care devices for the measurement of cardiac troponin: bench-top systems and handheld devices; key features relating to cardiac troponin measurement are reproduced in Table 1 [24,27,28]. Most devices measure cardiac troponin I, with only 2 systems measuring cardiac troponin T. There is no standardization of measurement of cardiac troponin I, with various different assay technologies in use and different cutoff levels for this biomarker applying to different instruments. In addition, there is a considerable variation among devices according to the amount and type of the biological sample (blood, plasma, or serum) required for measurement. Some systems measure multiple biomarkers simultaneously (eg, cardiac troponin I, CK-MB, and myoglobin). In general, assay times are of the order of 10 to 15 minutes (although the overall assay reporting time may depend on the number of biomarkers being measured for some systems). Additional technologies for point-of-care measurement of cardiac troponin are emerging, with the potential to reduce assay times to about 5 minutes [29].

## 4. How reliable are point-of-care assays for cardiac troponin?

In general, currently available point-of-care tests for cardiac troponin are less sensitive than central laboratory

**Table 1** Features of currently available quantitative point-of-care assay systems for measuring cardiac troponin, as reported by assay manufacturers

| Brand name/company | 99th percentile upper reference limit (μg/L) | Technology, reaction detection | Limit of blank (μg/L) | Sample | Analytic turnaround time (min) |
|---|---|---|---|---|---|
| i-Stat Troponin I/Abbott | 0.08 | ELISA, ALP | 0.02 | 16 μL whole blood | 10 |
| Triage troponin I/Alere | 0.056 | Chromatographic, fluorescence | 0.01 | 250 μL heparinized whole blood or plasma | 15 |
| PATHFAST troponin I/Mitsubishi | 0.029 | Magnetic beads, CL | 0.008 | 100 μL heparinized whole blood, plasma, or serum | 17 |
| AQT90 Flex troponin I/Radiometer | 0.023 | Sandwich immunoassay, fluorescence | ND | 1 mL EDTA or heparinized whole blood, plasma, or serum (40 μL for individual tests) | 18 |
| AQT90 Flex troponin T/Radiometer | 0.017 | Sandwich immunoassay, fluorescence | ND | 1 mL EDTA or heparinized whole blood, plasma, or serum (40 μL for individual tests) | 12 |
| RAMP troponin I/Response Biomedical Corp | <0.1 | Chromatographic, fluorescence | 0.03 | 75 μL EDTA whole blood | 18 |
| Cardiac Reader troponin T/Roche | <0.05 | Chromatographic, color | <0.05 | 150 μL heparinized whole blood | 12 |
| Stratus CS troponin I/Siemens | 0.07 | ELISA, ALP | 0.03 | 3 mL heparinized whole blood (100-200 μL plasma for individual tests) | 14 |

Data have been obtained from assay inserts and the official home pages of the respective companies. ELISA, enzyme-linked immunosorbent assay; ALP, Alkaline phosphatase; CL, chemiluminescence; ND, not determined or not available.
Manufacturer locations: Abbott, Illinois, USA; Alere, Waltham, MA, USA; Mitsubishi, Düsseldorf, Germany; Radiometer, Brønshøj, Denmark; Response Biomedical Corp, Vancouver, Canada; Roche, Basel, Switzerland; Siemens, Erlangen, Germany.

tests: this potentially limits their use for reliable ruling out of a diagnosis of acute myocardial infarction in the emergency department [30,31]. A survey of 1069 consecutive admissions to an emergency department in Sweden illustrated the importance of this point by comparing the performance of 2 point-of-care devices (i-Stat [Abbott Diagnostics, Illinois, USA] and Stratus CS [Siemens Healthcare Diagnostics, Erlangen, Germany]) with that of 2 central laboratory–based devices (Access AccuTnI [Beckman Coulter, Chaska MN, USA] and Architect cTnI [Abbott Diagnostics]) [32]. Using the 99th percentile as a medical decision limit for acute myocardial damage, as currently recommended, the central laboratory assays identified more patients as having elevated cardiac troponin I (39% and 48%, respectively) compared with 20% and 27% for the 2 point-of-care assays. At the same diagnostic cutoff, the laboratory assays identified 81% or 88% of all patients who died of cardiovascular disease during 35 months of follow-up, compared with 50% or 54% for the point-of-care assays. The authors concluded that "If a clinical suspicion of myocardial injury remains despite negative cardiac troponin I results with the point-of-care assays, such results should be complemented by results from sensitive laboratory assays." To be implemented successfully, a point-of-care test for cardiac troponin should significantly reduce turnaround time without worsening analytical performance (detection limit, etc) and, thus, diagnostic performance. In particular, emergency physicians would tolerate neither a significant increase in false-negative results (leading to discharge of patients with a persistent risk of cardiac adverse events) nor a substantial increase in "false positive" acute myocardial infarction classifications with the risk of unjustified therapeutic interventions.

A further difficulty is that data provided by device manufacturers with regard to sensitivity and specificity for ruling out acute myocardial infarction may use outdated definitions of acute myocardial infarction based on cardiac enzymes (Mendis and colleagues [33] have reviewed the development of definitions of acute myocardial infarction over time), rather than the current recommendations from expert cardiology societies from either side of the Atlantic [3]. Such levels of sensitivity are only adequate for the diagnosis of a large acute myocardial infarction, which can be often made more reliably based on the ECG and on history and symptoms.

## 5. What is the impact of point-of-care testing for cardiac troponin on outcome/safety?

The safety of an accelerated 90-minute protocol to exclude a diagnosis of acute myocardial infarction has been demonstrated in the emergency department setting in the United States in 2001, using serial multimarker point-of-care tests (cardiac troponin, CK-MB, myoglobin) [34]. All cases of acute myocardial infarction were diagnosed within 90 minutes, and admissions to the coronary care unit were decreased by 40%. In addition, 90% of patients with negative cardiac biomarkers and ECG findings were discharged, with only 1 returning with myocardial infarction within 1 month. The authors considered that their simple, inexpensive protocol provided rapid and effective triage for their population, although confirmation of this approach using the current universal definition of myocardial infarction [3] would be reassuring. Another study from the United States, published in the same year, focused on 817 consecutive emergency department admissions for suspected acute myocardial infarction [35]. Here, a point-of-care testing strategy involving measurement of CK-MB and cardiac troponin provided a sensitivity of 96.9% and a negative predictive value of 99.6% for the diagnosis of myocardial infarction within 90 minutes, facilitating prompt and reliable ruling out of acute myocardial infarction. The median turnaround time for the point-of-care tests was 24 minutes compared with 71 minutes for the central laboratory. A study in patients presenting to an emergency department in the United Kingdom between 2003 and 2004 showed that measurement of cardiac markers (cardiac troponin, CK-MB, and myoglobin) with point-of-care technology allowed rapid discharge of one-third of patients admitted with chest pain, with only 1% readmission with acute coronary syndromes and no deaths after 6 months of follow-up [36].

A systematic review of 11 observational and 2 randomized controlled trials published in 2009 concluded that there was no evidence that implementing point-of-care testing for cardiac markers significantly altered clinical outcomes [11]. Some operational benefits such as reduced length of stay, faster throughput, or fewer hospital admissions were noted in some studies, but results were variable. A further 3 randomized clinical trails have appeared since the publication of this review. Table 2 provides an overview of these randomized clinical trials and those included in the review described previously [37-42]: most of these studies, originating from a broad variety of countries, demonstrated a benefit for point-of-care vs the central laboratory. The finding of reduced time to the application of anti-ischemic therapy associated with the use of point-of-care testing [36] has been confirmed by a study based on a large registry in the United States [43].

In addition, the Randomised Assessment of Treatment using Panel Assay of Cardiac Markers (RATPAC) study demonstrated no significant differences in adverse events (death, myocardial infarction, hospitalization for acute coronary syndromes, life-threatening arrhythmia, or emergency revascularization) between patients randomized to clinical evaluation based on point-of-care measurement of cardiac biomarkers and those randomized to clinical evaluation based on standard care [40,41]. It should be remembered, however, that these studies used older definitions of myocardial infarction for adjudicated outcomes. Current high-sensitivity cardiac troponin I assays may identify additional patients who might benefit from

**Table 2** Overview of randomized trials comparing POC vs central laboratory measurement of cardiac biomarkers in patients presenting with suspected cardiac ischemia

| Reference | Patients (country) | Setting | Biomarkers measured | Key findings |
|---|---|---|---|---|
| [37] | 263 with suspected ACS (United Kingdom) | CCU | cTnT and CK-MB | Equivalent diagnostic accuracy and mortality with POC testing vs central laboratory. No overall change in LOS, but a significant decrease in a prespecified group of early discharge patients (145 h vs 80 h excluding the CCU, 209 h vs 150 h overall) |
| [38] | 860 with suspected ACS (France) | ED | cTnI | Decrease in time to anti-ischemic therapy of about 45 min for POCT vs central laboratory due to more rapid availability of cTnI data; no significant difference between groups for LOS or clinical outcomes |
| [39] | 2000 with suspected ACS at 4 centers (United States) | ED | cTnI | No overall change in LOS, but the effect of POC testing on LOS varied between centers |
| [40,41] | 2243 with suspected AMI at 6 centers (United Kingdom) | ED | cTnI, CK-MB, myoglobin | POC vs central laboratory resulted in more successful discharges (32% vs 13%; $P < .001$), reduced median initial hospital stay (9 h vs 14 h; $P < .001$), and greater use of coronary care facility (4% vs 3%; $P = .041$). Mean initial hospital stay or clinical outcomes did not differ between groups[a]. |
| [42] | 1194 with suspected ACS admitted to 2 EDs (Australia) | ED | cTnI, CK-MB, myoglobin | Despite underuse of POC, there was a 10% increase in the proportion discharged within 8 h ($P = .007$), together with a nonsignificant trend to shorter LOS. Benefits were greater when 24-h central laboratory support was unavailable. |

ACS, acute coronary syndrome; CCU, coronary care unit; cTn, cardiac troponin; ED, emergency department; LOS, length of hospital stay; POC: point of care.
[a]Within 4 hours with no adverse outcome within 3 months.

invasive interventions, as suggested by a recent study where lowering the detection threshold for myocardial necrosis from 0.20 to 0.05 $\mu$g/L reduced the risk of adverse clinical outcomes in patients presenting with suspected acute coronary syndromes [44].

## 6. What is the impact of point-of-care testing for cardiac troponin on the length of stay in the emergency department?

The average length of stay in the emergency department in the United States is increasing, particularly for patients from ethnic minorities [45], so that initiatives that could potentially shorten length of stay are of considerable clinical interest. Table 2 includes information on length of stay from randomized clinical trials that evaluated point-of-care platforms within the management of patients presenting with suspected acute myocardial infarction/acute coronary syndromes. Randomization of 263 patients admitted to the coronary care unit to cardiac biomarkers using point-of-care or central laboratory systems (with other aspects of management unchanged) did not reveal a significant effect on length of stay, even if length of stay in hospital was reduced significantly with point-of-care testing in 64 patients (24%) meeting the prespecified criteria for early discharge (the "rapid rule-out" group) [37]. "Ownership" of results by the nursing staff who performed the point-of-care tests, for example, facilitating early prompting of physicians, was identified as a factor that contributed to reduced length of stay in some cases. Length of stay was also unaffected in a further, relatively small trial in 860 patients, of whom 113 had a high risk of non–ST-elevation acute coronary syndromes [38].

The Disposition Impacted by Serial Point of Care Markers in Acute Coronary Syndromes trial set out to test the hypothesis that point-of-care testing for cardiac troponin I would reduce length of stay, relative to central laboratory testing, in a large sample of 2000 patients evaluated for suspected acute coronary syndromes [39]. Again, there was no overall change in length of stay, but findings varied between the 4 participating study centers, with significantly reduced length of stay in one center and significantly increased length of stay in another. However, there was no account taken of the rapid availability of results and no requirement to change the care pathway specified in the point-of-care testing arm of the study, which would have reduced the likelihood of detecting a consistent change in length of stay [46]. The authors concluded that reduced assay turnaround time per se was insufficient to influence length of stay and that point-of-care testing must impact on other aspects of patient management (eg, physicians being ready to receive and process biomarker measurements at the time they become available) to translate reduced assay turnaround time to more rapid discharge. Reducing "brain-to-brain time" (the time between a physician ordering a test and when he/she

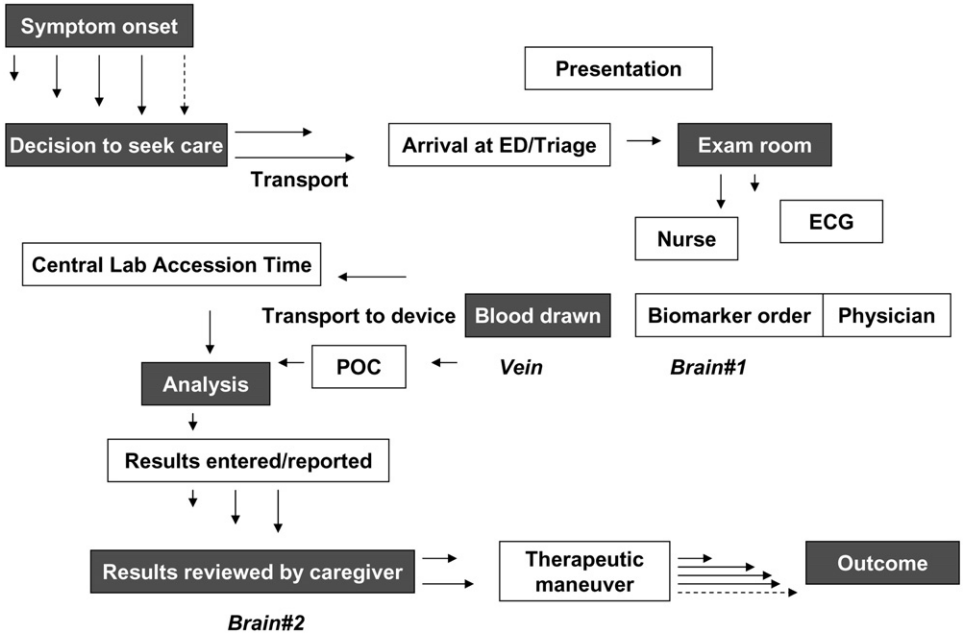


**Fig. 2** Sequence of events that determine the turnaround time after admission to an emergency department with a suspected acute coronary syndrome. Clear boxes indicate times generally recorded or known ("hard" times), whereas shaded boxes indicate times generally not, or variably, recorded ("soft" times). Arrow length roughly represents time duration; dashed arrows indicate times with large variability. Reproduced from Storrow et al [10], with the permission of the National Academy of Clinical Biochemistry, Washington, DC.

interprets its results; see Fig. 2) was considered key to reducing overall length of stay.

A similar finding emerged from the RATPAC trial, which set out to evaluate the effect of point-of-care cardiac biomarker testing on successful discharge rates in 2243 patients admitted with suspected acute myocardial infarction in 6 centers [40]. Median initial hospital stay was reduced, alongside an increased frequency of successful discharges, but there was no change in the mean hospital stay or the number of inpatient days during follow-up. Heterogeneity between lengths of stay in centers was again noted, and the authors considered that the way that point-of-care testing is incorporated within local practices and protocols is crucial in its effects on the length of stay [47]. A trial in 1194 patients with suspected acute coronary syndromes showed that 10% more patients were discharged in less than 8 hours with point-of-care vs central laboratory testing ($P = .007$), but that the differences in overall length of stay was not significant [42]. Finally, measurement of turnaround times for blood tests in a hospital in the United Kingdom showed that these had an impact on time to diagnosis [48]. Overall, the length of stay was influenced by the degree to which the process of care was altered to make use of the rapid turnaround time when using point-of-care testing.

## 7. What are the cost implications of point-of-care testing for cardiac troponin?

Improved operational efficiency of the emergency department should result in greater economic efficiency. An economic analysis of the RATPAC study concluded that a point-of-care panel of cardiac biomarkers was not cost-effective compared with standard practice, with overall costs per patient of $1006 for standard care vs $1217 for point-of-care [49]. However, as described above [40], it would be important to fully integrate point-of-care testing into hospital procedures to realize its potential benefits for efficiency and cost-effectiveness, which was not uniformly the case at RATPAC centers. A previous study from the United States involved 545 patients admitted to a cardiology unit with chest pain in roughly equal proportions immediately before or after the introduction of point-of-care testing for cardiac troponin I [50]. Charges to patients fell by 25% after the introduction of point-of-care testing due to reduced costs associated with boarding, other departments, pharmacy, laboratories, and cardiac or noncardiac procedures. Ultimately, a prospective randomized clinical trial is required to validate the true cost-effectiveness of a clinical pathway reengineered with point of care.

## 8. What is the potential impact of point-of-care testing for cardiac troponin on the management of patients presenting with chest pain?

### 8.1. Changes to clinical procedures

Preliminary evidence from randomized clinical trials, described previously, demonstrates the potential for point-of-care testing to deliver important operational benefits for the emergency department and the hospital. Nevertheless, these

effects are variable, and shortening the turnaround time alone without delivering additional benefits is clearly insufficient. A major limitation of some studies has been their failure to test the overall concept of point-of-care–driven decision making: successful implementation of point-of-care cardiac troponin testing requires a multidisciplinary approach where members of emergency department, primary care physicians, divisions of cardiology, hospital administrations, and clinical laboratories collectively develop an accelerated protocol for the evaluation of patients with suspected myocardial injury. This includes the use of quality assurance measures and evidence-based guidelines, with point-of-care testing results available on a central database accessible to different members of the team. Moreover, laboratory personnel must be involved in the selection of devices, training, maintenance, and regulatory compliance issues. It is also important that an account of any differences in the analytical sensitivity of the systems used in the central laboratory and point-of-care testing setting is taken; for example, if the point-of-care system is more sensitive, it may detect more cases ruled in (and vice versa for a less-sensitive assay). Critically, with regard to the pathway of care, the time at which decisions are made and implemented needs to be changed to take advantage of the faster delivery of results. Finally, the point-of-care testing device should be close to the patient so that transport delays/logistics are minimized.

Unlocking the full potential benefits of point-of-care technology requires changes to clinical pathways and services, a need identified clearly by previous work in this area. It has been noted during the conduct of randomized comparisons of point-of-care testing and central laboratory services that structured decision making must be incorporated alongside the introduction of point-of-care testing to reduce in-hospital stay [11], that operational changes must accompany the use of point-of-care testing to translate reduced turnaround time into meaningful improvements in length of stay [39], and that changes to training and maintenance programs need to contribute to a change in the clinical culture surrounding the use of point-of-care testing to support its effective introduction [42]. The rapid availability of results from point of care, for example, may render this technology useful during initial triage [51], and reduced length of stay in the emergency department has been observed when point-of-care testing for cardiac troponin is performed by nurses [52].

Fig. 2 summarizes the various activities that take place during the passage of a patient with suspected acute coronary syndromes through the emergency department [10]. This approach provides a framework for "lean thinking," a quality-driven approach to process improvements that focuses on reengineering of the decision-making pathway to remove inefficiencies (eg, unnecessary transport time or waiting time). The delay involved in waiting for the results from the central laboratory is clearly one such inefficiency. Point-of-care testing not only should reduce assay turnaround time (from drawing of blood to reporting of results) but would also reduce the "vein-to-brain" time (time from blood collection to action on result) and, more importantly, brain-to-brain time (the therapeutic turnaround time from the decision to order the test to the resulting clinical action based on the result). The latter point is crucial in optimizing the benefit from point-of-care testing: improving the speed of delivery of test results alone will not shorten the time to clinical intervention if the decision-making pathway is not optimized to act on rapidly produced test results [24].

By using this process, point-of-care testing will have the ability to reduce costs while simultaneously improving patient care. The concept of lean thinking, first described in the automotive industry, is being used increasingly to improve the flow of patients and information in the health care sector with concomitant improvement in the use of resources [53]. Lean thinking analyses 7 key aspects of the process, in terms of transport (moving people and materials), inventory (materials in stock, information in transit, and unfinished processes), motion (people moving around), waiting (for people or for things to happen), overproduction (more being done than the next person in the system actually requires), overprocessing (things being done that the next person does not need at all), and defects (inappropriate actions or inactions). Careful analysis of how and why actions take place, followed by stripping away waste at each stage, improves the overall efficiency, and flow through the system is improved. It is important to remember, as discussed previously, that the whole system must be reengineered to maximize the overall benefit from shortened turnaround times by point-of-care assays.

In the future, the introduction of high-performance point-of-care testing may have broader implications for the operation of the emergency department. At present, the value of point-of-care testing may lie principally in the reduced length of stay/early discharge, thereby optimizing bed use and improving the efficiency of the emergency department as a whole.

### 8.2. Modeling

The operational benefit of the reengineered pathway (with point of care) in comparison with the conventional strategy (without point of care) can be explored using modeling. A model representing a real-time simulation of patients through an urban emergency department, based on actual patient data, showed that reducing laboratory turnaround time had major positive impacts on patient flow through the department, length of stay, and on emergency medical system diversions [54]. The authors noted that these are important but inadequately studied measures that should receive prospective evaluation and validation.

### 8.3. Connectivity and clinical decision support systems

When making a diagnosis, the cardiac troponin result is just one piece of information that needs to be integrated with

other critical data such as ECG profiles, clinical history, and signs and symptoms. Arguably, in many situations, the portability of equipment is less important than having relevant information at hand and being able to translate it into patient-specific decisions. Computer-assisted clinical decision support is regarded as a promising tool to assist clinicians in this process. The contribution of clinical decision support to cardiovascular care in general has been evaluated, although studies are lacking in relation to the use of point-of-care testing for suspected acute coronary syndromes [55,56].

### 8.4. Barriers to the introduction of point-of-care testing in the clinical setting

There are significant barriers to the routine introduction of point-of-care testing. These include lack of confidence in the results, driven by lower performance of current generation point-of-care devices compared with central laboratory testing; practical issues relating to user (eg, training, maintenance, or accreditation); and perceived higher costs and reimbursement issues, particularly when laboratory services are run on a fee-for-service basis [57,58].

Current recommendations regarding point-of-care testing are largely based on expert consensus. To date, there is insufficient evidence to show that point-of-care testing for cardiac troponin has any impact on clinical outcome, largely because few studies (of varying designs) have addressed this question. The evidence base in support of point-of-care testing will need to be increased, with studies evaluating this approach embedded completely within the hospital decision-making structure, as described previously. New studies must evaluate the efficacy, safety (including longer-term outcomes), patient-centered outcomes (such as satisfaction with treatment), and health-economic outcomes of the point-of-care testing strategy.

## 9. Conclusions: can point-of-care testing for cardiac troponin improve the ruling out and ruling in of acute myocardial infarction?

The rationale for the use of troponin point-of-care cardiac troponin testing to improve global efficiency in patient care within the emergency department differs between the situations of patients presenting with STEMI or NSTEMI. For patients with STEMI, international guidelines recommend that diagnoses should be made using symptoms and specific ECG changes, with no need to wait for the result of a biomarker test, for immediate referral to coronary revascularization. For patients with NSTEMI, the added value of a rapid point-of-care test for cardiac troponin differs according to whether NSTEMI rule-in or rule-out is considered. Elevated cardiac troponin concentrations are crucial for the diagnosis of NSTEMI, but the added value from the time gain due to point-of-care testing remains a matter of debate. So far, no study has clearly demonstrated that saving 60 minutes in establishing the diagnosis of NSTEMI and the initiation of appropriate treatment reduces the risk of major adverse cardiac events during follow-up. From a patient's perspective, negative cardiac troponin concentrations may mean earlier relief; from an emergency department physician's perspective, it may point to other severe conditions needing to be ruled in or out more quickly.

High-risk patients with NSTEMI are usually referred immediately for catheterization. Lower-risk patients with NSTEMI should be examined within 48 to 72 hours, limiting the therapeutic relevance of obtaining a cardiac troponin measurement 30 to 60 minutes earlier than the current standard practice. Conversely, patients awaiting the ruling out of NSTEMI represent, by far, the most frequent and, therefore, time-consuming source of overcrowding of the emergency department, which is a major source of concern for emergency physicians, particularly with regard to the large subgroup of low-risk patients. For these patients, the availability of a sensitive and accurate point-of-care measure of blood cardiac troponin levels, at the same time as ECG recordings, would have a considerable impact on the time spent under diagnostic evaluation, with the potential for major benefits for patients in the emergency department.

Such potential for benefit from point-of-care testing is speculative, however, and new-generation, high-sensitivity point-of-care tests for cardiac troponin require evaluation in interventional studies (as do improved central laboratory tests). The introduction of novel high-performance point-of-care systems that at least match the performance of central laboratory systems for cardiac troponin testing, coupled with a systems engineering approach (lean thinking) to change clinical practice, will be required to deliver the full benefit of this emerging technology.

## References

[1] Goodacre S, Cross E, Arnold J, et al. The health care burden of acute chest pain. Heart 2005;91:229-30.
[2] Lindsell CJ, Anantharaman V, Diercks D, et al. The Internet Tracking Registry of Acute Coronary Syndromes (i*trACS): a multicenter registry of patients with suspicion of acute coronary syndromes reported using the standardized reporting guidelines for emergency department chest pain studies. Ann Emerg Med 2006;48:666-77.
[3] Thygesen K, Alpert JS, White HD. Joint ESC/ACCF/AHA/WHF Task Force for the Redefinition of Myocardial Infarction: universal definition of myocardial infarction. Eur Heart J 2007;28:2525-38.
[4] Thygesen K, Mair J, Katus H, et al. Recommendations for the use of cardiac troponin measurement in acute cardiac care. Eur Heart J 2010;31:2197-204.
[5] Apple FS, Jesse RL, Newby LK, et al. National Academy of Clinical Biochemistry and IFCC Committee for Standardization of Markers of Cardiac Damage Laboratory Medicine Practice Guidelines: analytical issues for biochemical markers of acute coronary syndromes. Clin Chem 2007;53:547-51.

[6] Morrow DA, Cannon CP, Jesse RL, et al. National Academy of Clinical Biochemistry Laboratory Medicine Practice Guidelines: clinical characteristics and utilization of biochemical markers in acute coronary syndromes. Clin Chem 2007;53:552-74.
[7] Amsterdam EA, Kirk JD, Bluemke DA, et al. Testing of low-risk patients presenting to the emergency department with chest pain: a scientific statement from the American Heart Association. Circulation 2010;122:1756-76.
[8] Novis DA, Jones BA, Dale JC, et al. Biochemical markers of myocardial injury test turnaround time: a College of American Pathologists Q-Probes study of 7020 troponin and 4368 creatine kinase-MB determinations in 159 institutions. Arch Pathol Lab Med 2004;128:158-64.
[9] Hwang U, Baumlin K, Berman J, et al. Emergency department patient volume and troponin laboratory turnaround time. Acad Emerg Med 2010;17:501-7.
[10] Storrow AB, Apple FS, Wu AH, et al. Use of cardiac biomarkers for acute coronary syndromes. In: Nichols JH, editor. National Academy of Clinical Biochemistry. Laboratory medicine practice guidelines; evidence-based practice for point-of-care testing. Washington, DC: AACC Press; 2006. p. 13-20. http://www.aacc.org/SiteCollectionDocuments/NACB/LMPG/POCTLMPG.pdf#page=1. (Accessed February 5, 2012).
[11] Storrow AB, Lyon JA, Porter MW, et al. A systematic review of emergency department point-of-care cardiac markers and efficiency measures. Point Care 2009;8:121-5.
[12] Saenger AK, Jaffe AS. Requiem for a heavyweight: the demise of creatine kinase-MB. Circulation 2008;118:2200-6.
[13] Steurer J, Held U, Schmid D, et al. Clinical value of diagnostic instruments for ruling out acute coronary syndrome in patients with chest pain: a systematic review. Emerg Med J 2010;27:896-902.
[14] Body R, Carley S, Wibberley C, et al. The value of symptoms and signs in the emergent diagnosis of acute coronary syndromes. Resuscitation 2010;81:281-6.
[15] Hess EP, Perry JJ, Calder LA, et al. Prospective validation of a modified thrombolysis in myocardial infarction risk score in emergency department patients with chest pain and possible acute coronary syndrome. Acad Emerg Med 2010;17:368-75.
[16] Hess EP, Agarwal D, Chandra S, et al. Diagnostic accuracy of the TIMI risk score in patients with chest pain in the emergency department: a meta-analysis. CMAJ 2010;182:1039-44.
[17] Morrow DA, Cannon CP, Rifai N, et al. Ability of minor elevations of troponins I and T to predict benefit from an early invasive strategy in patients with unstable angina and non-ST elevation myocardial infarction: results from a randomized trial. JAMA 2001;286:2405-12.
[18] Zahid M, Good CB, Singla I, et al. Clinical significance of borderline elevated troponin I levels across different assays in patients with suspected acute coronary syndrome. Am J Cardiol 2009;104:164-8.
[19] Christ M, Bertsch T, Popp S, et al. High-sensitivity troponin assays in the evaluation of patients with acute chest pain in the emergency department. Clin Chem Lab Med 2011 (6 September, epub ahead of print).
[20] Hamm CW, Bassand JP, Agewall S, et al, The Task Force for the Management of Acute Coronary Syndromes (ACS) in Patients Presenting Without Persistent ST-Segment Elevation of the European Society of Cardiology (ESC). ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. Eur Heart J 2011;32:2999-3054.
[21] Yan AT, Yan RT, Huynh T, et al. Understanding physicians' risk stratification of acute coronary syndromes: insights from the Canadian ACS 2 Registry. Arch Intern Med 2009;169:372-8.
[22] Apple FS. A new season for cardiac troponin assays: it's time to keep a scorecard. Clin Chem 2009;55:1303-6.
[23] Scharnhorst V, Krasznai K, van't Veer M, et al. Rapid detection of myocardial infarction with a sensitive troponin test. Am J Clin Pathol 2011;135:424-8.
[24] Collinson PO. Cardiac biomarkers by point-of-care testing. In: Morrow DA, editor. Cardiovascular biomarkers. Pathophysiology and disease management. Totowa, NJ: Humana Press; 2006. p. 559-74.
[25] Van de Werf F, Bax J, Betriu A, et al. Management of acute myocardial infarction in patients presenting with persistent ST-segment elevation: the Task Force on the Management of ST-Segment Elevation Acute Myocardial Infarction of the European Society of Cardiology. Eur Heart J 2008;29:2909-45.
[26] Than M, Cullen L, Reid CM, et al. A 2-h diagnostic protocol to assess patients with chest pain symptoms in the Asia-Pacific region (ASPECT): a prospective observational validation study. Lancet 2011;377:1077-84.
[27] Christenson RH, Azzazy HM. Cardiac point of care testing: a focused review of current National Academy of Clinical Biochemistry guidelines and measurement platforms. Clin Biochem 2009;42:150-7.
[28] International Federation of Clinical Chemistry and Laboratory Medicine. Troponin assay analytical characteristics. http://www.ifcc.org/PDF/ScientificActivities/IFCC_Troponin_Table_vDec_2010_FINAL_ug_L_28Jan11.pdf. Accessed February 5, 2012.
[29] Dittmer WU, Evers TH, Hardeman WM, et al. Rapid, high sensitivity, point-of-care test for cardiac troponin based on optomagnetic biosensor. Clin Chim Acta 2010;411:868-73.
[30] Bock JL, Singer AJ, Thode Jr HC. Comparison of emergency department patient classification by point-of-care and central laboratory methods for cardiac troponin I. Am J Clin Pathol 2008;130:132-5.
[31] Gruson D, Thys F, Ketelslegers JM, et al. Multimarker panel in patients admitted to emergency department: a comparison with reference methods. Clin Biochem 2009;42:185-8.
[32] Venge P, Ohberg C, Flodin M. Early and late outcome prediction of death in the emergency room setting by point-of-care and laboratory assays of cardiac troponin I. Am Heart J 2010;160:835-41.
[33] Mendis S, Thygesen K, Kuulasmaa K, et al. World Health Organization definition of myocardial infarction: 2008-09 revision. Int J Epidemiol 2011;40:139-46.
[34] Ng SM, Krishnaswamy P, Morissey R, et al. Ninety-minute accelerated critical pathway for chest pain evaluation. Am J Cardiol 2001;88:611-7.
[35] McCord J, Nowak RM, McCullough PA, et al. Ninety-minute exclusion of acute myocardial infarction by use of quantitative point-of-care testing of myoglobin and troponin I. Circulation 2001;104:1483-8.
[36] Rathore S, Knowles P, Mann AP, et al. Is it safe to discharge patients from accident and emergency using a rapid point of care Triple Cardiac Marker test to rule out acute coronary syndrome in low to intermediate risk patients presenting with chest pain? Eur J Intern Med 2008;19:537-40.
[37] Collinson PO, John C, Lynch S, et al. A prospective randomized controlled trial of point-of-care testing on the coronary care unit. Ann Clin Biochem 2004;41:397-404.
[38] Renaud B, Maison P, Ngako A, et al. Impact of point-of-care testing in the emergency department evaluation and treatment of patients with suspected acute coronary syndromes. Acad Emerg Med 2008;15:216-24.
[39] Ryan RJ, Lindsell CJ, Hollander JE, et al. A multicenter randomized controlled trial comparing central laboratory and point-of-care cardiac marker testing strategies: the Disposition Impacted by Serial Point of Care Markers in Acute Coronary Syndromes (DISPO-ACS) trial. Ann Emerg Med 2009;53:321-8.
[40] Goodacre SW, Bradburn M, Cross E, et al. The Randomised Assessment of Treatment using Panel Assay of Cardiac Markers (RATPAC) trial: a randomised controlled trial of point-of-care cardiac markers in the emergency department. Heart 2011;97:190-6.
[41] Goodacre S, Bradburn M, Fitzgerald P, et al. The RATPAC (Randomised Assessment of Treatment using Panel Assay of Cardiac markers) trial: a randomised controlled trial of point-of-care cardiac

markers in the emergency department. Health Technol Assess 2011;15:1-108.

[42] Loten C, Attia J, Hullick C, et al. Point of care troponin decreases time in the emergency department for patients with possible acute coronary syndrome: a randomised controlled trial. Emerg Med J 2010;27: 194-8.

[43] Takakuwa KM, Ou FS, Peterson ED, et al. The usage patterns of cardiac bedside markers employing point-of-care testing for troponin in non–ST-segment elevation acute coronary syndrome: results from CRUSADE. Clin Cardiol 2009;32:498-505.

[44] Mills NL, Churchhouse AM, Lee KK, et al. Implementation of a sensitive troponin I assay and risk of recurrent myocardial infarction and death in patients with suspected acute coronary syndrome. JAMA 2011;305:1210-6.

[45] Herring A, Wilper A, Himmelstein DU, et al. Increasing length of stay among adult visits to U.S. Emergency departments, 2001-2005. Acad Emerg Med 2009;16:609-16.

[46] Price CP, StJohn A, Christenson RH. Testing at the point of care: errors of omission in a care pathway context. Point Care 2011;10: 182-5.

[47] Bradburn M, Goodacre SW, Fitzgerald P, et al. Interhospital variation in the RATPAC trial (Randomised Assessment of Treatment using Panel Assay of Cardiac markers). Emerg Med J 2011;29:233-8.

[48] Gill D, Galvin S, Ponsford M, et al. Laboratory sample turnaround times: do they cause delays in the ED? J Eval Clin Pract 2012;18: 121-7.

[49] Fitzgerald P, Goodacre SW, Cross E, et al. Cost-effectiveness of point-of-care biomarker assessment for suspected myocardial infarction: the Randomized Assessment of Treatment Using Panel Assay of Cardiac Markers (RATPAC) trial. Acad Emerg Med 2011;18:488-95.

[50] Apple FS, Chung AY, Kogut ME. Decreased patient charges following implementation of point-of-care cardiac troponin monitoring in acute coronary syndrome patients in a community hospital cardiology unit. Clin Chim Acta 2006;370:191-5.

[51] Ordóñez-Llanos J, Santaló-Bel M, Mercé-Muntañola J, et al. Risk stratification of chest pain patients by point-of-care cardiac troponin T and myoglobin measured in the emergency department. Clin Chim Acta 2006;365:93-7.

[52] Singer AJ, Ardise J, Gulla J, et al. Point-of-care testing reduces length of stay in emergency department chest pain patients. Ann Emerg Med 2005;45:587-91.

[53] Price CP, St John A, Kricka LJ. Point of care testing in context: challenges of translating innovation into benefit. In: Price CP, St John A, Kricka L, editors. Point-of-care testing—needs, opportunity, and innovation. 3rd ed. Washington, DC: AACC Press; 2010. p. 571-81.

[54] Storrow AB, Zhou C, Gaddis G, et al. Decreasing lab turnaround time improves emergency department throughput and decreases emergency medical services diversion: a simulation model. Acad Emerg Med 2008;15:1130-5.

[55] McLachlan A, Wells S, Furness S. Equity of access to CVD risk management using electronic clinical decision support in the coronary care unit. Eur J Cardiovasc Nurs 2010;9:233-7.

[56] Riggio JM, Sorokin R, Moxey ED, et al. Effectiveness of a clinical-decision-support system in improving compliance with cardiac-care quality measures and supporting resident training. Acad Med 2009;84: 1719-26.

[57] FitzGibbon F, Huckle B, Meenan BJ. Barriers affecting the adoption of point-of-care technologies used in chest pain diagnosis within the UK National Health Service. Part 1: user issues. Point Care 2010;9: 70-9.

[58] FitzGibbon F, Huckle B, Meenan BJ. Barriers affecting the adoption of point-of-care technologies used in chest pain diagnosis within the UK National Health Service. Part 2: manufacturer pricing and reimbursement policy issues. Point Care 2010;9:80-90.