Challenges for learning health systems in the NHS. Case study: electronic health records in cardiology

Author: Amitava Banerjee

ABSTRACT

Electronic health records (EHRs) are at the centre of advances in health informatics, but also many other innovations in healthcare. However, there are still obstacles to implementation and realisation of the full potential of EHRs as there are with learning health systems (LHS). Cardiovascular disease, in the UK and globally, carries greater morbidity and mortality than any other disease. Therefore, planning and delivery of health services represent major costs to individuals and populations. Both the scale of disease burden and the growing role of technology in cardiology practice make analysis of experiences with EHRs in cardiology a useful lens through which to view achievements and gaps to date. In this article regarding LHS, EHRs in cardiology are used as a case study of LHS in the NHS.

KEYWORDS: Cardiology, digital, electronic health record and informatics

Introduction

Electronic health records (EHRs) are variably defined and variably implemented both within and across countries. The term EHR encompasses a wide range of information systems, from 'files compiled in single departments to longitudinal collections of patient data'.[1] EHRs include data from the routine care of patients, administrative data, registries and possibly clinical research databases.[2] The National Programme for IT (NPfIT) was the first national attempt to implement EHRs across all hospital trusts and failed because of a combination of political, cultural and design issues.[3–5] There is a renewed enthusiasm for digital health, including EHRs, in the 2016 NHS policy.[6] However, there is currently a contrast between the promise and the reality with multiple providers, multiple methods and poor interoperability across different domains, with no system-wide solution on the horizon.[6] In primary care, there has been higher penetration of EHRs, starting in the 1990s, with better interoperability and use of data to drive quality improvement.[7]

The tide may be turning for hospital IT as the need for connection between primary and secondary care grows. The effects of the large-scale cyber-attack by ransomware on the NHS in 2017 show that modern medicine cannot be practised without informatics.[8]

Several large-scale programmes are underway in the wake of the Wachter review,[6] including the development of an active chief clinical informatics officer network to exchange learning and experiences, the Digital Academy to train aspiring informatics leaders in the NHS,[9] the creation of the Faculty of Clinical Informatics[10] and the Federation of Informatics Professionals,[3] and the Global Digital Exemplar scheme.[11] Health Data Research UK will be established to capitalise on the progress of the Farr Institutes of Health Informatics Research and take forward healthcare data science in the UK.[12] 'Learning health system' was coined as a term to capture the need for information to flow freely between science (researchers), evidence (guideline- and policymakers) and care (health professionals) to reduce waste and increase patient safety.[13] In order for the EHR to fulfil its potential and transform both clinical practice and research in a learning health system (LHS), five challenges need to be overcome:

1 the gap between research and service
2 the gap between quality improvement/audit and research
3 lack of capacity and expertise in informatics among clinicians/non-clinicians
4 the trust of patients and public
5 the trust of clinicians in big data analytics and EHR.[13]

Cardiovascular disease (CVD) has enormous impact nationally and globally in terms of disease burden.[14] Historically and perhaps also because of this scale of disease, the specialty of cardiology has been at the forefront of both development and early adoption of innovation and technology in research and practice,[15] whether intracoronary interventions to prevent myocardial infarction or clinical trials of new drug therapies, spanning screening, prevention, diagnosis and treatment decisions. The same trends have applied to implementation and use of informatics in cardiology. In this article, I use examples from EHRs in cardiology to illustrate successes and failures with respect to the five challenges for LHS.

Research and service

Cardiovascular research is on the increase globally and much of the leading clinical research originates from the UK or involves UK collaborators.[16] Moreover, much of the research has exploited the population-wide reach of the NHS and EHRs.

Author: senior clinical lecturer in clinical data science and honorary consultant cardiologist, Farr Institute of Health Informatics Research, University College London, London, UK

In primary care, there are multiple resources, including both research (eg Clinical Practice Research Datalink[17] and The Health Improvement Network[18]) and clinical databases (eg Quality Outcomes Framework (QOF)[19]). In hospitals, there are also administrative or routine care datasets (eg hospital episode statistics[20]) as well as research or registry-based data (eg National Institute of Cardiovascular Outcomes Research (NICOR) audits[21]). These and other EHR data have been extensively and intensively used in research, planning of health services and developing the evidence base of cardiovascular medicine. As genomic research advances and the use of genomic information in clinical practice increases, this -omic data will be incorporated into routine EHRs.[22–24] Box 1 summarises the key areas where EHR research can drive forward CVD research and care in the UK.[17,20,25–40]

Box 1. Potential uses of electronic health records in cardiology research and clinical practice throughout the patient journey

Aetiology

- Disease-specific, eg risk factors for development of AF[25]
- Across diseases, eg alcohol consumption and CVDs[26]

Diagnosis

- Studying variations in definition, eg aortic dissection during pregnancy[20]
- Development of diagnostic tools, eg familial hypercholesterolaemia[27]

Screening

- CVD, eg AF[28]
- CVD in non-cardiovascular disease, eg late CVD in cancer survivors[29]

Public health

- Incidence and prevalence, eg AF[30]
- Trends in management, eg prescription of novel anticoagulants in AF[31]
- Resource utilisation, eg cost of AF[32] or HF[33] management
- International comparisons, eg NSTEMI management[33]
- Risk of CVD with non-cardiovascular diseases and drugs, eg CVD events with clarithromycin[34]

Prognosis

- Outcomes, eg HF[35]
- Derivation and validation of risk prediction tools, eg QRISK2[17] and 10-year risk of HF[36]

Intervention

- Comparative effectiveness, eg statins in different chronic diseases[37]
- Cost effectiveness, eg evolocumab[38]
- Trials, eg automated software to improve anticoagulation uptake in AF[39]
- Clinical decision support, eg dual antiplatelet therapy[40]

AF = atrial fibrillation; CVD = cardiovascular disease; HF = heart failure; NSTEMI = non-ST-segment elevation myocardial infarction

The potential value of EHRs for cardiovascular research is not in question. However, currently research and routine clinical care are largely parallel activities. Rather than using data from real-time EHRs, use of retrospective administrative data and linked datasets is the norm. For example, the CALIBER database has been constructed to link retrospective data from primary care (Clinical Practice Research Datalink), Office of National Statistics, national registries (eg Myocardial Infarction National Audit Project) and hospital episode statistics.[41] There are relatively few examples of research occurring as care is being delivered, using an integrated EHR. There are multiple contributory factors, including data security, ethics, infrastructure and culture. Clinical trials, whether in terms of recruitment, outcome ascertainment or follow-up, would be made far more efficient with greater integration of EHRs.[42] Until the alignment of research and care happens, it is difficult to envisage a true LHS and there will continue to be waste both on the side of care provision and research. Specific areas of research, such as precision medicine or personalised medicine, require detailed EHR data, whether for patient selection, disease phenotyping or patient follow-up, and lack of integrated EHR will stifle progress.[22,43] It is important to note that the existence of silos in research and clinical practice is not unique to EHRs or health informatics; these are problems that have been encountered by other social movements within medicine, including evidence-based healthcare, quality improvement (QI) and precision medicine.[44,45]

Quality improvement and audit versus research

NICOR is one of the most established national audit programmes in the UK and currently manages national clinical audits in six areas:

1 adult cardiac surgery
2 adult percutaneous interventions
3 cardiac rhythm management
4 congenital heart disease
5 heart failure
6 Myocardial Infarction National Audit Project (MINAP).

These audits have become a powerful resource, enabling trends in disease and management to be monitored, and have played a role in policymaking for specific CVDs at system level. For example, NICOR data have been used to give individual operator-specific outcomes for percutaneous coronary intervention and have shown the increasing use of trans-catheter aortic valve implantation with reducing complication rates.[46] Other diverse uses include showing ethnic variation in incidence rates of congenital heart disease around the UK[47] and the potential for post-marketing surveillance of prosthetic aortic valves.[48] Electronic data in the form of the QOF have been used to show that high-quality primary care is associated with improvements in outcome measures for coronary heart disease.[49] Local primary care data have been used to show that 'managed geographical practice networks' produce improved CVD performance indicators in east London.[50]

However, NICOR data are separate from routine EHR data and therefore involve separate data collection and analysis. The data are available retrospectively for research and are not usually used in real-time, locally or nationally. In terms of QI, there have been discrete projects; however, system-wide initiatives such as

NHS Health Checks are relatively uncommon.[51] Research using EHRs is generally not embedded in audit and QI activity. The effect, as with the divide between clinical service and research, is that the research that is done is not always aligned with clinical service and health system priorities. Similarly, analyses of audit data, rather than being targeted and proactive, are often *ad hoc* and reactive. Perhaps a more serious issue for the field of informatics is that, as a result of lag in coordination of research and QI/audit approaches, the evidence base for effectiveness or benefit of EHR-based approaches, such as decision support, is in its infancy.[52]

An alternative and entirely plausible model would be for continuous and semi-automated audit to be occurring using routine data. QI, trials of interventions and service provision could occur simultaneously using the same data in EHRs.[53,54] Box 2 summarises the potential impact of narrowing the gaps between research and service provision, audit and QI.

Lack of capacity and expertise in informatics among clinicians/non-clinicians

At present, there is relatively little 'e-health' or EHR training in undergraduate medical curricula.[55] The higher specialty curricula of all clinical disciplines are replete with content relevant to that specialty and selected subspecialties. Informatics is still not considered a key component of the core skills that a clinician requires and cardiology, like other specialties, barely pays lip service to IT or informatics at present. However, just as it is now considered essential that all clinicians have knowledge of audit cycles, QI methodology and principles of critical appraisal of research, informatics has become a necessary core competency that needs to be recognised, as in other countries.[56,57]

EHR and different linked data platforms mean that complex big data analytics are not only possible, but necessary to make optimal use of resources and also to improve patient outcomes. Techniques such as machine learning[58] and natural language processing[59] may have the potential to transform cardiovascular medicine in both service provision and research, but they are mostly in the latter. Without training, awareness and capacity building among non-clinical and clinical professionals, big data analytics using EHRs will be difficult to scale up across the health system.

An additional hurdle is that within the hospital the informatics departments are often not well-funded and do not always have resources for audit and research, despite the high incremental gain from these activities. The current initiatives to create leaders in both clinical and non-clinical spheres are to be applauded, but need to be supplemented by training of the wider healthcare profession and informatics workforce. Otherwise, the research and service potential of EHRs will fail to be realised because of motivational and capacity constraints.

Box 2. Impact of gap between research and clinical service/audit/quality improvement

Convergence of research and clinical service

- Disease and outcome phenotypes
- Research and clinical agendas
- Research and clinical cultures

Improved quality of data

- Better motivation to complete full dataset in electronic health records and long-term follow-up data
- Better interoperability between research and clinical systems
- Reduction in transcription errors because of lack of duplication

Less resource waste

- Improved use of routine data
- Less duplication of data
- Less duplication of resource (human, financial)
- Better use of synergies between evidence-based healthcare, quality improvement, informatics and service delivery

Better science

- Better translation of bench-to-bedside research
- Science more aligned with clinical need
- Better alignment of research interventions and clinical service needs

Improved patient care

- Better implementation of evidence-based guidelines
- Increased real-time monitoring in acute and chronic care
- Reduction in clinical errors and improved patient safety

Trust of patients and public

Administrative databases, clinical registries and EHRs have been joined by multiple, additional data sources, such as biometric and other data directly from patients (eg via wearable technologies), patient-reported data (eg health surveys), social media, medical imaging data and biomarker data (including 'omics' data).[52] The rise in m-health and other technologies has the potential to transform diagnosis, screening and monitoring of CVD.[60] However, integration of these data with routine clinical data is far from straightforward.[61] Moreover, the validity and quality of data from wearables and novel sources may not be adequate for use in clinical care.[62]

The public has conflicting concerns regarding data security, ownership and inadequate use of data. Direct-to-consumer advertising and sales have created a thriving health technology sector, but may be fuelling unrealistic expectations, which are not necessarily supported by evidence and are driven by commercial factors.[63,64] Patient engagement and trust are crucial for collection and use of data, particularly secondary use for research and data linkage, as shown by recent mixed-methods studies from the UK.[65–67] Giving patients access to their own health data is part of the solution.[68]

Trust of clinicians in EHRs

The quality improvements that have occurred using NICOR data and QOF data exemplify how clinicians can drive system change using EHR data, whether in primary angioplasty[69] or control of hypertension in chronic renal impairment.[70] Professional organisations must ensure that clinical practice embraces the LHS approach, as a recent American Heart Association scientific statement exemplifies.[71] The EHR 'faces the same implementation challenges as other healthcare quality interventions, and will require the same skill sets and resources…to be integrated successfully into the clinical workflow and achieve clinical utility'.[52] Any move towards an LHS will need to engage the clinical workforce because without 'buy-in' from clinicians, there will be incomplete implementation, wastage of resources and poor data quality.

Conclusions

EHRs are integral to the modern practice of cardiovascular medicine and LHS. Although there are convincing examples of their value in improving research and clinical practice in both the UK and other countries, the implementation and optimisation of use of EHRs faces significant barriers. Through EHRs and LHS, there are huge opportunities to bridge gaps across diseases, as well as research and clinical spheres, in order to improve patient outcomes. Research and service requirements need to be assessed and incorporated at the planning, procurement, implementation and evaluation stages of EHRs. QI and audit must be coordinated and integrated into EHRs to make the process continuous and semi-automated. Informatics capacity and expertise need to be addressed at local and system level. Patient and public engagement at planning, implementation and evaluation stages will increase acceptability and usability of EHRs. Clinician trust and engagement are a prerequisite to the successful use of EHR from an early stage of planning. Capitalising on the opportunities of EHR will require investment in infrastructure and people as well as changes in culture. ■

Author contributions

AB was solely responsible for this manuscript.

Conflicts of interest

The authors have no conflicts of interest to declare.

Twitter

Amitava Banerjee tweets using the moniker @amibanerjee1

References

1 Hayrinen K, Saranto K, Nykanen P. Definition, structure, content, use and impacts of electronic health records: a review of the research literature. *Int J Med Inform* 2008;77:291–304.
2 Logan J. Electronic health information system implementation models – a review. *Stud Health Technol Inform* 2012;178:117–23.
3 UKCHIP. *December 2016: UKCHIP passes the baton to Fed-IP 2016*. Usk: UKCHIP, 2016. http://www.ukchip.org/ [Accessed 24 August 2017].
4 House of Commons Committee of Public Accounts. The dismantled National Programme for IT in the NHS. *London: House of Commons*, 2013.
5 Sood HS, Mcneil K. How is health information technology changing the way we deliver NHS hospital care? *Future Healthcare Journal* 2017;4:117–20.
6 UK Department of Health. *Making IT work: harnessing the power of health information technology to improve care in England*. London: Department of Health, 2016.
7 Sheikh A, Jha A, Cresswell K, Greaves F, Bates DW. Adoption of electronic health records in UK hospitals: lessons from the USA. *Lancet* 2014;384:8–9.
8 O'Dowd A. Major global cyber-attack hits NHS and delays treatment. *BMJ* 2017;357:j2357.
9 Heather B. NHS Digital Academy to train 300 CCIOs and CIOs. *London: Digital Health*, 2017. www.digitalhealth.net/2017/03/nhs-digital-academy-for-300-ccio-cios/ [Accessed 24 August 2017].
10 Faculty of Clinical Informatics. www.facultyofclinicalinformatics.org.uk/ [Accessed 25 August 2017].
11 NHS England. Global Digital Exemplars. www.england.nhs.uk/digitaltechnology/info-revolution/exemplars/ [Accessed 25 August 2017].
12 Medical Research Council. *Director appointed for new UK health and biomedical informatics research institute*. London: MRC, 2017. www.mrc.ac.uk/news/browse/director-appointed-for-new-uk-health-and-biomedical-informatics-research-institute/ [Accessed 25 August 2017].
13 Olsen LA, Aisner D, McGinnis JM (eds). *The learning healthcare system: workshop summary*. Washington, DC: National Academies Press, 2007.
14 Newton JN, Briggs AD, Murray CJ *et al*. Changes in health in England, with analysis by English regions and areas of deprivation, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015;386:2257–74.
15 DeMaria AN. Innovation. *J Am Coll Cardiol* 2013;62:253–4.
16 Huffman MD, Baldridge A, Bloomfield GS *et al*. Global cardiovascular research output, citations, and collaborations: a time-trend, bibliometric analysis (1999–2008). *PLoS One* 2013;8:e83440.
17 Hippisley-Cox J, Coupland C, Vinogradova Y *et al*. Predicting cardiovascular risk in England and Wales: prospective derivation and validation of QRISK2. *BMJ* 2008;336:1475–82.
18 Taylor CJ, Ryan R, Nichols L *et al*. Survival following a diagnosis of heart failure in primary care. *Fam Pract* 2017;34:161–8.
19 Mejzner N, Clark CE, Smith LF, Campbell JL. Trends in the diagnosis and management of hypertension: repeated primary care survey in South West England. *Br J Gen Pract* 2017;67:e306–e13.
20 Banerjee A, Begaj I, Thorne S. Aortic dissection in pregnancy in England: an incidence study using linked national databases. *BMJ Open* 2015;5:e008318.
21 Bashir M, Shaw MA, Grayson AD *et al*. Development and validation of elective and nonelective risk prediction models for in-hospital mortality in proximal aortic surgery using the National Institute for Cardiovascular Outcomes Research (NICOR) database. *Annals of Thoracic Surgery* 2016;101:1670–6.
22 Tenenbaum JD. Translational bioinformatics: past, present, and future. *Genomics Proteomics Bioinformatics* 2016;14:31–41.
23 Thompson R, Johnston L, Taruscio D *et al*. RD-Connect: an integrated platform connecting databases, registries, biobanks and clinical bioinformatics for rare disease research. *J Gen Intern Med* 2014;29 (Suppl 3):S780–7.
24 Mosley JD, Shoemaker MB, Wells QS *et al*. Investigating the genetic architecture of the PR interval using clinical phenotypes. *Circ Cardiovasc Genet* 2017;10:e001482.
25 Allan V, Honarbakhsh S, Casas JP *et al*. Are cardiovascular risk factors also associated with the incidence of atrial fibrillation? A systematic review and field synopsis of 23 factors in 32 population based cohorts of 20 million participants. *Thromb Haemost* 2017;117:837–50.
26 Bell S, Daskalopoulou M, Rapsomaniki E *et al*. Association between clinically recorded alcohol consumption and initial presentation of 12 cardiovascular diseases: population based cohort study using linked health records. *BMJ* 2017;356:j909.
27 Weng SF, Kai J, Andrew Neil H, Humphries SE, Qureshi N. Improving identification of familial hypercholesterolaemia in primary care: derivation and validation of the familial hypercholesterolaemia case ascertainment tool (FAMCAT). *Atherosclerosis* 2015;238:336–43.
28 Rhys GC, Azhar MF, Foster A. Screening for atrial fibrillation in patients aged 65 years or over attending annual flu vaccination clinics at a single general practice. *Qual Prim Care* 2013;21:131–40.
29 van Laar M, Feltbower RG, Gale CP *et al*. Cardiovascular sequelae in long-term survivors of young peoples' cancer: a linked cohort study. *Br J Cancer* 2014;110:1338–41.
30 Lane DA, Skjoth F, Lip GYH, Larsen TB, Kotecha D. Temporal Trends in incidence, prevalence, and mortality of atrial fibrillation in primary care. *J Am Heart Assoc* 2017;6;e005155.

31 Loo SY, Dell'Aniello S, Huiart L, Renoux C. Trends in the prescription of novel oral anticoagulants in UK primary care. *Br J Clin Pharmacol* 2017;83:2096–106.
32 Boggon R, Lip GY, Gallagher AM, van Staa TP. Resource utilization and outcomes in patients with atrial fibrillation: a case control study. *Appl Health Econ Health Policy* 2012;10:249–59.
33 Hollingworth W, Biswas M, Maishman RL *et al*. The healthcare costs of heart failure during the last five years of life: a retrospective cohort study. *Int J Cardiol* 2016;224:132–8.
34 Root AA, Wong AYS, Ghebremichael-Weldeselassie Y *et al*. Evaluation of the risk of cardiovascular events with clarithromycin using both propensity score and self-controlled study designs. *Br J Clin Pharmacol* 2016;82:512–21.
35 Koudstaal S, Pujades-Rodriguez M, Denaxas S *et al*. Prognostic burden of heart failure recorded in primary care, acute hospital admissions, or both: a population-based linked electronic health record cohort study in 2.1 million people. *Eur J Heart Fail* 2016;doi: 10.1002/ejhf.709. [Epub ahead of print]
36 Hippisley-Cox J, Coupland C. Development and validation of risk prediction equations to estimate future risk of heart failure in patients with diabetes: a prospective cohort study. *BMJ Open* 2015;5:e008503.
37 Sheng X, Murphy MJ, MacDonald TM, Wei L. The comparative effectiveness of statin therapy in selected chronic diseases compared with the remaining population. *BMC Public Health* 2012;12:712.
38 Toth PP, Danese M, Villa G *et al*. Estimated burden of cardiovascular disease and value-based price range for evolocumab in a high-risk, secondary-prevention population in the US payer context. *J Med Econ* 2017;20:555–64.
39 Holt TA, Dalton A, Marshall T *et al*. Automated software system to promote anticoagulation and reduce stroke risk: cluster-randomized controlled trial. *Stroke* 2017;48:787–90.
40 Pasea L, Chung SC, Pujades-Rodriguez M *et al*. Personalising the decision for prolonged dual antiplatelet therapy: development, validation and potential impact of prognostic models for cardiovascular events and bleeding in myocardial infarction survivors. *Eur Heart J* 2017;38:1048–55.
41 Denaxas SC, George J, Herrett E *et al*. Data resource profile: cardiovascular disease research using linked bespoke studies and electronic health records (CALIBER). *Int J Epidemiol* 2012;41:1625–38.
42 Cowie MR, Blomster JI, Curtis LH *et al*. Electronic health records to facilitate clinical research. *Clin Res Cardiol* 2017;106:1–9.
43 Antman EM, Loscalzo J. Precision medicine in cardiology. *Nat Rev Cardiol* 2016;13:591–602.
44 Banerjee A, Stanton E, Lemer C, Marshall M. What can quality improvement learn from evidence-based medicine? *J Roy Soc Med* 2012;105:55–9.
45 Anaya JM, Duarte-Rey C, Sarmiento-Monroy JC *et al*. Personalized medicine. Closing the gap between knowledge and clinical practice. *Autoimmun Rev* 2016;15:833–42.
46 Ludman PF, de Belder MA, Redwood S, Banning A. United Kingdom: coronary and structural heart interventions from 2010 to 2015. *EuroIntervention* 2017;13:Z83–Z8.
47 Knowles RL, Ridout D, Crowe S *et al*. Ethnic and socioeconomic variation in incidence of congenital heart defects. *Arch Dis Child* 2017;102:496–502.
48 Hickey GL, Bridgewater B, Grant SW *et al*. National registry data and record linkage to inform postmarket surveillance of prosthetic aortic valve models over 15 years. *JAMA Intern Med* 2017;177:79–86.
49 Kiran T, Hutchings A, Dhalla IA, Furlong C, Jacobson B. The association between quality of primary care, deprivation and cardiovascular outcomes: a cross-sectional study using data from the UK Quality and Outcomes Framework. *J Epidemiol Community Health* 2010;64:927–34.
50 Robson J, Hull S, Mathur R, Boomla K. Improving cardiovascular disease using managed networks in general practice: an observational study in inner London. *Br J Gen Pract* 2014;64:e268–74.
51 Robson J, Dostal I, Sheikh A *et al*. The NHS Health Check in England: an evaluation of the first 4 years. *BMJ Open* 2016;6:e008840.
52 Rumsfeld JS, Joynt KE, Maddox TM. Big data analytics to improve cardiovascular care: promise and challenges. *Nat Rev Cardiol* 2016;13:350–9.
53 Murdoch TB, Detsky AS. The inevitable application of big data to health care. *JAMA* 2013;309:1351–2.
54 Longhurst CA, Harrington RA, Shah NH. A 'green button' for using aggregate patient data at the point of care. *Health Affair* 2014;33:1229–35.
55 Walpole S, Taylor P, Banerjee A. Health informatics in UK medical education: an online survey of current practice. *JRSM Open* 2016;8:2054270416682674.
56 Mantas J, Ammenwerth E, Demiris G *et al*. Recommendations of the International Medical Informatics Association (IMIA) on education in biomedical and health informatics. First revision. *Methods Inf Med* 2010;49:105–20.
57 Li S, Bamidis PD, Konstantinidis ST *et al*. Setting priorities for EU healthcare workforce IT skills competence improvement. *Health Informatics J* 2017:1460458217704257.
58 Ng K, Steinhubl SR, deFilippi C, Dey S, Stewart WF. Early detection of heart failure using electronic health records: practical implications for time before diagnosis, data diversity, data quantity, and data density. *Circ Cardiovasc Qual Outcomes* 2016;9:649–58.
59 Kaufman DR, Sheehan B, Stetson P *et al*. Natural language processing-enabled and conventional data capture methods for input to electronic health records: a comparative usability study. *JMIR Med Inform* 2016;4:e35.
60 Milani RV, Franklin NC. The role of technology in healthy living medicine. *Prog Cardiovasc Dis* 2017;59:487–91.
61 Lobelo F, Kelli HM, Tejedor SC *et al*. The wild wild west: a framework to integrate mHealth software applications and wearables to support physical activity assessment, counseling and interventions for cardiovascular disease risk reduction. *Prog Cardiovasc Dis* 2016;58:584–94.
62 Jo E, Lewis K, Directo D, Kim MJ, Dolezal BA. Validation of biofeedback wearables for photoplethysmographic heart rate tracking. *J Sports Sci Med* 2016;15:540–7.
63 Joyner MJ. Precision medicine, cardiovascular disease and hunting elephants. *Prog Cardiovasc Dis* 2016;58:651–60.
64 Bhavnani SP, Narula J, Sengupta PP. Mobile technology and the digitization of healthcare. *Eur Heart J* 2016;37:1428–38.
65 Papoutsi C, Reed JE, Marston C *et al*. Patient and public views about the security and privacy of electronic health records (EHRs) in the UK: results from a mixed methods study. *BMC Med Inform Decis Mak* 2015;15:86.
66 Aitken M, Cunningham-Burley S, Pagliari C. Moving from trust to trustworthiness: experiences of public engagement in the Scottish Health Informatics Programme. *Sci Public Policy* 2016;43:713–23.
67 Laurie G, Ainsworth J, Cunningham J *et al*. On moving targets and magic bullets: can the UK lead the way with responsible data linkage for health research? *Int J Med Inform* 2015;84:933–40.
68 Prey JE, Polubriaginof F, Kuperman GJ *et al*. A global analysis of approaches to sharing clinical data with patients. *Stud Health Technol Inform* 2015;216:907.
69 Ludman PF, de Belder MA, McLenachan JM *et al*. The importance of audit to monitor applications of procedures and improve primary angioplasty results. *EuroIntervention* 2012;8 (Suppl P):P62–70.
70 Karunaratne K, Stevens P, Irving J *et al*. The impact of pay for performance on the control of blood pressure in people with chronic kidney disease stage 3-5. *Nephrol Dial Transplant* 2013;28:2107–16.
71 Maddox TM, Albert NM, Borden WB *et al*. the learning healthcare system and cardiovascular care: a scientific statement from the american heart association. *Circulation* 2017;135:e826–e57.

Address for correspondence: Dr Amitava Banerjee, Farr Institute of Health Informatics Research, 222 Euston Road, London, NW1 2DA, UK.
Email: ami.banerjee@ucl.ac.uk

