Published in final edited form as:

Point Care. 2010 June ; 9(2): 53–64. doi:10.1097/POC.0b013e3181d9d45c.

Emergency Cardiac Biomarkers and Point-of-Care Testing: Optimizing Acute Coronary Syndrome Care Using Small-World Networks In Rural Settings

Gerald J. Kost, MD, PhD, MS, FACB^{1,2}, Laurie E. Kost, MS³, Audhaiwan Suwanyangyuen, MBA², Simrin K. Cheema, BS¹, Corbin Curtis¹, Stephanie Sumner¹, Jimmy Yu, BS¹, and Richard Louie, PhD¹

¹Point-of-Care Testing Center for Teaching and Research (POCT•CTR), and the UC Davis-LLNL Center for Point-of-Care Technologies [NIBIB, NIH]; Pathology and Laboratory Medicine, School of Medicine, University of California, Davis, California, USA 95616 ²College of Populations Studies, Chulalongkorn University, Bangkok, Thailand ³Stanford University, Stanford, California, and Hopkins Marine Station, Pacific Grove

Keywords

Ambulance; animai; cardiac troponin (cTnI, cTnT); community hospital (CH); heart center; Isaan; Mekong River; O₂ saturation; proBNP (brain natriuretic peptide); Primary Care Unit (PCU); regional hospital (RH); Thailand; therapeutic turnaround time (TTAT)

Introduction

The goals of this paper are a) to facilitate the efficient diagnosis of patients who present with episodes of acute chest pain in rural emergency rooms located in low-resource community hospitals, b) to systematically optimize point-of-care (POC) testing using small-world networks (SWNs) adapted to unique and challenging geographic settings, and c) to align POC cardiac biomarker testing with referral options and treatment modalities available to local emergency medicine nurses and physicians.

Methods

Field Surveys

Field surveys focused primarily on a) cardiac biomarker testing and related cardiology and emergency medical system (EMS) services (Figure 1), b) point-of-care testing (POCT) resources and competency levels, and c) healthcare delivery systems within and between provinces in Isaan, northeastern Thailand. We visited and surveyed on site 3 referral hospitals

Corresponding Author: Gerald J Kost, MD, PhD, MS, FACB, Director and PI, POC Technologies Center [NIBIB, NIH] & POCT•CTR, Professor, Pathology and Laboratory Medicine, School of Medicine, 3455 Tupper Hall, University of California, Davis, CA 95616, Phone 530-574-3945, Fax 530-752-4548, gjkost@ucdavis.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

in Khon Kaen City, 5 province regional hospitals (RHs), and 10 community hospitals (CHs) administered by the Thai government in 6 provinces (Tables 1 and 2).

Response Rate

The research process was developed carefully during prior field surveys in Sakaeo Province as part of Fulbright-sponsored research¹⁻³ and subsequently improved for several other regions of Thailand⁴ and the United States⁵. Most POCT and clinical laboratory equipment was photo documented. Live interviews and telephone follow-up yielded a 100% return rate on survey questions, which included needs assessment.

On-Site Interviews

Interviews were conducted in the Thai language. At each site a defined list of questions (“short form”) was used to structure data gathered for consistency during discussions with hospital administrators, clinical directors, physicians, nurses, EMS personnel, ambulance drivers, laboratory technologists, and other staff in CHs and RHs. Additionally, we investigated Primary Care Units (PCUs) in follow-up.

Demography

From on-site interviews, we collected health demography facts about each medical site, such as the number of hospital beds, numbers and types of physicians, the status of critical care units (e.g., ICU, CCU, OR, and ER), and the impact of patients with acute coronary syndrome (ACS) and acute myocardial infarction (AMI) on emergency services. National databases were consulted for population and health resources data⁶⁻⁸.

Province populations, PCUs, beds, physicians, professional nurses, technical nurses, and pharmacists were 977508, 157, 1105, 104, 898, 155, and 73 for Kalasin; 1752414, 146, 3748, 540, 2915, 454, and 212 for Khon Kaen; 936005, 79, 1065, 100, 1002, 149, and 76 for Maha Sarakham; 697105, 161, 831, 63, 747, 122, and 58 for Nakhon Phanom; 902618, 78, 1015, 99, 821, 127, and 65 for Nong Khai; 1113064, 166, 1368, 118, 1070, 179, and 70 for Sakon Nakhon; and 1530686, 143, 2315, 253, 1630, 305, and 128 for Udonthani, respectively.

Qualitative and Quantitative Data

We recorded qualitative and quantitative data, including descriptors of the health network for PCUs and anamais (small clinics) served by each hub hospital. Interviewees were asked as part of assessment to list needs and to delineate how they can better deliver optimal emergency cardiac care within their relatively isolated local healthcare systems, which we designate “small-world networks”⁹. We asked interviewees about the value of POC cardiac biomarker testing.

Small-World Networks (SWNs) and Metrics

We presented regional topographical roadmaps to interviewees, several of them EMS personnel, who then drew routes of transportation to emergency rooms with annotation of distances and travel times experienced by ambulance drivers. When in doubt, EMS personnel contacted colleagues by radio to determine actual ambulance rescue intervals. Hand-drawn map information was extracted and rendered by computer to formalized SWNs. EMS personnel also provided distances and travel times to distant referral centers, such as the RH and Heart Center in Khon Kaen City. Data reported here represent the rescue transport times to local emergency rooms or equivalent settings. The times necessary for ambulances to report to the sites of the victims were not included.

Survey Follow-Up

Supplemental survey “long forms” were left with medical staff, laboratory staff, EMS personnel, and administrators to complete following on-site visits and then mail to the research team headquarters at Chulalongkorn University in Bangkok, where data were collated using spreadsheet and statistics software, supported also by the POCT•CTR in the U.S. When necessary, team members initiated follow-up telephone, facsimile, and email contacts for clarification. High impact sites, including the three referral centers in Khon Kaen City, were contacted by phone several times to fill in table details.

Results

Table 1 shows healthcare resources in Khon Kaen City and the provinces surveyed. One regional province, Udon Thani, which lies between Nong Khai and Khon Kaen, was not visited, because of its proximity to tertiary care centers in Khon Kaen, ease of transportation to them, large number (6) of private hospitals within the province, and relatively low resource ratios (see below). In contrast, Kalasin (0), Nakhon Phanom (0), Nong Khai (3), and Sakon Nakhon (1) had only four private hospitals collectively.

The primary site for cardiovascular specialty services in this region of Isaan is the Queen Sirikit Heart Center located close to two other major referral centers in Khon Kaen City. The distances and times in Table 1 reflect ambulance travel to Srinagarind RH within Khon Kaen City, and for the other provinces, travel from the province RH to a partner referral hospital outside the province, as indicated in the table.

Table 2 presents details of CHs. In this case, ambulance transport distances and times are to the province RH, except for Bung Khla and Sangkhon CHs in Nong Khai Province, which refer patients to more central CHs within the same province. Such referral, however, complicates the care path. ER staff in these types of small capacity CHs often performed 24/7 bedside glucose, hematocrit, urine protein (by dipstick), and pregnancy testing (see ref. 4 for details). Only one CH clinical laboratory visited operated a microbiology laboratory. Table 3 further details test clusters available at the ten CHs. Only one offered blood gasses and O₂ saturation monitoring.

Tables 4A, 4B, and 4C compare cardiac biomarker testing and cardiology support in the different levels of the hospitals surveyed. Cardiac troponin (cTn) testing was encountered only rarely. Handheld devices (Figures 2), were encountered a) in a large RH clinical laboratory (h 232) and the intensive care unit (i-STAT) in Nong Khai Province, b) in a small laboratory facility in Somdet CH in Kalasin Province, and c) once at the bedside in the Queen Sirikit Heart Center in Khon Kaen City. Follow-up during a 2010 invited keynote lecture (by GK) for Khon Kaen University revealed another site of handheld cTnT (h 232) implemented at Kuchai Naria Community Hospital in Kalasin Province after the survey.

Only one CH offered cTnI testing (Table 4A), while cTnT and proBNP were found infrequently at province RHs (Table 4B). These tests typically were performed by means of large analyzers (e.g., Elecysis 2010, Roche Diagnostics) at the three primary referral centers (Table 4C) serving the surrounding provinces east and north to the Mekong River bordering Laos. Only Khon Kaen centers had cardiologists at the time of the initial field survey. None were assigned to CHs or RHs in outlying provinces. This deficiency severely limits local treatment options, and as of January, 2010, there still was no routine helicopter rescue of patients with acute myocardial infarction.

Figure 3 contrasts a relatively linear healthcare delivery system in Nong Khai Province (population about 900,000). Mean (SD) [median, range] distance and emergency ambulance

travel time from 12 CHs to the RH were 129 (68) [117, 40-236] km and 84 (43) [77.5, 30-150] min, respectively. In Maha Sarakham Province (not illustrated), the mean (SD) [median, range] distance and emergency ambulance travel time from 10 CHs to the RH were 47 (22) [47.5, 18-82] km and 34 (16) [34.5, 13-59] min.

Figure 4 shows the geographically isolated SWN for Sakon Nakhon Province (population over 1.1 million), which also provides care for patients transferred from the neighboring province, Nakhon Phanom (population about 700,000), to the east. Mean (SD) [median, range] distance and emergency ambulance travel time from the within-province 17 CHs to the Sakon Nakhon RH were 67 (32) [57, 22-120] km and 59 (33) [60, 15-120] min, respectively, and from the Si Songkhram, Phon Sawan, and Pla Pak CHs in Nakhon Phanom to the Sakon Nakhon RH, 71 (8) [67, 65-80] km and 52 (8) [50, 45-60] min.

Kalasin Province (not illustrated), with a population of about 1 million people, suffers from medical personnel shortages plus rugged geographic terrain. Within this SWN, the mean (SD) [median, range] distance and *emergency ambulance* travel time from 17 Community Hospitals (CHs) to the Kalasin RH were 53 (30) [46, 13-109] km and 57 (32) [60, 15-120] min, respectively, with much longer distances and travel times to the Heart Center in the city of Khon Kaen to the west. To a large extent, these health care delivery systems are defined by the government referral schemes set up within each province.

Figure 5 presents demographics of resources and the ratios of people to available PCUs, hospital beds, physicians (MD), professional nurses (PNs, equivalent to registered nurses or RNs), technical nurses (TN or LVNs), and pharmacists (P) within this seven-province region. The highest resource ratios observed were: 12,003 persons per PCU in Khon Kaen Province; 889/bed, Nong Khai; 11,065/MD, Nakhon Phanom; 1,099/PN, Nong Khai; 6,307/TN, Kalasin; and 15,901/P, Sakon Nakhon. Provinces demonstrating the most severe deficiencies in these key healthcare personnel (e.g., Nakhon Phanom, Nong Khai, and Sakon Nakhon) also presented the greatest challenges for emergency patient transport, as evidenced by the SWNs shown in Figures 3 and 4 and by the extraordinary distances and times from Khon Kaen City.

Discussion

Table 5 summarizes literature published since 2000^{5,10-37} where investigators studied POC cardiac biomarker testing in emergency and disaster settings. Evidence-based results are varied, most probably because of lack of a uniformly systematic approach to the implementation and use of a variety of POC devices, as well as the heterogeneous test clusters employed in dissimilar environments.

However, in sum the picture is clear—POC resources improve efficiency and effectiveness during periods of heavy patient volumes, times of emergencies, and disaster conditions. With regard specifically to emergency medicine, several of the studies demonstrated statistically significant findings of high impact relevant to rural communities where the distances and times to coronary rescue threaten survival of patients who report to emergency rooms with complaints of severe chest pain.

The provinces we studied will benefit from regional coordination of small-world networks to deliver urgent cardiac care for a population of about eight million people. Since emergency room personnel generally work in close proximity to laboratory facilities in CHs and already operate common POC devices, such as glucose meters^{4,38,39}, widespread implementation of POC cardiac biomarker testing will succeed, providing point-of-care coordinators assure operator competency, institute quality assurance, and oversee testing at the point of need. Principles of oversight and application of POCT in primary care are described clearly in a

unique monograph in the Thai language³⁹. In fact, this monograph was designed to assure quality.

Use of ergonomic handheld devices (see Figure 2) allows testing to be performed in the typically small clinical laboratories of community hospitals by day. By night when these facilities are closed, the POC devices can be placed directly in emergency rooms with testing performed by emergency room staff who are properly trained.

Increased value is added by continuity of medical management and accumulation of physician knowledge of diagnostic-therapeutic cycles (Figure 6). The Thai system of levels of excellence for heart centers should embrace POC cTn testing flexibly throughout all levels. In other words, diagnostic information should be available rapidly irrespective of the level and the results should be accessible through connectivity of instruments, patient records, and regional registries that identify demographic deficiencies for strategic planning and resource deployment.

Immediate cardiac biomarker results, namely cardiac troponin T or I, will represent not only an improvement over currently available test clusters (e.g., CK, rarely CK-MB, and LD—see Tables) that lack highly specific markers, but also will facilitate triage decisions regarding patient transport out of small-world networks to distant referral centers where cardiologists are available to administer definitive treatment. Future public health planning should fund cardiologists positioned closer to patients with POCT also available on site, an advantage current Thai guidelines fail to emphasize⁴⁰.

Public health administrators should consider implementing POC cTn testing a) in remote emergency rooms of Community Hospitals where physicians do not want to hold acute myocardial infarction patients overnight because of the risk of death; b) at “Super-PCUs” that have physicians living in residence on site; c) on connected edges of small-world networks when, after approval, patients can be sent by ambulance directly to the referral center (i.e., by pass the Regional Hospital); d) when using a screening questionnaire for the triage of PCU patients who present with chest pain at the village level; and e) in Community and Regional Hospitals where the clinical laboratory cannot deliver cTn results in less than one hour, or in busy ERs of regional provincial hospitals, within fifteen minutes.

Additionally, determining the effectiveness of patient ventilation by means of POC finger O₂ saturation (pulse oximeter) monitoring⁴ during transport will enhance safety. Therefore, ambulances and ERs should be equipped with small portable battery-operated devices (e.g., the Nonin Onyx II 9550) for this purpose.

Conclusions

Rapid response testing accelerates decision making and supports the standard of care for acute coronary syndromes. Small-world network strategies optimize fast diagnosis, treatment, and care paths within single provinces and the surrounding geographic regions.

POC cardiac biomarker testing strategically placed in small-world networks in low-resource rural settings will help reduce or eliminate significant delays in emergency room diagnosis and regional care paths⁴¹⁻⁴³, and in parallel, will expedite therapy to restore cardiac function and minimize unnecessary excess morbidity and mortality.

In regional hospitals serving large concentrated populations, such as those in Khon Kaen City serving Maha Sarakham, Kalasin, and Roi Et provinces, striking deficiencies in the availability of cardiologists, in comparison to regional hospitals in less fortunate provinces of northern Isaan, should be rectified to help reduce rural-urban mortality inequities⁴⁴.

High sensitivity⁴⁵ POC cardiac troponin biomarker testing can enhance cardiology services wherever specialists and trained local physicians are located, as both groups can provide crucial immediate treatment of appropriate targeted regimens [for STEMI and NSTEMI⁴⁶] once the diagnosis is documented, working either locally in emergency rooms or via telemedicine to improve cost-effectiveness and patient outcomes in the regional system of small-world networks.

Acknowledgments

The authors are greatly indebted to Ms. Narisara Peungposop, PhD, for administrative support of the research team at Chulalongkorn University. Ms. Suwanna Tawonrungronj, RN, and Wanvisa Boonlert, PhD, both faculty at Naresuan University in Phitsanulok, Thailand, provided translation of the Thai guideline cited in the reference list.

This research was supported in part by the Edward W. and Ora I. Kost Foundation; the Point-of-Care Testing Center for Teaching and Research (POCT•CTR), School of Medicine, University of California, Davis; and a NIBIB Point-of-Care Technologies Center grant (Dr. Kost, PI, NIH U54 EB007959).

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Biomedical Imaging and Bioengineering or the National Institutes of Health.

Figures and tables were provided courtesy and permission of Knowledge Optimization[®], Davis, CA. The College of Population Studies, Chulalongkorn University, provided general research resources in demography, survey methods, and sponsorship, for which the author, an Affiliate Faculty with the College, is very grateful.

Funding: This research was supported in part by the Edward W. and Ora I. Kost Foundation; the Point-of-Care Testing Center for Teaching and Research (POCT•CTRSM), School of Medicine, University of California, Davis; and a NIBIB Point-of-Care Technologies Center grant (Dr. Kost, PI, NIH U54 EB007959). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Biomedical Imaging and Bioengineering or the National Institutes of Health.

References

1. Kost, GJ.; Peungposop, N.; Kulrattanamaneeporn, C., et al. Minimizing health problems to optimize the demographic dividend: The role of point-of-care testing. In: Wongboonsin, K.; Guest, P., editors. *The Demographic Dividend: Policy Options for Asia*. Vol. chapter 3. Bangkok: College of Population Studies, Chulalongkorn University; Asian Development Research Forum; and the Thailand Research Fund; 2005. p. 56-89.
2. Kost, GJ. *Fulbright Thailand*. Vol. 10. Bangkok: Thailand-U.S. Educational Foundation; 2004 Aug. *The Demography of Immediate Medical Care*; p. 7-8.
3. Kost, GJ.; Tuntideelert, M.; Kulrattanamaneeporn, S., et al. *Fulbright Thailand*. Vol. 13. Bangkok: Thailand-U.S. Educational Foundation; 2005 Jul. *The Tsunami, POCT, and Future Disaster Planning*; p. 5-7.
4. Kost, GJ. Point-of-care testing in province hospitals and primary care units (PCUs): Optimizing critical care and disaster response. In: Charuruks, N.; Manarom, W., editors. *Point of Care Testing for Thailand*. Vol. Chapter 10. Bangkok: 2006. p. 159-177. In the Thai language
5. Kost GJ, Tran NK, Tuntideelert M, et al. Katrina, the tsunami, and point-of-care testing: Optimizing rapid response diagnosis in disasters. *Amer J Clin Pathol* 2006;126:513–520. [PubMed: 16938656]
6. Ministry of Public Health (MPOH) website. Thailand: [19 October 2009]. Numbers of beds, physicians, professional nurses, technical nurses, and pharmacists classified by province in calendar year 2005. <http://eng.moph.go.th/HealthSit/index.php>
(http://service.nso.go.th/nso/nso_center/project/table/files/2100200/2548/000/40_2100200_2548_000_000000_01000.xls)
7. Ministry of Interior. Population in calendar year 2008. [30 December 2009]. <http://eng.moph.go.th/HealthSit/index.php>
8. Primary Care Unit telephone communications with MOPH officers in each province.
9. Kost GJ. Newdemics, public health, small-world networks, and point-of-care testing. *Point-of-Care: The Journal of Near-Patient Testing and Technology* 2006;5:138–144.

10. Amin AP, Mukhopadhyay E, Napan S, et al. Value of early cardiac troponin I to predict long-term adverse events after coronary artery bypass graft surgery in patients presenting with acute coronary syndromes. *Clin Cardiol* 2009;32:386–392. [PubMed: 19609893]
11. Christenson R, Azzazy H. Cardiac point of care testing: a focused review of current National Academy of Clinical Biochemistry guidelines and measurement platforms. *Clin Biochem* 2009;42:150–157. [PubMed: 18929551]
12. Ekelund U, Fordber JL. New methods for improved evaluation of patients with suspected acute coronary syndrome in the emergency department. *Emerg Med J* 2007;24:811–814. [PubMed: 18029508]
13. Friess U, Stark M. Cardiac markers: a clear cause for point-of-care testing. *Anal Bioanal Chem* 2009;393:1453–1462. [PubMed: 19148628]
14. Kost GJ, Tran NK. Point-of-care testing and cardiac biomarkers: the standard of care and vision for chest pain centers. *Cardiol Clin* 2005;23:467–490. [PubMed: 16278118]
15. Lee-Lewandrowski E, Corboy D, Lewandrowski K, et al. Implementation of a point-of-care satellite laboratory in the emergency department of an academic medical center. Impact on test turnaround time and patient emergency department length of stay. *Arch Pathol Lab Med* 2003;127:456–460. [PubMed: 12683874]
16. Lee-Lewandrowski E, Lewandrowski K. Perspectives on cost and outcomes for point-of-care testing. *Clin Lab Med* 2009;29:479–489. [PubMed: 19840681]
17. Lee-Lewandrowski E, Nichols J, Van Cott E, et al. Implementation of a rapid whole blood D-dimer test in the emergency department of an urban academic medical center. *Am J Clin Pathol* 2009;132:326–331. [PubMed: 19687307]
18. Leman P, Guthrie D, Simpson R, et al. Improving access to diagnostics: an evaluation of a satellite laboratory service in the emergency department. *Emerg Med J* 2004;21:452–456. [PubMed: 15208229]
19. Lewandrowski K. Point-of-care testing for cardiac markers in acute coronary syndromes and heart failure. *Clin Lab Med* 2009;29:561–571. [PubMed: 19840688]
20. Loria V, Dato I, De Maria GL, et al. Markers of acute coronary syndrome in emergency room. *Minerva Med* 2008;99:497–517. [PubMed: 18971915]
21. Macdonald SP, Nagree Y. Rapid risk stratification in suspected acute coronary syndrome using serial multiple cardiac biomarkers: a pilot study. *Emerg Med Australasia* 2008;20:403–409.
22. 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;104:1583–1488.
23. McDonnell B, Hearty S, Leonard P, et al. Cardiac biomarkers and the case for point-of-care testing. *Clin Biochem* 2009;42:549–561. [PubMed: 19318022]
24. Ng SM, Krishnaswamy P, Morrissey R, et al. Mitigation of the clinical significance of spurious elevations of cardiac troponin I in settings of coronary ischemia using serial testing of multiple cardiac markers. *Am J Cardiol* 2001;87:994–999. [PubMed: 11305993]
25. Reichlin T, Hochholzer W, Bassetti S, et al. Early diagnosis of myocardial infarction with sensitive cardiac troponin assays. *N Engl J Med* 2009;361:858–867. [PubMed: 19710484]
26. 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;15:216–224. [PubMed: 18304051]
27. Ryan R, Lindsell C, Hollander J, 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;53:321–328. [PubMed: 18691791]
28. Saiki A, Iwase M, Takeichi Y, et al. Diversity of the elevation of serum cardiac troponin I levels in patients during their first visit to the emergency room. *Circ J* 2007;71:1458–1462. [PubMed: 17721028]
29. Selvaraj CL, Van De Graaff EJ, Campbell CL, et al. Point-of-care determination of baseline platelet function as a predictor of clinical outcomes in patients who present to the emergency department with chest pain. *J Thromb Thrombolysis* 2004;18:109–115. [PubMed: 15789177]

30. 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;45:587–591. [PubMed: 15940089]
31. 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 Lab Med* 2008;15:1130–1135.
32. Straface A, Myers J, et al. A rapid point-of-care cardiac marker testing strategy facilitates the rapid diagnosis and management of chest pain patients in the emergency department. *Am J Clin Pathol* 2008;129:788–795. [PubMed: 18426740]
33. Suzuki M, Hori S, Fujishima S, et al. Diagnostic value of a bedside test for cardiac troponin T in the patient with chest pain presenting to the emergency room. *Keio J Med* 2000;49:74–79. [PubMed: 10900832]
34. 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. [PubMed: 19743496]
35. Talwalkar SS, Bon Homme M, Miller JJ, et al. Ischemia modified albumin, a marker of acute ischemic events: a pilot study. *Ann Clin Lab Sci* 2008;38:132–137. [PubMed: 18469358]
36. Wang J, Hong B, Kai J, et al. Mini sensing chip for point-of-care acute myocardial infarction diagnosis utilizing micro-electro-mechanical system and nano-technology. *Adv Exp Med Biol* 2009;645:101–107. [PubMed: 19227457]
37. Zun LS. Analysis of the literature on emergency department throughput. *West J Emerg Med* 2009;10:104–109. [PubMed: 19561830]
38. Charuruks, N.; Manarom, W. Point of Care Testing for Thailand. Bangkok: Thaipim Press; 2006. p. 207 in the Thai language
39. Wiwanitkit, V. Basic Knowledge of Laboratory Diagnosis at the Point of Care. Bangkok: Chulalongkorn Press; 2008. p. 103 in the Thai language
40. Clinical Practice Guideline for the Care of the Patient with Ischemic Heart Disease. [7 February 2010]. http://thaiheart.org/file_attach/10Jul200834-AttachFile1215662854.pdf
41. Dudek D, Siudak Z, Dziewierz A, et al. Local hospital networks for STEMI treatment for a population of half a million inhabitants increase the use of invasive treatment of acute coronary syndromes to the European recommended level. *Kardiol Pol* 2008;66:489–497. [PubMed: 18537056]
42. Dziewierz A, Siudak Z, Dykla D, et al. Management and mortality in patients with non-ST-segment elevation vs. ST-segment elevation myocardial infarction. *Kardiol Pol* 2009;67:115–120. [PubMed: 19288373]
43. Knot JH, Widimsky P, Wijns W, et al. How to set up an effective national primary angioplasty network: lessons learned from five European countries. *EuroIntervention* 2009;5:299, 301–309. [PubMed: 19736153]
44. Kinsman LD, Buykx P, Humphreys JS, et al. A cluster randomised trial to assess the impact of clinical pathways on AMI management in rural Australian emergency departments. *BMC Health Serv Res* 2009 May 25;9:83. [PubMed: 19463196]
45. Cramer GE, Kievit PC, Brouwer MA, et al. Lack of concordance between a rapid bedside and conventional laboratory method of cardiac troponin testing: impact on risk stratification of patients suspected of acute coronary syndrome. *Clin Chim Acta* 2007;381:164–166. [PubMed: 17467677]
46. Kumar A, Cannon CP. Acute coronary syndromes: diagnosis and management, part I. *Mayo Clin Proc* 2009;84(10):917–38. [PubMed: 19797781]

Figure 1. Characterizing, Linking, and Integrating Small-World Networks (SWN) with Heart and Referral Centers

Frame A illustrates how Emergency Medical System (EMS) personnel characterized regional networks for patient rescue by highlighting ambulance routes directly on a high quality roadmap. **Frame B** shows (in orange) the SWNs for Community Hospitals in Kalasin and Maha Sarakham Provinces. The green route transports referred patients directly to the Queen Sirikit Heart Center and other hospitals in Khon Kaen City. Transport from regional and community hospitals in the extremes of other provinces requires as long as four hours, and is prohibitive for acute care. Helicopter rescue is not available. “Hybrid” transportation routes (pink) evolve to link SWNs and referral centers where cardiologists provide interventional

therapy. Because of limited resources, cardiologists generally are not assigned to provincial regional hospitals. Thus, care paths need to focus on local SWNs and their integration.

Figure 2. Handheld Cardiac Biomarker Testing in Isaan—cTnT

We encountered the Cobas h 232 (cTnT, Roche Diagnostics Thailand) in one community hospital (Somdet), one regional hospital (Nong Khai), and the Heart Center in Khon Kaen (see Table 4). This ergonomic handheld device is being implemented aggressively throughout the country, including sites within these regions of Isaan since we conducted the survey, but is not yet licensed for diagnostic use in the United States. The i-STAT (not shown; Abbott) has the potential for cTnI testing, but in the Nong Khai Regional Hospital (the only location we encountered it), was used for blood gases and pH measurements in the ICU. [Photo by author (GK) on site at Nong Khai.]

Figure 3. Topographic SWN along the Mekong River—Nong Khai Province

This northern most province in Isaan borders the Mekong River and gateways Laos via a bridge to the capitol city of Vientiane on the other side of the Mekong River opposite Nong Khai, the namesake principal city. A sinuous long topography encourages low-income Laotians to cross the Mekong by any means available to seek medical assistance for acute and chronic problems in Nong Khai, but they cannot pay, thereby burdening already scant health resources. Newly initiated telemedicine in this province will augment animai (small clinics—triangles), but animais operate during the day and generally do not have POCT.

Figure 4. Partnering Provinces—Sakon Nakhon and Nakhon Phanom SWN

This SWN provides healthcare services for Sakon Nakhon and the adjacent province, Nakhon Phanom, located to the northeast along the Mekong River and Laos. Travel to Khon Kaen would require helicopter transport, but virtually none, except rare private or military transport, is available, and when available, typically fly wealthy patients directly to specialty tertiary care centers in Bangkok. Some animai (triangles) have telehealth capability.

Figure 5. Demographic Distribution of Healthcare Resources

Overly burdened general practitioners and nurses lack support of specialists within Isaan SWNs where cardiologists, intensivists, and emergency medicine physicians are badly needed, especially for acute coronary syndrome (ACS), cardiac catheterization, and percutaneous intervention (PCI) in provincial regional hospitals.

Figure 6. Value Proposition for POC Cardiac Biomarker Testing in SWN ERs

Rapid therapeutic turnaround time (TTAT) adds value, but requires an integrated approach that encompasses the entire healthcare delivery system, that is, the SWN in order to generate fast treatment decisions for value synthesis. If not efficient (pathway to the right), traditional laboratory testing may introduce lengthy confounding processing delays for the diagnosis of ACS and AMI patients, for whom time to treatment and diagnosis are of the essence.

Table 1

Regional Hospitals in Khon Kaen and North Isaan

Province	Khon Kaen City		Province Regional Hospitals					
Factor	Srinagarind	Khon Kaen Regional	Queen Sirikit Heart Center	Maha Sarakham	Kalasin	Sakhon Nakhon	Nakhon Phanom	Nong Khai
Number of beds	900	867	150	472	505	564	306	349
Number of MDs	300	166	31	67	35	48	22	33
Number of Nurses	782	566	147	324	364	462	319	336
Number of Lab Staff	83	69	9	32	35	39	20	23
Primary Care Units	2	22	-	9	29	2	1	19
ER (beds)	8	5	13	12	5	8	8	10
Operating Rooms	21	9	4	8	9	8	8	6
Type of surgery	Heart General Urology Obstetric Ophthalmic Orthopedic Otolaryngology	General Neuro Urology Obstetric Ophthalmic Orthopedic	Heart	General Urology Obstetric Ophthalmic Orthopedic Otolaryngology	Neuro General Urology Obstetric Ophthalmic	General	General Urology Obstetric Ophthalmic Orthopedic	General Urology Obstetric Orthopedic Otolaryngology
ICU (beds)	20	20	8	8	3	8	6 rooms	12
Newborn ICU (beds)	-	8	6	26	1 room	8	6	-
CCU (beds)	8	6	6	-	-	-	-	-
LR (beds)	12	5	-	3	2 rooms	8 rooms	7	12
Referral hospital	-	Srinagarind	Srinagarind	Khon Kaen	Srinagarind	Udonthani	Supprasitprasong	Udonthani
Distance (km)	-	10	0.3	68	80	176	270	53
Travel time	-	30 min	5 min	50 min	1 hr	2.5 hrs	4 hrs	1 hr
Ambulances	6	6	2	4	5	8	3	4
Diagnostic Lab Service								
• Weekdays (hr)	24	24	24	24	24	24	8:00-16:00	24
• Weekends (hr)	24	24	24	24	24	24	8:00-16:00	24
• On-call service	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Microbiology lab	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes

Table 2

Community Hospitals in North Issarn

Province	Maha Sarakham		Kalasin		Sakon Nakhon		Nakhon Phanom		Nong Khai	
Factor	Kosum	Kanthara Phisai	Yang Wichai	Somdet Talat	Khok Si Suphan	Tha Uthen	Renu Nakhon	Na Kae	Bung Khla	Sangkham
Number of beds	120	30	90	60	30	30	30	60	10	30
Number of MDs	7	4	8	4	2	2	3	3	2	2
Number of RNs	73	45	96	100	30	45	37	44	15	22
Number of Lab Staff	5	4	7	4	2	1	5	2	1	1
Primary Care Units	10	4	7	9	4	8	11	2	3	2
ER (beds)	5	2	3	3	3	2	4	2	2	3
Operating rooms	2	1	2	1	1	1	1	1	1	1
Type of surgery	Trauma Urology	Vasectomy Trauma	Appendix Delivery Trauma	Appendix Trauma	Appendix Delivery	Trauma	Trauma	Trauma Delivery	Trauma	Trauma
ICU (beds)	-	-	-	-	-	-	-	-	-	-
NICU (beds)	-	-	-	-	-	-	-	-	-	-
CCU (beds)	-	-	-	-	-	-	-	-	-	-
LR (rooms)	1	1	1	1	1	1	1	1	1	1
Referral hospital	Maha Sarakham	Maha Sarakham	Kalasin	Kalasin	Sakon Nakhon	Nakhon Phanom	Nakhon Phanom	Sakon Nakhon	Buang Kan	Tha Bo
Distance (km)	28	17	17	40	25	24	52	48	45	60
Travel time (min)	30	20	20	30	30	20	45	30	30	40
Ambulances	3	4	4	3	2	2	2	3	4	2
Diagnostic Lab Service										
• Weekdays	24 hr	8:30 - 20:30	8:00 - 20:30	8:30 - 16:30	8:00 - 16:00	8:30 - 16:30	8:00 - 16:00	7:00 - 16:00	8:00 - 16:00	8:00 - 16:00
• Weekends	24 hr	8:30 - 20:30	8:00 - 12:30	8:30 - 16:30	8:00 - 16:00	8:30 - 12:00	closed	8:00 - 12:00	8:00 - 16:00	closed
• On-call service	Yes	-	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes
Microbiology lab	Yes	-	-	-	-	-	-	-	-	-

Table 3

Diagnostic Testing at Community Hospitals

Province	Maha Sarakham	Kalasin	Sakon Nakhon	Nakhon Phanom	Nong Khai
Factor	Kosum Phisai	Kanthara Wichai	Khok Si Suphan	Tha Uthen	Bung Khla
Blood Gases	pH, pO ₂ , pCO ₂ , O ₂ Sat.	-	-	-	-
Electrolytes	Na ⁺ , K ⁺ , Cl ⁻ , TCO ₂	Na ⁺ , K ⁺ , Cl ⁻ , TCO ₂	Na ⁺ , K ⁺ , Cl ⁻ , TCO ₂	Na ⁺ , K ⁺ , Cl ⁻ , TCO ₂	K ⁺
Microbiology Lab					
a) Malaria	Blood smear	Blood smear	Blood smear	Blood smear	Blood smear
b) Dengue Fever	CBC/Hct	CBC/Hct	CBC/Hct	IgG/IgM Test Kit	IgG Test Kit
Hematology	CBC	CBC	CBC	CBC	CBC
Homeostasis	PT, PTT, Clotting & bleeding time	PT, Clotting & bleeding time	Clotting & bleeding time	Clotting & bleeding time	Clotting & bleeding time
CSF Exam	Cell count, Glucose, Protein	Cell count	Cell count	Cell count, Glucose, Protein	Cell count, Glucose, Protein

Table 4

Cardiac Biomarker Testing in North Isaan

Table 4A. Community Hospitals (CH)									
Province	Maha Sarakham			Kalasin		Sakon Nakhon		Nakhon Phanom	
Cardiac Biomarker	Kosum Phisai	Kanthara Wichai	Yang Talat	Somdet	Khok Si Suphan	Tha Uthen	Renu Nakhon	Na Kae	Bung Khla
cTnT 0.1 - 2.0 ng/mL	-	-	-	cTnT h232 (Roche)	-	-	-	-	-
cTnI 1 ng/mL	-	-	-	-	-	-	-	-	-
Other	CK-MB LD, CK	-	-	-	-	-	-	LD	-
Cardiologists	-	-	-	-	-	-	-	-	-
CH to RH (medians)	47.5	47.5	46	46	57	67 (To S.N.)	67	67	117
Distance (km)	34.5	34.5	60	60	60	50 (To S.N.)	50	50	77.5
Ambulance time (min)									
Table 4B. Provincial Regional Hospitals (RH)									
Province	Maha Sarakham			Kalasin		Sakon Nakhon		Nong Khai	
Cardiac Biomarker									
cTnT 0.1 - 2.0 ng/mL	-	-	-	-	-	-	-	-	-
Quantitative cTnT	cTnT Elecysis 2010	-	-	cTnT Elecysis 2010	-	cTnT Reader (Roche)	-	cTnT h232 (Roche)	-
Other	CK-MB, LD, CK	-	-	CK-MB, LD, CK	-	CK-MB, LD, CK	-	CK-MB, LD, CK	-
proBNP	-	-	-	-	-	-	-	h232 (Roche)	-
Cardiologists	-	-	-	-	-	-	-	-	-
Table 4C. Khon Kaen City Hospitals									
Province	Khon Kaen City			Khon Kaen		Queen Sirikit Heart Center			
Cardiac Biomarker	Srinagarind								
cTnT 0.1 - 2.0 ng/mL	-	-	-	-	-	-	-	-	-
Quantitative cTnT	cTnT Elecysis 2010	-	-	cTnT Elecysis 2010	-	cTnT Elecysis 2010	-	cTnT Elecysis 2010	-
Other	CK-MB, LD, CK	-	-	CK-MB, LD, CK	-	CK-MB, LD, CK	-	CK-MB, LD, CK	-
proBNP	h232 (Roche)	-	-	-	-	h232 (Roche)	-	h232 (Roche)	-
Cardiologists	6	-	-	1	-	12	-	12	-

Table 5

Emergency and Disaster Sites

Author Reference	Medical Setting	POCT, or if not, Format	Cardiac Biomarkers	Main Outcomes	Conclusions and Impact on Emergency and Disaster Care
Amin Clin Cardiol 2009;32:386	ED	Single Assay Device	cTnI	High cTnI after CABG associates 3% faster to adverse events (P<0.001)	"Early cTnI measurement after admission can predict adverse outcomes after CABG"
Christenson Clin Biochem 2008;42:150	Review	Multiplex, single assay devices	CK-MB, cTnI, cTnT, Myo	Quality of test must not compromise POC	cTn POC measurements are viable alternative when labs overwhelmed
Ekelund Emerg Med J 2007;24:811	ED Review	POCT, ECG, cardiac imaging, IET and CPU	Importance of use of multiple markers	Reduce over-admissions of patients strategy	Combination multiple biomarkers, cardiac imaging best overall
Friess Anal Bioanal Chem 2009;393:1453	Review	Multiplex, single assay devices	Importance of implementing POCT and new markers	"New analytes may indicate MI earlier than traditional markers"	Cardiac POCT main focus: method standardization, usability, analytical performance
Kost Cardiol Clin 2005; 23:467	Review of CPU and ED	Multiplex, single Assay Devices	BNP, CK-MB, CRP, cTn I/T, D-dimer, H-FABP, MLC-1, Myo	User-friendly POC instrument needed	"Existing devices are poorly adapted for emergency field response"
Kost Am J Clin Pathol 2006;126:513	Disaster situations	Cardiac STATus i-STAT Triage Cardiac Panel	BNP, CK-MB, cTnI, Myo	No quantitative cardiac biomarker tests available	POCT must be available in disaster: tsunami and Hurricane Katrina
Lee-Lewandrowski Arch Pathol Lab Med 2003;127:456	ED	Spectral Diagnostics Status test kit	cTnI, CK-MB	Combining tests LOS was decreased 41.3 min (P=0.006)	POCT satellite laboratory decreased test TAT and ED LOS
Lee-Lewandrowski Clin Lab Med 2009;29:479	Review	Glucose, Blood gas, Cardiac Markers	BNP, cTn, CK-MB, D-dimer	POCT improved patient outcomes in hospitals	Rapid TAT provided by POCT main factor responsible for improvement in outcomes
Lee-Lewandrowski Am J Clin Pathol 2009; 132:326	ED	Biosite Triage VIDAS D-dimer	D-dimer	Decreased ED LOS, admissions decreased, and earlier discharge	"Rapid D-dimer test was associated with a shorter ED LOS and fewer hospital admissions"
Leman Emerg Med J 2004;21:452	ED	Roche Cardiac Reader Nyo Card Reader II	cTnT, D-dimer	Decisions to discharge patients were decreased to 28.2 min (P<0.0001)	"Satellite laboratory service is an important adjunct to improve the timeliness of care in the ED"
Lewandrowski Clin Lab Med 2009;29:561	ED Review	Multiplex Devices	cTn, CK-MB, Myo, BNP	Decreased ER LOS, overall cost, and earlier discharge	Rapid POC assays facilitated reconstruction of conventional approach to ACS and heart failure

Author Reference	Medical Setting	POCT, or if not, Format	Cardiac Biomarkers	Main Outcomes	Conclusions and Impact on Emergency and Disaster Care
Loria Minerva Med 2008;99:497	ED Review	Multiplex Devices	Importance of ACS biomarkers	25% patients admitted affected by ACS but often atypical presentation	Need for early markers that reliably rule out ACS from ED at presentation
Macdonald Emerg Med Australasia required. 2008; 20:403	ED Panel	Triage Cardiac	Myo, CK-MB, cTnI	Triage Panel accurately predicted cTnI values for 12-h (SN 100%) elevation and 30 day (SN 86%) events	CK-MB, cTnI, and Myo can identify patients suitable for early discharge Large multicentre study is
McCord Circulation 2001;104:1483	ED	Triage Cardiac Panel	cTnI, CK-MB, Myo	Median time from sampling to reporting was 47 min shorter for POC (P<0.001)	AMI can be excluded rapidly in ED by use of POC during first 90 min after presentation
McDonnell Clin Biochem 2009;42:549	Review	POCT Commentary	"Importance of early prediction"	Physician inertia in ED is now ... barrier to POCT Implementation	Implement multiplexed emerging cardiac biomarkers on robust POC platforms for ED
Ng Am J Cardiol 2001;87:994	ED	Triage Cardiac Panel	cTnI, CK-MB, Myo	91% accuracy diagnosing AMI when using all markers	Use of multiple markers helps avoid use of spurious elevations of cTnI
Reichlin N Engl J Med 2009; 361:913	ED	Single Assay Devices	cTn	AUC significantly higher with the sensitive cTn assays versus standard Roche Troponin T assay	Sensitive cTn assays can improve early diagnosis of AMI.
Renaud Acad Emerg Med 2008;15:216	ED	Stratus CS	cTnI	POCT decreased TTAT 0.75 hr (P<0.001)	POCT decreased time to initial AIT delivery for suspected NSTE-ACS
Ryan Ann Emerg Med 2009;53:321	ED	i-STAT	cTnI	POCT decreased test turnaround time 0.72 hr	Effect of POCT on LOS varies between settings
Saiki Circ J 2007;71:1458	ED	Non POC Device	cTnI	cTnI levels elevated with AMI, UAP, SAP, HF, RF, CM, MC, PAF, PSVT, PE	Elevations of cTnI frequently observed in patients in ER with diseases other than ACS
Selvaraj J Thromb Thrombolysis 2004;18:109	ED	New POC assay studied	PAU	Mean PAU significantly lower in group experiencing MACE	POCT of platelet function deserves further study for risk assessment and future therapy
Singer Ann Emerg Med 2005; 45:587	ED	POC devices for cTn testing	cTn	Introduction of POCT decreased ED LOS and gave faster results	POC testing of cTn by nurses significantly reduced ED LOS
Storrow Acad Emerg Med 2008;15:1130	ED	POCT observations	Importance of POCT in ED	110 min. decrease in TAT lead to 0.6 hr decrease in ED LOS	Decreasing TAT positively affects ED efficiency

Author Reference	Medical Setting	POCT, or if not, Format	Cardiac Biomarkers	Main Outcomes	Conclusions and Impact on Emergency and Disaster Care
Stratface Am J Clin Pathol 2008;129:788	ED	Triage Cardiac Panel	cTnI, CK-MB, Myo	POCT decreased weighted average ED LOS by 1.5 hrs (P=0.02)	POC multimer protocol superior to cTn only approach
Suzuki Keio J Med 2000;49:74	ED	Single Assay	cTnT	100% patients with ACS 3 hrs after onset tested cTnT positive (P<0.01)	cTnT levels should be evaluated considering time interval from onset of chest pain
Takakuwa Clin Cardiol 2009; 32:498	ED	Cardiac POC technologies	cTn, Myo, CK-MB	High POC usage led to shorter ED length of stay	"Positive POC results are associated with expedited and higher use of anti-ischemic therapies"
Talwalkar Ann Clin Lab Sci 2008;38:132	ED	Single Assay	cTnT, IMA	Markers added significant information about presence of ACS (P=0.028)	Useful for triage of patients presented to ER with chest pain
Wang Adv Exp Med Biol 2009;645:101	Laboratory	Mini sensing chip	BNP, CRP, Myo cTnI	MEMS device accurately quantify four cardiac biomarkers simultaneously	Four cardiac marker sensing may be performed in ER
Zun West J Emerg Med 2009;10:104	ED Review	POC Literature review	Importance of using POC	Few papers used the same techniques to reduce patient throughput	Low patient census, in-room registration, POCT, and an urgent care area increased throughput

Terminology: AIT, anti-ischemic therapy; AMI, acute myocardial infarction; AUC, are under the receiver-operating characteristic curve; BNP, brain natriuretic peptide [NT-BNP, N-terminal BNP]; CK-MB, creatine kinase MB isoenzyme; CM, cardiomyopathy; CRP, C-reactive protein; cTn, cardiac troponin ("T" or "I"); ED, emergency department; HF, heart failure; hs-cTn, high sensitivity cTn; hs-CRP, high sensitivity CRP; IMA, ischemia-modified albumin; LOS, length of stay; MACE, major adverse cardiac events; MC, myocarditis; MEMS, micro-electro-mechanical system; MI, myocardial ischemia; MPO, myeloperoxidase; Myo, myoglobin; NSTEMI-ACS, non-ST-segment elevation acute coronary syndrome; PAF, paroxysmal atrial fibrillation; PAPP-A, pregnancy-associated plasma protein-A; PAU, platelet activation units; PE, pulmonary embolism; PSVT, paroxysmal supraventricular ventricular tachycardia; RF, renal failure; SAP, stable angina pectoris; SN, sensitivity; STEMI, ST segment elevation MI; TTAT, therapeutic turnaround time; UAP, unstable angina pectoris; and others [e.g., AST, CK, d-dimer, LDH].

Websites: Cardiac STATus, <http://www.nanogen.com/products/cardiacstatus/>; i-STAT, <http://www.abbottpointofcare.com/ISTAT/index.asp>; Stratus CS, http://www.medical.siemens.com/webapp/wcs/stores/servlet/ProductDisplay~q_catalogId~e_111~a_catTree~e_100001,1023069,1023067~a_langId~e_-111~a_productId~e_182056~a_storeId~e_10001.htm; and Triage Cardiac Panel, <http://www.biosite.com/products/cardiac.aspx>.