Point of Care Testing—Current and Emerging Quality Perspectives

Maurice J. O'Kane, MD

Abstract: The volume and repertoire of point-of-care testing (POCT) is increasing rapidly, and it is now used in a variety of settings, including patient self-testing. Point-of-care testing offers the significant advantage of rapidly available test results, which have the potential to expedite clinical decision making and improve patient outcomes. Modification of traditional patient care pathways may be required to attain the maximum clinical benefit from POCT. Although POCT simplifies the testing process, it may be more prone to error than conventional laboratory testing. Operator-related error has emerged as a significant risk factor. Efforts to minimize POCT-related quality errors should focus on better and more robust instrument design with increased automation, improved training, and assessment of POCT operators and an enhanced regulatory and governance framework. A key quality measure is the impact of POCT on clinical outcomes, but this generally has been less well documented. Evidence on the effect of self-monitoring of blood glucose in diabetes and self- International Normalized Ratio testing for patients on long-term anticoagulant therapy in improving clinical outcomes measures highlight the potential for POCT to enhance patient care.

Key Words: point of care, quality

(*Point of Care* 2014;13: 1–5)

The term point-of-care (POC) testing (POCT) refers to the performance of a diagnostic test at or near the site of the patient. Point-of-care testing may take place in a variety of settings, most commonly at the bedside or in the physician's office but also in locations as diverse as ambulances or ships from which there is no access to laboratory testing. Point-of-care testing is now increasingly performed in the patient's own home, by the patient as part of self-management programs for conditions such as diabetes or long-term oral anticoagulant therapy. The key advantage of POCT is that it eliminates the need for transport of the sample to the laboratory so that the test result is rapidly available to the physician with the potential for expediting clinical decision making and improving patient outcomes. Other advantages include the reduction in time-dependent changes in analyte concentrations, for example, glucose, potassium, which can occur in vitro, and also that the sample volumes needed are generally very small in comparison to the requirements of laboratory testing. Although it might seem obvious that POCT should improve patient outcomes, the evidence base for this is, at present, somewhat sparse and inconsistent.

From the Clinical Chemistry Laboratory, Altnagelvin Hospital, Londonderry, N.Ireland, BT 47 6SJ.

Reprints: Maurice J. O'Kane, MD, Clinical Chemistry Laboratory, Altnagelvin Hospital, Londonderry, N Ireland, BT 47 6SJ. E-mail: Maurice.Okane@westerntrust.hscni.net.

The author is the chief executive officer of the Clinical Translational Research and Innovation Centre, which has undertaken commissioned research for Nova Biomedical. MOK received an honorarium from the American Association of Clinical Chemistry for delivering the lecture on which this paper is based.

ISSN: 1533-029X

There has been a rapid expansion in the POCT market with the forecast US revenue likely to increase from $1500 m to $3800 m in the decade from 2006 to 2016.[1] The range of tests available for POCT is expanding with infectious disease, cardiac biomarkers, and coagulation testing likely to account for more than 50% of the POCT market by 2016.[1] Given the increasingly important role played by POCT in health care delivery, it is essential to understand the contribution it makes to the quality of patient care and any associated risks. In 1999, the Institute of Medicine published a report ("To err is human: building a Safer Health System"), which drew attention to the issue of patient safety and quality in health care.[2] The report estimated that up to 98,000 deaths in the United States were directly attributable to medical error (and therefore preventable). Although there has been subsequent debate about the accuracy of this figure, there is general agreement that medical error is a major cause of patient morbidity and mortality. Given that laboratory medicine tests are thought to influence approximately 70% of clinical decisions (although the evidence base for this figure is unclear),[3] it is obvious that errors in laboratory medicine may have a major impact on quality of care and patient outcomes. Whereas there has been much systematic research on errors in the medical laboratory, less is known about POCT-related errors. With the expansion of POCT, it is particularly important to understand the frequency, causes, and impact of POCT-related errors and what steps can be taken to minimize these.

In medical laboratories, the concept of quality was previously focused very much on the analytical phase and the development of quality control/quality assurance procedures. However, the concept has widened to consider all stages in the testing process from test selection by the physician right through to interpretation of the result and appropriate clinical action. Although this paradigm is useful in that it breaks the testing process up into a series of discrete steps, which can be subject to risk assessment and quality management, it lacks a patient focus. Patients tend to frame quality questions in a different way from laboratory staff or physicians: the healthcare professionals are often focused on processes, whereas patients are focused on clinical outcomes, for example, "Will this improve my treatment?", "Am I more likely to make a recovery?". In this broader context, quality of POCT must be considered so that we can understand both the benefits and risks of POCT, how it can be most effectively integrated into patient care pathways, and how it can contribute to improved patient outcomes.[4,5]

QUALITY OF THE POC TESTING PROCESS—THEORETICAL CONSIDERATIONS

The process for laboratory testing is complex and comprises a large number of discrete steps (Fig. 1). Point-of-care testing has the potential to eliminate or simplify some of the steps involved and may therefore reduce the risk of error associated with these.[6] In particular, POCT removes the requirement for transport of the specimen to the laboratory; this saves time and also minimizes any in vitro changes to the concentrations of certain analytes, for example, glucose, potassium, and blood gases that might otherwise

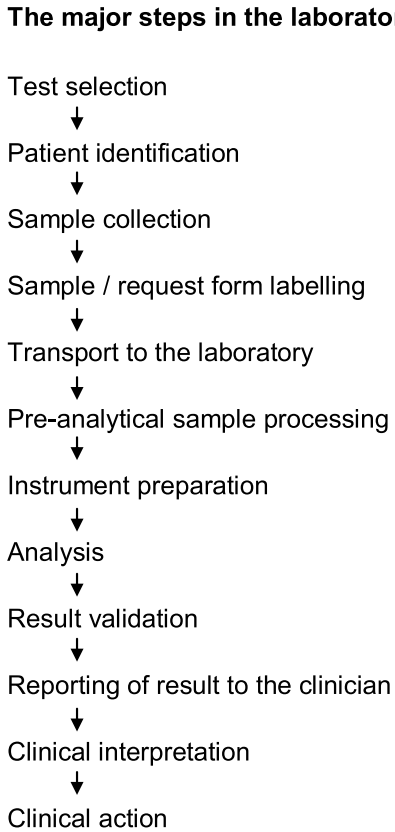

FIGURE 1. Major steps in the laboratory testing process.

occur. In addition, POCT simplifies the process of reporting: the result is directly available to the testing physician within a very short time frame. This is the great advantage, which makes the adoption of POCT so attractive in certain situations.

However, specimen transportation and result reporting aside, the other steps in the testing pathway are similar for both POCT and laboratory testing and may therefore be prone to similar types of quality error, and indeed the risk may be increased for POCT. Kost [7] proposed a taxonomy of POCT errors based on the standard breakdown of the testing process into the preanalytical, analytical, and postanalytical phases as had been described for laboratory testing (Table 1).

In the preanalytical phase, errors may arise in test ordering, patient identification, sample collection, and sample assessment. Preanalytical factors such as hemolysis or icterus, which would be detected in laboratory testing of plasma/serum, will be undetected in POCT systems that use whole blood and may therefore give rise to spurious results.

The analytical phase is very operator dependent, with a requirement to follow the correct test procedure, including calibration, quality control check, and result validation. The patient self-testing environment may pose particular challenges with regard to quality control and quality assurance. In addition, the constraints of providing an assay in a POCT platform may mean that some testing devices have an analytical performance that is less good than the equivalent laboratory test and does not meet the performance requirements for a particular clinical application. For example, the analytical performance of some POCT glucose analysers may not be appropriate in situations where high accuracy is required, such as tight glycemic control regimens in critically ill patients.[8]

In the postanalytical phase, errors may arise in the report format, the units and reference ranges used, especially if these differ from those used in the laboratory, for example, an ionized calcium result generated by POCT may be interpreted as a total calcium concentration by the physician more accustomed to viewing laboratory reports. Furthermore, there may be transcription errors in result documentation, delays in communication of the result to the appropriate physician, and problems arising from POCT results not being integrated with the patient record in the laboratory information system.

Meier and Jones,[9,10] borrowing from the work of the industrial psychologist James Reason,[9,10] proposed the concept of "latent" conditions, which gives rise to POCT errors. A latent condition is a failure of organization or design that contributes to the occurrence of errors. For example, operator incompetence constitutes a latent condition that makes the process inherently error prone. Meier and Jones[9] identified "amplifiers," which interact with the latent condition to increase the likelihood of an error or the likelihood of patient harm resulting from it. In a review of studies in the US Federal Certificate of Waiver laboratories they reported that POC errors were relatively common: 19% of operators were untrained in the test undertaken, 32% were unable to locate the relevant standard operating procedure (SOP), 25% failed to follow the SOP, and 32% failed to undertake appropriate quality control procedures. From these studies, they categorized the latent conditions, giving rise to error as POCT operator incompetence, nonadherence of the operator to the SOP, and the use of uncontrolled reagents or equipment. The amplifiers, which increased the likelihood of error or increased the resulting likelihood of patient harm, were an absence of proper regulation ("incoherent regulation") for POC testing, the immediate availability of the result and rapid clinical decision making based on an erroneous result.[9]

FREQUENCY OF QUALITY ERROR IN POCT

Given the widespread adoption of POCT by a range of operators in diverse clinical settings, it is perhaps surprising that there is little information on the error rates associated with POCT and on the clinical consequences of those errors. In contrast, there is a relatively large body of evidence on error rates associated with central laboratory testing, which vary between 0.085% and 0.6% of all tests depending on the setting.[11] In part, this relates to the difficulties in detecting quality errors: someone has to recognize

TABLE 1. POCT Error Classification (Adapted from Kost)[7]

Preanalytical Phase
• Test ordering
• Patient/Specimen identification
• Specimen collection
• Specimen quality assessment
Analytical phase
• Inadequate assay characteristics
• Instrument calibration
• Result generation
• Result validation
Postanalytical phase
• Report format
• Documentation
• Routing
• Interpretation and appropriate clinical response

TABLE 2. Sources of Error in POCT and Laboratory Testing[11,12]

Phase	POCT (%)	Laboratory (%)
Preanalytical	32	88.9
Analytical	65.3	9.6
Postanalytical	2.7	1.5

that a quality error has occurred and then log the occurrence. Error recognition may pose greater challenges in POCT for the reason that the operators are usually clinical staff and may be able to identify only the very obvious errors.

A recent UK study examined the frequency and clinical consequences of POCT errors occurring in 400,000 tests (blood glucose, blood ketones, hemoglobin A1c (HbA1c), blood gas/electrolyte, urine pregnancy testing, urine drugs-of-abuse screening, and dip stick urinalysis).[12] The study took place at 2 acute care and one non–acute care hospitals within a single UK health care trust. Point-of-care testing was organized through an accredited clinical chemistry laboratory service. The method of quality error ascertainment was by an established quality query reporting system. The quality error rate for POCT varied between 0% for blood ketone analysis and 0.65% for HbA1c measurement. This is almost certainly an underestimate, with the probability that some quality errors went unrecognized and that others, although recognized, were not logged. Most errors (65.3%) occurred in the analytical phase unlike laboratory testing where most occur in the preanalytical phase (Table 2).[11] For the most part, the POCT errors related to operator factors rather than instrument or assay factors such as failure or inability to operate the instrument correctly or undertake basic instrument procedures/maintenance. The quality errors identified were considered as having either no or minimal clinical impact, and none resulted in adverse patient management. The study recognized, however, that the potential for adverse patient impact was much higher.

These findings underline the observations of Meier and Jones that operator factors constitute the single most common impediment to generating an accurate and timely POCT analytical result. The reasons for this seem obvious. In the laboratory, the entire focus of the trained analyst is to generate an accurate test result and report this in a timely manner to the requesting physician. In contrast, the POCT operator is generally a nonlaboratory health care professional whose focus is on the delivery of direct care to patients. In a busy clinical environment with competing clinical demands, the requirements of POCT may be given a lower priority than direct clinical care. This reinforces the need for strong regulation and local governance of POCT.

It is instructive to compare the impact of errors occurring in the stat laboratory. Statistical testing and POCT are similar in that the rapid availability of a test result allows early clinical decision making and therapeutic intervention. In the paradigm of Meier and Jones, this might amplify the clinical consequences of an inaccurate result.

In a 2007 study of stat testing, Plebani documented an error frequency of 3092 ppm and found that although most errors (75.6%) had no adverse impact on patient outcomes, 16.9% resulted in test repetition, 5.6% instigated further inappropriate investigation, 1.3% inappropriate transfusion, and 0.6% inappropriate intensive care unit admission.[13,14] Although there are many differences between stat testing and POCT, these results do warn of the potential consequences of testing errors in emergency situation.

HOW MIGHT POCT QUALITY ERRORS BE MINIMIZED?

Strategies to reduce POCT quality errors must focus on a number of discrete areas[5,6]:

[a] The development of better and more robust technology with functionality that can help eliminate operator error (eg, sample recognition, automatic calibration, reagent quality check, quality control checks with operator lockout, and connectivity to the laboratory information system).

[b] A programme of comprehensive training and competency assessment of operators.

[c] Rigorous regulation and robust local governance of POCT.

The importance of organizational and management structures within which POCT takes place is recognized in the standards for the performance of POCT produced by a range of accreditation and regulatory bodies.[15,16] Organizational and governance arrangements for patient self-testing programs may pose particular challenges.

POCT—THE QUALITY OF THE CARE PATHWAY AND CLINICAL OUTCOMES

There are 2 main types of outcomes relevant to POCT. The first is a "process outcome," which refers to the operation and efficiency of the care pathway and will include a range of process metrics such as time to diagnosis and patient length of stay. Such metrics are generally easy to measure, and there is abundant evidence that POCT can improve the efficiency of patient care. In contrast, "clinical outcome" refers to patient morbidity and mortality or some surrogate measure of these. Such outcomes are much more difficult to quantify and require large numbers of patients with lengthy follow-up. It is not surprising therefore that there is a much smaller evidence base regarding the impact of POCT on clinical outcomes. Nevertheless, this remains the most important quality measure of the effectiveness of POCT.

For POCT to have maximum impact on patient care, it often requires a reconfiguration of the care pathway rather than merely being used as a substitute for laboratory testing. The term "disruptive technology" was coined by Christensen in his 1997 book *The Innovator's dilemma*.[17] Christensen designated new technologies as either disruptive or 'sustainable. Sustainable technologies build incrementally on existing technology. In contrast, disruptive technologies provide opportunities for completely new approaches to addressing problems and require innovative thinking on how the technology can be best applied. In some respects, POCT may be regarded as a disruptive technology in that in certain situations, it allows the transformation of patient care in a way that is not possible using traditional laboratory testing. Many bodies have highlighted the need for redesign of clinical practice if the full benefits of POCT are to be attained. The most striking example of this disruptive approach is in the use of POCT by patients at home for self-management of their condition. Patients can use self-testing results to monitor their clinical status and adjust treatment, which in theory might contribute to better clinical management and improved outcomes in a way that was not possible before the advent of POCT.

Two examples of self-management using POCT will be considered: self–blood glucose measurement in patients with diabetes and self-testing of international normalised ratio (INR) for the monitoring of long-term anticoagulant therapy. Both examples

are instructive in that they demonstrate the importance of redesigning care pathways to harness the benefit of POCT and of the desirability of showing improvement in clinical outcome measures.

SELF-MONITORING OF BLOOD GLUCOSE

Home glucose testing was first mooted in the early 1960s when patients took finger-prick blood samples, which were applied to filter paper, posted to the laboratory where the blood was eluted and the glucose concentration measured.[18] Since then, there has been rapid development of glucose meters that require smaller samples and generate more rapid results to the extent that the self-monitoring of blood glucose (SMBG) is now incorporated into routine patient care. The ultimate quality measure is whether SMBG improves clinical outcomes in patients with diabetes. For patients with insulin-requiring diabetes who can adjust their insulin dose against blood glucose results, the advantage of SMBG seems self-evident. Despite the widespread use of SMBG, it is somewhat surprising that there is in fact little robust evidence that it is associated with either better glycemic control or improved outcomes.[19] In part, this is due to the methodological difficulties in isolating the effect of a particular self-management intervention in a condition where self-management of other elements such as diet, exercise, and medication concordance plays such a central role. The situation for patients with non–insulin-requiring diabetes (most patients with diabetes) has been even less clear. Whereas observational studies have generally supported the view that SMBG improves glycemia in non–insulin-requiring diabetes, prospective randomized controlled trials have tended to find minimal or no effect.[20] However, the answer depends very much on how SMBG is used as a clinical tool. In the Structured Testing Programme study, Polonsky et al [21] developed a sophisticated intervention in which the patients received intensive training on how to interpret their results, identify problematic glycemic patterns, and how best to address these through dietary and physical activity measures. This intervention was tested in a prospective randomized controlled trial against a more conventional SMBG testing regimen. The patients in the structured testing program achieved a 0.3% reduction in Hb A1c compared to the control group. For those patients who adhered closely to the intervention, the HbA1c reduction was even greater at 0.5%. Furthermore, the patients in the structured testing program reported higher levels of general well-being. This is one of the few prospective studies to demonstrate a benefit of SMBG in non–insulin-requiring diabetes, and it is significant that the successful intervention required redesign of the care pathway.

SELF-MONITORING OF ANTICOAGULATION

The coumarin anticoagulant warfarin reduces the thromboembolic complications of a range of common conditions including atrial fibrillation and deep venous thrombosis. However, it has a narrow therapeutic window, as underanticoagulation will increase the risk of a thrombotic event whereas overanticoagulation will increase the risk of bleeding. There is therefore a requirement for regular monitoring of the INR to ensure that anticoagulation is tightly controlled. Traditionally, this was undertaken through anticoagulation clinics at which the patient attends at regular intervals for measurement of INR and dose adjustment by clinic staff using standardized protocols. Despite this, many studies have shown that between 15% and 50% of patients on warfarin remain outside the target INR range. The availability of INR as a POCT allowed patients the possibility of self-testing at home . Patients either self-test ("patient self-testing") and telephone the result to the clinic for dose adjustment, or patients self-test and self-dose using a dosing algorithm ["patient self-management"]. The potential benefits of self-testing/self-management include the possibility of more frequent INR monitoring (and therefore more frequent dose adjustment and better anticoagulant control), greater convenience for patients, and better overall concordance with treatment.

What is the evidence that self-testing and self-management of anticoagulation benefits patients? This has been the object of intensive research, and a recent meta-analysis of 22 trials incorporating 8413 patients demonstrated that patient self-testing and patient self-management were associated with a lower mortality (odds ratio, 0.74), lower risk of thromboembolic events (odds ratio, 0.58) but with no increased bleeding risk.[22] This is very compelling evidence that self-monitoring of INR by patients using a POCT device results in a better standard of care with improved patient outcomes than can be delivered in a traditional clinic-based model. It is of course the case that self-monitoring will not be suitable for all patients and that careful patient selection and education is required if the intervention is to be successful.

There are two important messages from these studies on SMBG and self-INR measurement. First, to derive the optimum benefit from POCT, care must be delivered in a new and innovative way and not simply be bolted on to an existing care pathway. Second, these studies demonstrate the desirability and importance of measuring the overall quality of the intervention with regard to patient outcome measures.

CONCLUSIONS

Point-of-care testing offers new possibilities for the diagnosis and treatment of patients. The major advantage of POCT is the rapid availability of the test result, with the possibility of earlier clinical decision making. It has also allowed increased patient self-management, most notably the self-monitoring of blood glucose in diabetes and INR testing for patients on anticoagulant therapy. Point-of-care testing seems to be much more susceptible to operator error than is laboratory testing. Strategies to reduce error associated with POCT will require strong regulation and governance to minimize operator-related error. The most important quality indicators are clinical outcomes rather than process outcomes. Studies on SMBG and home INR monitoring have demonstrated that POCT can improve patient outcomes. The successful application of POCT may however require innovative thinking and changes to traditional care pathways.

REFERENCES

1. IVD Technology. Popular topics. Available at http://www.ivdtechnology.com. Accessed September 30, 2012.
2. Kohn IT, Corrigan JM, Donaldson MS, eds. *To err is human: building a safer health system*. Washington DC: National Academy Press; 1999.
3. Hallworth MJ. The '70% claim': what is the evidence base? *Ann Clin Biochem*. 2011;48:487–488.
4. Collinson PO. Point-of-care testing—can we move from anecdote to evidence. *Clin Chem Lab Med*. 2006;44:1049–1051.
5. National Institute of Biomedical Imaging and Bioengineering/ National Heart, Lung and Blood Institute/National Science Foundation Workshop Faculty, Price CP, Kricka LJ. Improving healthcare accessibility through point-of-care technologies. *Clin Chem*. 2007;53:1665–1675.
6. Plebani M. Does POCT reduce the risk of error in laboratory testing? *Clin Chim Acta*. 2009;404:59–64.
7. Kost GJ. Preventing medical errors in point-of-care testing. *Arch Pathol Lab Med*. 2001;125:1307–1315.

8. O'Kane MJ. The accuracy of point-of-care glucose measurement. *Ann Clin Biochem*. 2012;49:108–109.
9. Meier FA, Jones B. Point-of-care testing error. *Arch Pathol Lab Med*. 2005;129:1262–1267.
10. Reason J. *Human Error.* Cambridge, UK: Cambridge University Press; 1990.
11. O'Kane M, Lynch PLM, McGowan N. The development of a system for the reporting, classification and grading of quality failures within the clinical biochemistry laboratory. *Ann Clin Biochem*. 2008;45:129–134.
12. O'Kane MJ, McManus P, McGowan N, et al. Quality error rates in point-of-care testing. *Clin Chem*. 2011;57:1267–1271.
13. Plebani M, Carraro P. Mistakes in a stat laboratory: types and frequency. *Clin Chem*. 1997;43:1348–1351.
14. Carraro P, Plebani M. Errors in the stat laboratory: types and frequencies 10 years later. *Clin Chem.* 2007;53:1338–1342.
15. Clinical Pathology Accreditation [UK] Ltd. Additional standards for point-of-care testing [POCT] facilities. http://www.cpa-uk.co.uk/dpmed.htm [Accessed August 2012]
16. Medicines and Health Care Regulatory Agency. *Management and use of point of care test devices DB 2010[02]*. London: MHRA; 2010.
17. Cristensen C. *The Innovator's dilemma: when new technologies cause great firms to fail*. Harvard, MA: Harvard Business Review Press; 1997.
18. Knight RK, Keen H. Blood sugar by post. *Br Med J.* 1961;1:1168.
19. Hirsch IB. Home blood glucose monitoring in type 2 diabetes. *Diabetes Care*. 2011;34:527–528.
20. O'Kane MJ, Bunting B, Copeland M, et al. Efficacy of self monitoring of blood glucose in patients with newly diagnosed type 2 diabetes [ESMON study]: randomised controlled trial. *BMJ.* 2008;336:1174.
21. Polonsky WH, Fisher L, Schikman CH et al. Structured self-monitoring of blood glucose significantly reduces A1c levels in poorly controlled noninsulin-treated type 2 patients. *Diabetes Care.* 2011;34:262–267.
22. Bloomfield HE, Krause A, Greer N et al. Meta-analysis: effect of patient self-testing and self-management on long-term anticoagulation on major clinical outcomes. *Ann Int Med*. 2011;154:472–482.

