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Health system preparedness for emerging infectious diseases: A synthesis of the literature

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ABSTRACT

This review reflects on what the literature to date has taught us about how health systems of low- and middle-income countries (LMICs) respond to emerging infectious disease (EID) outbreaks. These findings are then applied to propose a conceptual framework characterising an EID prepared health system. A narrative synthesis approach was adopted to explore the key elements of LMIC health systems during an EID outbreak. Overarching themes ('core health system constructs') and sub-themes ('elements') relevant to EID preparedness were extracted from 49 peer-reviewed articles. The resulting conceptual framework recognised six core constructs: four focused on material resources and structures (i.e. system 'hardware'), including (i) Surveillance, (ii) Infrastructure and medical supplies, (iii) Workforce, and (iv) Communication mechanisms; and two focused on human and institutional relationships, values and norms (i.e. system 'software'), including (i) Governance, and (ii) Trust. The article reinforces the interconnectedness of the traditional health system building blocks to EID detection, prevention and response, and highlights the critical role of system 'software' (i.e. governance and trust) in enabling LMIC health systems to achieve and maintain EID preparedness. The review provides recommendations for refining a set of indicators for an 'optimised' health system EID preparedness tool to aid health system strengthening efforts.

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Emerging infectious diseases; health systems; low- and middle-income country; health system strengthening

Introduction

Calls for strong and resilient health systems have arisen in the wake of several emerging infectious disease (EID) outbreaks. The 2009 pandemic of influenza A(H1N1), the 2013–2016 West Africa Ebola epidemic and, most recently, the 2015–16 Zika outbreaks in Latin America and South-East Asia, demonstrate how countries with weak health systems struggle to withstand large scale health system shocks (Boozary, Farmer, & Jha, 2014; Castro, 2016; Purohit et al., 2018). In our increasingly mobile society, EIDs present a considerable threat to public health and health security globally. Their risk of rapid geographic spread is fuelled by frequent cross-border travel, workforce migration and tourism (Horby, Pfeiffer, & Oshitani, 2013).

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While the language of strong health systems is familiar in the global health literature, health systems resilience is a relatively new – and somewhat contested (Barasa, Cloete, & Gilson, 2017; Haldane, Ong, Chuah, & Legido-Quigley, 2017) – concept. Several frameworks seek to encapsulate the core domains of health systems to focus strengthening initiatives, the most well-known being the World Health Organization's (WHO) framework of six building blocks (World Health Organization, 2007; World Health Organization, 2010). Critical analyses of the building blocks, however, highlight the framework's inadequate capture of health system complexity, including the dynamic, multi-directional interactions between system components, and an overall neglect of a 'whole system' perspective (Chee, Pielemeier, Lion, & Connor, 2013; Mounier-Jack, Griffiths, Closser, Burchett, & Marchal, 2014; van Olmen, Marchal, Van Damme, Kegels, & Hill, 2012). Previous efforts to apply the building blocks framework to the evaluation of programmes for the control of infectious diseases have exposed its limitations as a practical tool for system planners (Hanvoravongchai et al., 2011; Mounier-Jack et al., 2014). Indeed, this siloed presentation of system 'inputs' results in a framework predominantly focused on material resources and structures (i.e. health system 'hardware') rather than the human and institutional relationships, values and norms that transform these into a dynamic system (i.e. health system 'software') (Sheikh et al., 2011).

Health system 'hardware' refers to the tangible organisational, policy, legal and financing arrangements that structure any health system, as well as resources that underpin clinical and service delivery requirements. The 'software' encompasses the ideas and interests, values and norms, and affinities and power dynamics that guide actions and underpin the relationships among system actors and elements (Sheikh et al., 2011). Understanding how to achieve health system preparedness for EIDs requires recognition of the centrality of software components of the health system which hold the hardware together. Recent efforts to categorise health system resilience in light of the Ebola epidemic have highlighted the centrality of both hardware and software components noting the need for health systems to be aware, diverse, self-regulating, integrated and adaptive (Kruk, Myers, Varpilah, & Dahn, 2015). However, given that in order to be resilient a health system must first be strong (and not vice versa), it is important to link the resilience required to respond to an EID outbreak to a need to strengthen health systems more broadly (Abimbola & Topp, 2018; Abimbola, Topp, Palagyi, Marais, & Negin, 2017b). To inform such strengthening efforts, we must identify those features of a strong – or prepared – health system that would confer resilience.

In this paper, we sought to: (1) review the literature on health systems preparedness for EIDs to identify preparedness determinants, and (2) use those determinants to develop a conceptual framework characterising health system preparedness for EID threats.

Methods

Design

A structured, systematic review and narrative synthesis of peer-reviewed publications was performed to explore the functionality, gaps and key elements of health systems before, during or after an EID outbreak. Synthesis of the literature relies on the researcher comparing, contrasting and extrapolating like-themes (Mays, Pope, & Popay, 2005); here, we sought to thematically group health system elements to produce a conceptual framework characterising EID preparedness. The narrative approach is commonly used to evaluate and synthesise qualitative literature, and was applied here as it is considered appropriate for generating new insights or knowledge by systematically and transparently bringing together existing research findings (Jones, 2004; Mays et al., 2005).

Search strategy

A comprehensive search of the literature was undertaken initially in March 2017 using the electronic databases MEDLINE, EMBASE and Global Health. Relevant English-language publications (from

inception to the date of search) were identified using the following terms from title, abstract or keywords: (health system* OR healthcare system* OR health care system*) AND (emerging infectious disease* OR Ebola OR influenza OR SARS OR Zika) AND (prepared* OR resil* OR sustain*). The search was rerun in July 2018 to identify relevant new literature published since March 2017. We included descriptive studies, case studies, frameworks, systematic reviews, opinion pieces and commentaries reporting functionality, gaps and/or key elements of a health system before, during or after an EID outbreak. EIDs were defined as infections that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range. We focussed specifically on evidence from low- and middle-income countries (LMICs).

The review was conducted in two stages. In stage 1, the title and abstract of initial search results were screened and assessed for relevance, and duplicate results were removed. The full text of potentially relevant publications was retrieved and reviewed for inclusion. The reference lists of the final included publications were hand-searched for additional articles relevant to the review. The reason for excluding a publication following full text review was noted. This search process is shown in Figure 1.

Data abstraction

In stage 2 of the review, the author names, year of publication, publication type and geographical focus of included literature were tabulated. Each publication was then reviewed to identify the

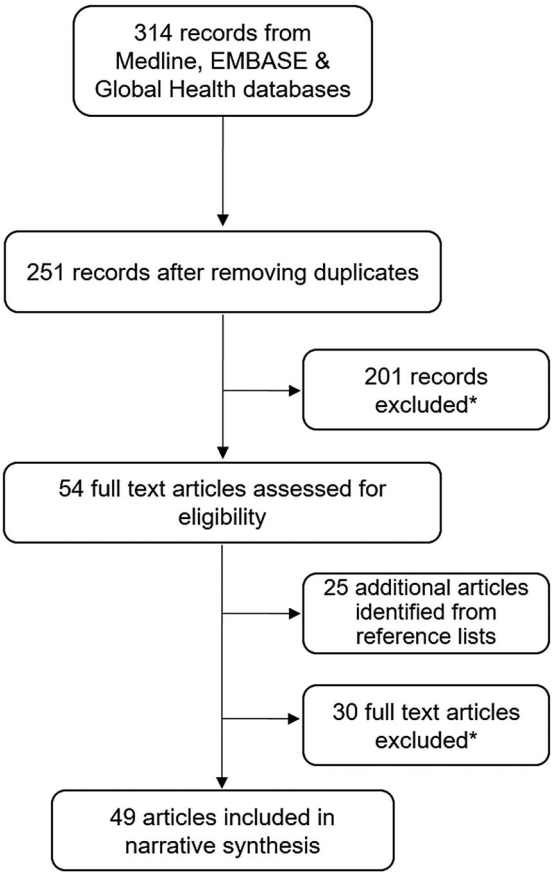

Figure 1. Flow chart of literature selection. *Not applicable to health system preparedness in the context of low- and middle-income countries and/or an emerging infectious disease outbreak.

various sub-elements of a health system contributing to preparedness for EIDs; these sub-elements were summarised and collated in an initial coding framework. Once all included literature were assessed, the identified health system sub-elements were reviewed for repetition and similarity, and refined with consensus.

Synthesis

A preliminary synthesis identified emergent overarching themes ('core health system constructs') and sub-themes ('elements') through thematic analysis of the sub-elements arising from the literature review. We applied the hardware-software framing of health systems (Sheikh et al., 2011) to analyse the literature and identify the determinants of health system preparedness for EIDs. Following a series of discussions among all authors, a final set of health system constructs, encompassing both hardware and software components, were agreed upon, and the various sub-elements were sorted and categorised in order to develop a literature-informed conceptual framework.

Results

The review identified 49 articles (19 commentaries, 13 research articles, 8 reviews, 7 reports and 2 case studies) exploring the functionality, gaps and key elements of health systems before, during or after an EID outbreak (see Supplemental Online Material). Thirty articles (61%) were published in response to the 2014–2015 West African Ebola virus epidemic. The remaining publications addressed the 2009 H1N1 influenza pandemic (seven articles); avian influenza A (H7N9), severe acute respiratory syndrome (SARS) and Zika virus (two articles each); Middle East Respiratory Syndrome (MERS) (one article); and EIDs generally (six articles).

The resulting conceptual framework of health system preparedness for EIDs comprised six health system constructs, including four hardware constructs: (i) Surveillance, (ii) Infrastructure and medical supplies, (iii) Workforce, and (iv) Communication mechanisms (Table 1); and two software constructs: (i) Governance, and (ii) Trust (Table 2). A schematic representation of the proposed conceptual framework is provided in Figure 2. An overview of the literature is presented here according to each of the core health system software and hardware constructs identified.

Hardware

Surveillance

Twenty-three articles highlighted surveillance, incorporating the early detection and monitoring of infectious diseases, as an overarching enabler of EID preparedness. The need for complementary indicator- and event-based human disease surveillance systems with broad geographic coverage was noted as fundamental both in the wake of the Ebola virus (Balajee, Arthur, & Mounts, 2016; Lapao, Silva, Pereira, Vasconcelos, & Conceicao, 2015) and the 2009 H1N1 pandemic (Stoto et al., 2013). Indicator-based surveillance refers to the routine reporting of cases of disease, usually from health care providers to public health officials; event-based surveillance is the organised and rapid capture of information about events that are a potential risk to public health, through both formal and informal channels (WHO Western Pacific Region, 2008). A qualitative study by Adokiya and Awoonor-Williams (2016) linked major gaps in event-based Ebola surveillance systems in Ghana to inadequate early case detection and response preparedness to prevent Ebola virus outbreaks and spread. An absence of Ebola surveillance systems was noted by Forrester et al. (2014) during a 2014 assessment of emergency preparedness in south-eastern Liberia. This led to a series of surveillance training workshops and creation of an Ebola incident management system which is thought to have enhanced preparedness and reduced Ebola case burden in the region compared to other areas of the country.

Table 1. Conceptual framework representing the essential health system 'hardware' for EID preparedness: a synthesis of the literature.

Construct	Element	Sub-element
Surveillance	• Human disease surveillance • Animal and zoonotic disease surveillance • Screening and referral processes • Vector control programmes • Prediction modelling	• Systems for human (and domestic/wild animal) disease surveillance (Jacobsen et al., 2016; Kaufman, 2008; Zumla et al., 2016) – Indicator based surveillance (Balajee et al., 2016; Kruk et al., 2015; Lapao et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015) – Event based surveillance (Adokiya & Awoonor-Williams, 2016; Balajee et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Garcia Serpa Osorio-de-Castro, Silva Miranda, Machado de Freitas, Rochel de Camargo, & Cranmer, 2017; Kruk et al., 2015; Lapao et al., 2015; McPake et al., 2015; Nyarko et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015; Stoto et al., 2013; Thiam et al., 2015), with use of community health monitors (Balajee et al., 2016; Jacobsen et al., 2016; Martineau, 2016; McPake et al., 2015; Nyarko et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015; Scott et al., 2016; Thiam et al., 2015) – Verification of reported signal events (Balajee et al., 2016; Espinal et al., 2016; Lapao et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015; Siedner et al., 2015) – Appropriate referral of suspected cases (Siekmans et al., 2017; Thiam et al., 2015) – Response system for suspected cases (Adokiya & Awoonor-Williams, 2016; Espinal et al., 2016) – Linked systems for human, domestic animal and wildlife health (Jacobsen et al., 2016; Kaufman, 2008; Zumla et al., 2016) • Established contact tracing and monitoring procedures (Bhatnagar et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Jacobsen et al., 2016; Lapao et al., 2015; McPake et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015; Siekmans et al., 2017; Thiam et al., 2015; Wolfe et al., 2017) • Effective screening processes for patients meeting specified syndromic criteria (Adokiya & Awoonor-Williams, 2016; Espinal et al., 2016; Parsons & Naeem Ahmad, 2015) • Border protection for the screening of travellers (Adokiya & Awoonor-Williams, 2016; Lapao et al., 2015; McPake et al., 2015; Nyenswah et al., 2016) • Integrated vector management strategy (Garcia Serpa Osorio-de-Castro et al., 2017; Omole & Folaranmi, 2016) • Feedback/information on ID surveillance to health facilities (Adokiya & Awoonor-Williams, 2016; Jacobsen et al., 2016; Stoto et al., 2013) • Use of prediction modelling to assess disease risk using GIS technology (Jacobsen et al., 2016; Kruk et al., 2015)
Workforce	• Key skill sets • Health workforce numbers • Competency (training) • Deployment	• Epidemiologists to define/validate signal events and translate data into public health interventions (Balajee et al., 2016; Siedner et al., 2015) • Adequate staff numbers: doctors, nurses, CHWs (Adokiya & Awoonor-Williams, 2016; Boozary et al., 2014; Cancedda et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Gostin & Friedman, 2015; Kieny et al., 2014; Kruk et al., 2015; Lapao et al., 2015; McPake et al., 2015; Mulinge & Soyemi, 2016; Regmi et al., 2015; Siedner et al., 2015; Siekmans et al., 2017); also at sub-regional level (Gostin & Friedman, 2015; Kruk et al., 2015; Regmi et al., 2015) • Health worker training and continuing education (Adokiya & Awoonor-Williams, 2016; Boozary et al., 2014; Cancedda et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Gostin & Friedman, 2015; Kruk et al., 2015; Lapao et al., 2015; McPake et al., 2015; Mulinge & Soyemi, 2016; Nyarko et al., 2015; Regmi et al., 2015; Siedner et al., 2015; Siekmans et al., 2017; Thiam et al., 2015); understanding of community knowledge and beliefs (Buseh et al., 2015; Dhillon & Kelly, 2015; Martineau, 2016; Regmi et al., 2015; Scott et al., 2016; Thiam et al., 2015) • Traditional healers trained in infection control and public health messages (Alexander et al., 2015; McPake et al., 2015) • Trained laboratory technicians able to collect, analyse, package specimens (Adokiya & Awoonor-Williams, 2016; Balajee et al., 2016; Bhatnagar et al., 2016)

(*Continued*)

Table 1. Continued.

Construct	Element	Sub-element
		• Community engagement and health education (Alexander et al., 2015; Buseh et al., 2015; Cancedda et al., 2016; Dhillon & Kelly, 2015; Forrester et al., 2014; Garcia Serpa Osorio-de-Castro et al., 2017; Jacobsen et al., 2016; Kruk et al., 2015; Li, Xie, Yang, & Frost, 2016; Martineau, 2016; McGillis Hall & Kashin, 2016; McPake et al., 2015; Nyarko et al., 2015; Nyenswah et al., 2016; Omole & Folaranmi, 2016; Ozawa et al., 2016; Purohit et al., 2017; Qiu et al., 2018; Regmi et al., 2015; Scott et al., 2016; Siedner et al., 2015; Siekmans et al., 2017; Thiam et al., 2015)
Infrastructure & medical supplies	• Health care facilities • Equipment • Laboratory systems • Essential medicines & technologies	• Adequate number of hospital facilities (Boozary et al., 2014; Cancedda et al., 2016; Espinal et al., 2016; Purohit et al., 2017; Regmi et al., 2015) • Adequate number of hospital beds (Cancedda et al., 2016; McPake et al., 2015; Purohit et al., 2017) • Accessible healthcare facilities (Buseh et al., 2015; Kaufman, 2008; Siekmans et al., 2017) • Isolation centres: adequate number (Adokiya & Awoonor-Williams, 2016; Bhatnagar et al., 2016; Espinal et al., 2016; Regmi et al., 2015; Thiam et al., 2015) • Isolation centres: adequate beds (Adokiya & Awoonor-Williams, 2016; McPake et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015; Thiam et al., 2015) • Adequate transport for patients (Buseh et al., 2015; Forrester et al., 2014; Lapao et al., 2015; Thiam et al., 2015) • Adequate medical equipment (including personal protective equipment for health workers) (Adokiya & Awoonor-Williams, 2016; Bhatnagar et al., 2016; Boozary et al., 2014; Buseh et al., 2015; Cancedda et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Jacobsen et al., 2016; Lapao et al., 2015; McGillis Hall & Kashin, 2016; McPake et al., 2015; Mulinge & Soyemi, 2016; Nyarko et al., 2015; Parsons & Naeem Ahmad, 2015; Regmi et al., 2015; Siekmans et al., 2017; Stoto et al., 2013; Thiam et al., 2015) • Available essential medicines and vaccines; effective medicines supply chain (Buseh et al., 2015; Lapao et al., 2015; Mulinge & Soyemi, 2016; Purohit et al., 2017; Siekmans et al., 2017; Stoto et al., 2013) • Laboratories available, accredited and accessible (Adokiya & Awoonor-Williams, 2016; Balajee et al., 2016; Bhatnagar et al., 2016; Cash & Narasimhan, 2000; Espinal et al., 2016; Kaufman, 2008; Lapao et al., 2015; McPake et al., 2015; Nyenswah et al., 2016; Siedner et al., 2015) • Laboratories and diagnostic testing in under-served areas (Cash & Narasimhan, 2000; Jacobsen et al., 2016; Regmi et al., 2015; Thiam et al., 2015) • Laboratory information management system (Balajee et al., 2016) • Laboratory equipment maintenance (Balajee et al., 2016) • National reference laboratory identified (Lapao et al., 2015); linked to international reference laboratory (Balajee et al., 2016; Espinal et al., 2016; Thiam et al., 2015) • Transport mechanisms for specimens (including international) (Adokiya & Awoonor-Williams, 2016; Balajee et al., 2016; Espinal et al., 2016; Forrester et al., 2014; Thiam et al., 2015) • Pathogen testing systems relevant to context (cost, reagent availability, sustainability, compatibility with platforms, training) (Balajee et al., 2016; Espinal et al., 2016; Jacobsen et al., 2016; Nyenswah et al., 2016; Thiam et al., 2015)
Communication mechanisms	• National reporting and notification systems • Health facility protocols • Laboratory protocols	• WHO reporting requirements clear and applied (Garcia Serpa Osorio-de-Castro et al., 2017; Qiu et al., 2018; Wilson et al., 2010) • Risk-communication strategy available and implemented (Espinal et al., 2016; Garcia Serpa Osorio-de-Castro et al., 2017; Jacobsen et al., 2016; Lapao et al., 2015; Li et al., 2016; McPake et al., 2015; Purohit et al., 2018; Qiu et al., 2018; Siekmans et al., 2017; Stoto et al., 2013)

(*Continued*)

Table 1. Continued.

Construct	Element	Sub-element
	• Media and public health messages • Community engagement	• Health worker protocols for infectious disease management (Bhatnagar et al., 2016; Boozary et al., 2014; Cancedda et al., 2016; Mulinge & Soyemi, 2016; Regmi et al., 2015; Siekmans et al., 2017) • Security protocols at reference hospitals (Cancedda et al., 2016; Lapao et al., 2015) • Patient isolation protocol (Bhatnagar et al., 2016; McPake et al., 2015; Regmi et al., 2015) • Biosafety protocols available and adhered to in laboratories (Bhatnagar et al., 2016) • Directory of reference laboratories and laboratory contact information (Balajee et al., 2016) • Media supportive of prevention and control efforts (Kaufman, 2008; Lapao et al., 2015; Li et al., 2016; McPake et al., 2015; Nyarko et al., 2015; Ozawa et al., 2016; Purohit et al., 2018; Qiu et al., 2018) • Community-led communications (especially women, leaders)(Buseh et al., 2015; Cancedda et al., 2016; Jacobsen et al., 2016; McPake et al., 2015; Nyarko et al., 2015; Ozawa et al., 2016; Regmi et al., 2015; Siekmans et al., 2017) • Community protocols for infectious disease management (Cancedda et al., 2016; Espinal et al., 2016; McPake et al., 2015; Stoto et al., 2013)

CHW, community health worker; EID, emerging infectious diseases; GIS, geographic information system; ID, infectious diseases.

Table 2. Governance and trust – the essential health system 'software' for EID preparedness.

Construct	Element	Sub-element
Governance	• Health leadership • Multisectoral coordination • Partnerships • Health worker management and support • Community engagement	• Global health leadership (World Health Organization) (Gostin & Friedman, 2015) • National/subnational leadership (Cancedda et al., 2016; Kruk et al., 2015; McPake et al., 2015; Nyenswah et al., 2016; Purohit et al., 2018; Scott et al., 2016) • Regional/transnational cooperation (Cancedda et al., 2016; Gostin & Friedman, 2015; Scott et al., 2016) • National-level coordination (Kaufman, 2008; Lapao et al., 2015; McPake et al., 2015; Thiam et al., 2015); subnational coordination (Kruk et al., 2015; Lapao et al., 2015; McPake et al., 2015; Stoto et al., 2013; Thiam et al., 2015) • Inter/multi-sectoral action for health (Kaufman, 2008; Purohit et al., 2018; Scott et al., 2016) • Coordination between Ministry of Health, migration services, and Ministry of Agriculture (Kaufman, 2008; Lapao et al., 2015) • Partnership and coordination between government and non-government organisations (Buseh et al., 2015; Cancedda et al., 2016; Espinal et al., 2016; Gostin & Friedman, 2015; Kaufman, 2008; Martineau, 2016; McPake et al., 2015; Nyarko et al., 2015; Nyenswah et al., 2016; Purohit et al., 2018; Regmi et al., 2015; Siedner et al., 2015; Stoto et al., 2013) • Engagement & partnerships with civil society (Buseh et al., 2015; Cancedda et al., 2016; Gostin & Friedman, 2015; Martineau, 2016; Regmi et al., 2015; Siedner et al., 2015; Thiam et al., 2015) • Emergency operations centre for monitoring, coordination and information dissemination (Balajee et al., 2016; Jacobsen et al., 2016; Nyenswah et al., 2016) • Established processes for rapid deployment of health personnel in emergencies (Cancedda et al., 2016; Gostin & Friedman, 2015; Siedner et al., 2015; Stoto et al., 2013) • Effective coordination of international aid (Cancedda et al., 2016; McPake et al., 2015; Nyenswah et al., 2016; Regmi et al., 2015) • Effective leadership and management of health workers (Kruk et al., 2015; McPake et al., 2015; Purohit et al., 2018; Regmi et al., 2015; Scott et al., 2016) • Frequent and adequate supervision for districts and hospitals (Adokiya & Awoonor-Williams, 2016; Regmi et al., 2015; Siekmans et al., 2017) • Assurances for frontline health workers (health insurance, disability insurance, workers comp)(Kinsman, 2012; McPake et al., 2015; Nyarko et al., 2015; Thiam et al., 2015) • Incentives to attract and retain health workers in rural postings (McPake et al., 2015) • Involvement of a community advisory board (Siedner et al., 2015; Siekmans et al., 2017)
Trust	• Institutional trust • Workplace trust • Patient-provider trust	• Local perception of fair and effective government (Buseh et al., 2015; Martineau, 2016; McPake et al., 2015; Nyarko et al., 2015; Ozawa et al., 2016) • Open and transparent international reporting of outbreaks (Davies, 2017; Gostin, 2009; Qiu et al., 2018; Wilson et al., 2010) • Local perception of good quality health services (Alexander et al., 2015; Buseh et al., 2015; Dhillon & Kelly, 2015; Kruk et al., 2015; Martineau, 2016; McGillis Hall & Kashin, 2016; McPake et al., 2015; Nyarko et al., 2015; Ozawa et al., 2016; Regmi et al., 2015; Scott et al., 2016; Siekmans et al., 2017; Thiam et al., 2015) • Health care workers feeling safe, stable and secure (Alexander et al., 2015; Balajee et al., 2016; Kruk et al., 2015; Martineau, 2016; McGillis Hall & Kashin, 2016; McPake et al., 2015; Nyarko et al., 2015; Siekmans et al., 2017; Thiam et al., 2015) • Commitment of health care workers to provide quality care (Alexander et al., 2015; Kruk et al., 2015; McGillis Hall & Kashin, 2016; McPake et al., 2015; Nyarko et al., 2015; Shiao et al., 2007; Siekmans et al., 2017)

EID, emerging infectious diseases.

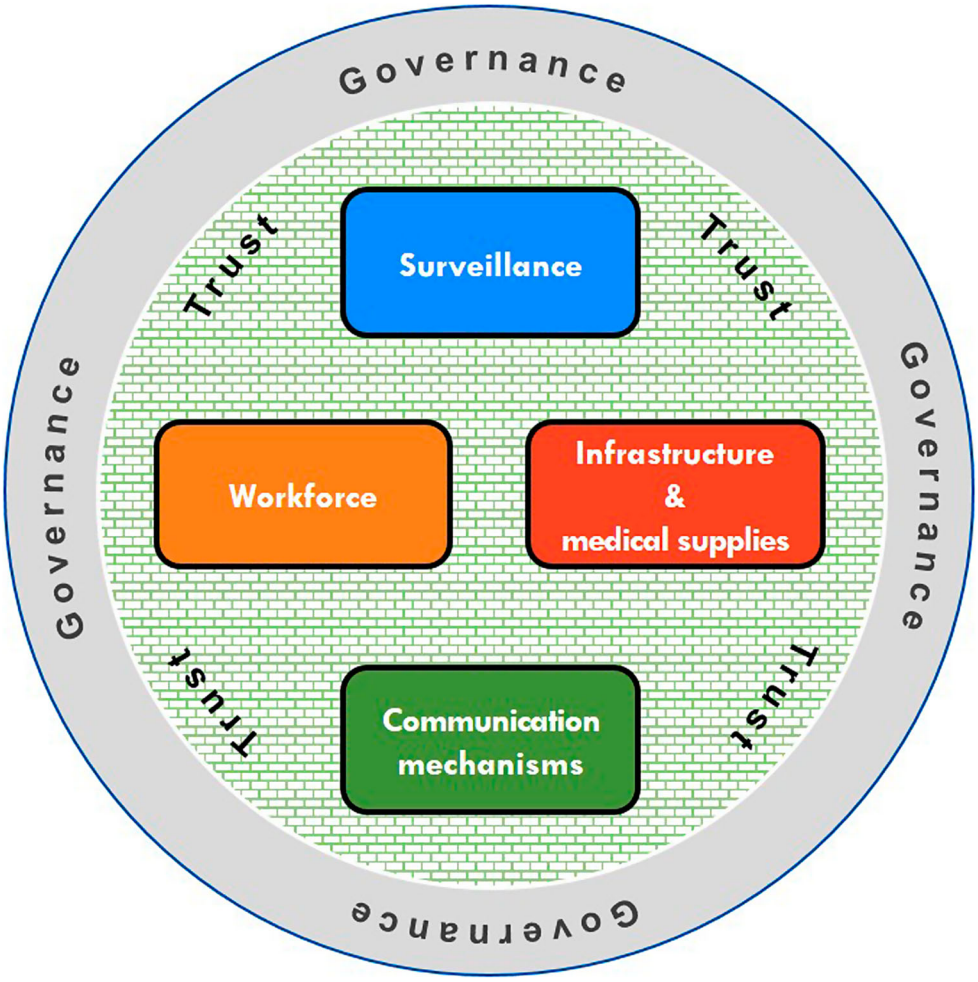

Figure 2. Schematic representation of the health system 'software' and 'hardware' essential for emerging infectious diseases preparedness.

The ability to rapidly implement effective patient screening processes for EIDs, and maintain such processes alongside systems for identification of known existing infectious diseases, was emphasised as a vital preparedness factor by Parsons and Naeem Ahmad (2015) in their discussion of lessons learned from the West African Ebola outbreak. Siekmans et al. (2017) showed how an integrated community-based child illness case management system no longer functioned effectively during the 2014 Ebola crisis in Liberia. Here, diagnoses of sick children by community health workers (CHWs) providing outreach services were hampered by Ebola-driven directives not to touch others, resulting in a large number of direct referrals to government health facilities. Thiam et al. (2015) also point to a reduction in immunisation coverage and an increase in cases of severe malaria among children during the 2014 Ebola outbreak in Guinea. They further highlighted logistical failures in the referral of suspected cases for specimen collection during the Guinea Ebola outbreak, coupled with inadequate transport medium for specimens to testing laboratories, as key issues affecting the timely diagnosis, containment and management of patients.

Established contact tracing and monitoring procedures were another essential element of effective EID surveillance. These included contact identification and listing, classification of risk status, daily monitoring for symptoms and the effective management of symptomatic contacts (including

precautionary quarantine). Wolfe et al. (2017) showed how the collaboration between the contact tracing team, active case finding teams and case investigation teams resulted in the detection of previously unidentified Ebola virus disease (EVD) contacts and the locations of missing contacts in a 2015 cluster outbreak in Monrovia, Liberia. They also highlighted the importance of a functional data management system and procedures for data sharing, in addition to the need for contact tracers to practise '*subtlety and diplomacy*' during often extended periods of personal interactions in situations of high stress and fear. The important role of community health monitors in active (and early) case finding, contact tracing and the quarantine of high-risk individuals in the eventual 2014–15 control of Ebola transmission in Liberia was described by Nyenswah et al. (2016). Mbonye et al. (2014) outlined the significance of community-appointed Village Health Teams in supporting outbreak response activities that resulted in the quick containment of Ebola and Marburg virus epidemics in Uganda. This strategy of strong community mobilisation also increased acceptability of the community to bring patients to isolation facilities.

Zumla et al. (2016) emphasised the inclusion of both zoonotic and animal surveillance to optimise local, national, and global EID surveillance and monitoring systems, using the examples of Ebola, West Nile virus, Nipah virus, severe acute respiratory syndrome (SARS) and Zika virus as notable emerging zoonotic infectious diseases of humans that have been caused by pathogens arising from animal reservoirs. The authors state the importance of a 'One Health' approach to controlling zoonotic pathogens, involving sustainable and equitable collaborations between the animal, human, ecosystem, and environmental health sectors at the local, national, and international levels. Jacobsen et al. (2016) commented on the necessity for proactive zoonotic and animal surveillance activities in their review of lessons learned from the Ebola outbreak. They signalled the need for effective human – animal health collaboration and coordination, including simultaneous monitoring and linkage of human and animal disease surveillance systems, to promote early detection of potential pandemic pathogens, and rapid response to protect health in both populations.

Workforce

The availability of frontline healthcare workers (including doctors, nurses and midwives) in sufficient numbers and with appropriate training was identified in 13 articles as a key characteristic of an EID-prepared health system. Three of these articles (Gostin & Friedman, 2015; Kruk et al., 2015 and Regmi, Gilbert, & Thunhurst, 2015) reinforced the need for a strong health workforce appropriately distributed at the sub-national level, rather than just a target aggregate number of health workers nationally. Continuity of health worker training, particularly around infection, prevention and control, was stressed as a critical aspect of EID prevention by both Thiam et al. (2015) and Nyarko, Goldfrank, Ogedegbe, Soghoian, and de-Graft Aikins (2015). Regmi et al. (2015) advocated for appropriate disease-specific health worker training programmes, tailored to the local circumstance, with inclusion of veterinary public health awareness, and training for health managers in outbreak and emergency response systems.

Other studies noted the requirement for sufficiently skilled epidemiologists able to define and validate signal events, integrate data from a variety of information sources and translate these into a public health response (Balajee et al., 2016; Siedner, Gostin, Cranmer, & Kraemer, 2015). Balajee et al. (2016) support the concept of 'field epidemiology training' where, under the mentorship of more experienced epidemiologists, public health workers use real-life local events to develop the necessary skills to gather and assess critical disease data and use this to inform action. Trained laboratory officers with capacity to collect, prepare, analyse and store specimens were also identified as a critical addition to the frontline health workforce (Adokiya & Awoonor-Williams, 2016; Balajee et al., 2016; Bhatnagar, Grover, Kotwal, & Chauhan, 2016).

Eight articles addressed the need for trained CHWs to enhance the routine provision of essential primary health care services in addition to outbreak response activities. Siekmans et al. (2017) described the successful involvement of CHWs in communicating awareness and prevention messages through village-based activities during the Ebola crisis in Liberia. Thiam et al. (2015) presented

views of local stakeholders in Guinea, who underlined the essential role of both CHWs and members of community-based organisations in bridging the gap between communities and international agencies in Ebola response activities. The importance of this bridging role was reinforced by Scott, Crawford-Browne, and Sanders (2016) who, using evidence from the West Africa Ebola outbreak, highlighted the difficulties in engaging communities in prevention and response activities without a network of health workers who were both accountable to, and embedded within, those communities. Two articles (Alexander et al., 2015; McPake et al., 2015) advocated for the training of traditional healers in infection control and the delivery of public health messages as an important mechanism for sharing accurate and constructive information with communities regarding outbreak prevention and control. This needs to be balanced against the risks of providing traditional healers legitimacy within the health care system, if there is no system to ensure acceptable practice and minimal standards of care (Krah, de Kruijf, & Ragno, 2018).

Aspects of financing and incentivising the health workforce for effective EID preparedness were discussed by McPake et al. (2015), who described how non- and delayed payment of financial incentives implemented to attract, retain and motivate health workers in rural postings served as a source of demotivation and attrition during the 2014–15 Ebola outbreak in Sierra Leone. The authors list financial (along with logistical and managerial) investment in the health workforce as integral to building trust between communities and health providers. Attracting and retaining a well-educated workforce to rural and remote locations poses a major challenge (Grobler, Marais, & Mabunda, 2015; Wilson et al., 2009). Nyarko et al. (2015) cite a lack of indemnities such as health insurance, workers' compensation and other services for health care workers in Ghana as a barrier to their commitment and continued quality care in the event of an Ebola virus outbreak.

Infrastructure and medical supplies

Adequate numbers of health facilities and inpatient beds for population size, and their distribution relative to the geographic location of communities, were highlighted as factors integral to a health system's outbreak response capacity (Boozary et al., 2014; Cancedda et al., 2016; Espinal, Aldighieri, St John, Becerra-Posada, & Etienne, 2016; McPake et al., 2015; Regmi et al., 2015). Likewise, the presence of operationally ready isolation centres, able to treat patients in a safe environment as necessary. Studies also reinforced the need to ensure accessibility of health care facilities, both geographically (Buseh, Stevens, Bromberg, & Kelber, 2015; Siekmans et al., 2017) and financially (Kaufman, 2008). Kaufman (2008) discussed China's health system as a probable 'weak link' in global EID outbreak preparedness at the time, noting financially-driven disparities in health care access between the 'more developed east' and the 'less developed west' as a significant threat to EID prevention, detection and control.

The importance of available and well-maintained medical equipment was commonly emphasised (19/49 articles), with particular attention to the lack of personal protective equipment (PPE) in West Africa health facilities during the Ebola crisis. Cancedda et al. (2016) described the important role of a Government-NGO partnership in strengthening existing health facility infrastructure for the scale up of services for Ebola patients at the height of the 2014 outbreak in Sierra Leone, which included bolstering PPE supply chains. A lack of basic supplies of gloves, gowns and intravenous fluid were noted by Boozary et al. (2014) as limiting the abilities of front-line health workers; a product of inadequate supply and distribution systems. The authors commented that the systems required for high-quality care during a crisis are the same as those required for effective routine health care and chronic disease management. The impact of weak existing medicines supply chain systems was revealed in a qualitative study of community health workers in Liberia, where the Ebola outbreak response interrupted the district supply of essential medicines for community case management of diarrhoea and pneumonia (Siekmans et al., 2017).

The essential elements of a public health laboratory system underpinning early EID outbreak detection and response were described in 13 articles. These included: readiness of trained personnel and accessories for appropriate specimen collection (Bhatnagar et al., 2016; Cash & Narasimhan,

2000); availability of sample collection and transport kits at select sites in the laboratory network (Balajee et al., 2016); safe and rapid transport mechanisms to both national (Lapao et al., 2015) and international (Espinal et al., 2016; Forrester et al., 2014; Thiam et al., 2015) reference laboratories; and timely characterisation of pathogens with mechanisms for the efficient feedback of results to national focal points to enable rapid and appropriate responses (Balajee et al., 2016). Cash and Narasimhan (2000) described how a lack of functional diagnostic laboratories during the 1994 outbreak of plague in Surat, India resulted in excessive clinical diagnoses, leading to inflated case numbers and overreaction by the international community. The authors highlighted the importance of having low-cost, easy-to-use diagnostic testing in underserved areas to improve early containment of emerging threats. This point was also made by Jacobsen et al. (2016) who listed the need for point-of-care diagnostic assays among lessons learned from the West Africa Ebola outbreak of 2014–15.

Communication mechanisms

We found 23 articles illustrating communication mechanisms underpinning effective EID prevention and response. Ten of these reinforced the necessity of a risk-communication strategy to guide a timely, coordinated and standardised approach to information sharing during outbreak management. However, a strategy not implemented remains ineffective, and Espinal et al. (2016) described the lack of clarity surrounding actual implementation of existing risk-communication strategies in countries of Latin American and the Caribbean. Cash and Narasimhan (2000) and Kinsman (2012) highlighted the importance of involving '*people and institutions who are credible*' when communicating public health risks, with the example given of widespread panic induced by unsubstantiated and sensationalist media reports of the suspected 1994 plague outbreak in Surat, India. The importance of partnership between national health organisations and media agencies to ensure dissemination of clinically accurate messages supportive of prevention and control efforts during public health emergencies was confirmed in a further eight articles. Ozawa, Paina, and Qiu (2016) discussed how negative messages about vaccines from the media in Ebola-affected countries could undermine efforts to rebuild community trust in the health system following system-wide shocks.

The valuable role of community members as key players in risk communication activities was widely acknowledged. Nyarko et al. (2015) described the significance of bi-directional communication in devising educational messages for Ebola preparedness, i.e. engaging communities to understand fears, challenges and opinions on how issues should be addressed, through a co-production process involving community leaders and members, frontline healthcare workers and community-based organisations. Buseh et al. (2015) labelled this approach an 'empowerment model', in which community leaders are enabled to contribute positively to programmes that embrace and represent the values of their community members, with the aims of reducing fear and stigma, and to encourage care-seeking.

Established and documented protocols, guidelines and procedures were widely affirmed by the literature as an integral element of the communications mechanisms associated with EID preparedness. For secondary and tertiary health facilities, these included a health worker protocol for infectious disease management (Bhatnagar et al., 2016; Boozary et al., 2014; Cancedda et al., 2016; Mulinge & Soyemi, 2016; Regmi et al., 2015; Siekmans et al., 2017), security protocols for both facility infrastructure and personnel (Cancedda et al., 2016; Lapao et al., 2015), and procedures for patient isolation (Bhatnagar et al., 2016; McPake et al., 2015; Regmi et al., 2015). Four articles also addressed the need for standardised procedures to guide social mobilisation for EID prevention and response, and community-centred infection prevention and control protocols championed by local leaders and CHWs (Cancedda et al., 2016; Espinal et al., 2016; McPake et al., 2015; Stoto et al., 2013). In contrast to the model of empowerment promoted by Buseh et al. (2015), these studies promote a classic centralised response to community engagement for EID communication processes, i.e. mechanistic consultation, versus redistribution of power (Aitken, Haggett, & Rudolph, 2016). Bhatnagar et al. (2016) drew learnings from the 2014 West Africa Ebola outbreak to reinforce the need for a laboratory

biosafety protocol, together with adherence to this by laboratory personnel. A simple, accessible directory containing the contact details of reference laboratories and contact information of key national (and subnational) laboratory personnel was also recommended as necessary for improving capacity for outbreak response (Balajee et al., 2016).

Software

Governance

Governance here refers to a relational view emphasising the making, changing, monitoring and enforcing of the rules that govern the demand and supply of health services (Abimbola, Negin, Martiniuk, & Jan, 2017a). In the reviewed publications, leadership and coordination across global, regional, national and sub-national levels were presented as critical enablers of an effective, cohesive response to EID threats. Gostin and Friedman (2015) discussed the vital role of an empowered global health leader (i.e. the WHO) in steering the overall direction, and coordinating the many participants, of an epidemic response. Scott et al. (2016) and Cancedda et al. (2016) highlighted the need for shared regional and national governance in mitigating the transboundary threat posed by many EIDs: Scott citing weak national governance in Sierra Leone and Guinea as lessening the ability of already compromised national health systems to manage the spread of Ebola virus associated with the movement of communities across country borders. The requirement for sub-national (local) governance structures that promote district-level coordination and management of EID detection and response featured in five articles (Kruk et al., 2015; Lapao et al., 2015; McPake et al., 2015; Stoto et al., 2013; Thiam et al., 2015). Thiam et al. (2015) provided the example of Regional and Prefecture Response Committees in the coordinated response to the 2014 Ebola outbreak in Guinea. They found that the effectiveness of these structures were weakened by a lack of community consultation in the appointment of Committee coordinators. Other studies also highlight the centrality of community advisory bodies, formed by national and local governments, in responding to an EID outbreak (e.g. Siedner et al., 2015; Siekmans et al., 2017). Ideally, such groups would represent a broad spectrum of community interests and comprise religious leaders, community leaders, representatives from NGOs, and other stakeholders.

The capacity of governments to engage and partner with non-state actors and civil society was another facet of good governance identified as supporting health system preparedness for EID. Central to such effective engagement and partnerships is the ability to rapidly mobilise additional resources in the event of an EID outbreak – including emergency teams of clinicians and logistics personnel (Kaufman, 2008; Siedner et al., 2015), community resources (Cancedda et al., 2016; Mbonye et al., 2014), and national and international non-government organisations (Gostin & Friedman, 2015). Buseh et al. (2015) emphasised the need for public-private partnerships, both regionally and internationally, to strengthen the capacity of affected countries to handle infectious disease outbreaks while maintaining the provision of basic health care. McPake et al. (2015) described how stable governance arrangements facilitated effective coordination of international agencies in the containment and control of the 2000–2001 Ebola outbreak in Uganda, drawing contrast with the aid co-ordination problems undermining Ebola control efforts in Sierra Leone in 2014–15. The rapid control of the 2014–15 Ebola outbreak in Liberia was also attributed to effective engagement and collaboration between government and international partners by Nyenswah et al. (2016).

Another key aspect of governance in achieving health system preparedness for EIDs relates to the effective management and support of health personnel. Studies identified the need for systems of routine health worker supervision that remain consistent during times of health system stress, such as those induced by an EID outbreak (Regmi et al., 2015; Siekmans et al., 2017). Siekmans et al. (2015) found that the absence of regular supervision of CHWs during the 2014 Ebola outbreak in Liberia impacted the quality of routine primary health care, evidenced by inconsistencies in CHWs' treatment decisions and referral patterns. Strategies of supervision that overcome barriers to in-person follow-up, such as the use of mobile phones or telehealth, may enable maintenance

of supportive supervision in times of crisis. By applying a primary health care lens to the analysis of the response to the Ebola epidemic, Scott et al. (2016) advocated the building of planning and management capacity of district level management to support CHWs and primary level health facilities.

Trust

The concept of trust – from the community level through to global governance – emerged as a fundamental element of health system preparedness for an EID outbreak, extending across each of the five identified core constructs. The notion of trust has been defined as encompassing both interpersonal trust between, for example, patient and provider as well as institutional trust between individuals/communities and the health system or government (Topp & Chipukuma, 2016).

Kruk et al. (2015) incorporated trust as one of several preconditions for health system resilience – '*Health systems that earn the trust and support of the population and local political leaders by reliably providing high-quality services before crisis have a powerful resilience advantage*' – reinforcing the need for inclusive and robust community engagement with the health system. Both Thiam et al. (2015) and Alexander et al. (2015) highlighted the role of community distrust of frontline health services in generating resistance to seeking health care and implementing infection control measures during the Ebola crisis. Through interviews with community leaders and community-based organisations, Thiam et al. (2015) found that the use of personal protective equipment by authorities during village-level infection control activities engendered fear in the community, and heightened mistrust of Western medicine and practices. Such negative reaction was primarily a result of the absence of both initial community consultation and appropriate community-led education on infection prevention and control. Alexander et al. (2015) discussed how a fear of Western medical practices led to individuals depending on traditional healers or family members for care during the Ugandan outbreak (Chan, 2014), with many patients fleeing hospitals after linking the hospital environment to likelihood of death. Dhillon and Kelly (2015) presented a case study demonstrating how mistrust of formal power structures led to community members hiding the sick from Ebola response teams. They recommended that trust be built through close, long-term engagement with community members and local leaders, and the incorporation of community preferences into infection prevention and control measures. Jacobsen et al. (2016) further identifies the centrality of community in the success of global zoonotic surveillance activities, suggesting that active community involvement builds trust, increases participation in zoonotic monitoring and improves existing surveillance systems.

Health workers' trust in their local health leadership and government was identified by Nyarko et al. (2015) as essential to the effective control of infectious disease transmission. Based on a roundtable discussion involving frontline clinicians, they identified '*inadequate staff, space, stuff and systems*' as the foundation of increased health worker fear and insecurity in the management of patients with suspected EVD, eroding both confidence and commitment to providing care. Accounts of healthcare worker reluctance to examine patients with fever during the 2009 H1N1 influenza pandemic in Ghana were provided, along with reports of nursing staff claiming they would leave their jobs out of fear 'if Ebola comes'. The legitimacy of these claims was evidenced during the year 2000 Ebola epidemic in Uganda, where an account of nurses abandoning their posts at Kampala hospital following the suspicious death of a male patient was widely reported in the media (Kinsman, 2012). The distrust of healthcare workers in their leadership's ability and commitment to mobilise resources in the event of an EID outbreak was also noted by Nyarko in the Ghanaian context, arising from feelings of ineptness in dealing with EVD-like symptoms and inadequate availability of personal protective equipment. In a study of factors contributing to nursing staff considering leaving their jobs during the 2003 severe acute respiratory syndrome (SARS) outbreak in Taiwan, Shiao, Koh, Lo, Lim, and Guo (2007) found that 'organisational support' underpinned nurse commitment, and that this was most strongly exemplified by their perceived ability of health managers to rapidly implement policies and protocols during the SARS outbreak.

Martineau (2016) applied evidence from the 2014–2016 West African Ebola outbreak to reinforce the importance of understanding, and engaging with, social and cultural dynamics in preparing health systems for future crises. Such relationships span those with and between national governments, non-formal health crisis response actors, non-health actors, non-government organisations, and influential local leaders (in addition to communities, health care providers and local leadership described previously). They suggested that initiatives to strengthen a health system '*must embed explicit localised efforts to build mutual trust, respect and dignity between health actors and the communities they serve …*' (Martineau, 2016, p. 308). Davies (2017) discussed the role of distrust in creating discrepancies between non-state and state reports of outbreak information in relation to the revised International Health Regulations (IHR; World Health Organization, 2005), using the example of the Middle East Respiratory Syndrome (MERS) outbreak in Saudi Arabia in 2012. Here, a hospital microbiologist's lack of trust in the readiness of the Saudi government to share details of the first detected case of MERS Coronavirus with the international community led him to report the information himself via the internet disease surveillance platform, ProMED-mail. This action triggered a chain of events including his own dismissal, intense review and criticism by the international community (including WHO) of the government's response to the MERS outbreak, and the removal of Saudi health ministers for their alleged failure to accurately track and disclose MERS cases.

Discussion

In this review, we identified a range of health system characteristics common to the state of preparedness for emerging disease threats in LMICs. We applied thematic analysis to synthesise these characteristics into six core health system constructs, uniquely grounded in the software-hardware framing of health systems, summarised in Tables 1 and 2. Although reinforcing the interconnectedness of the traditional health system 'building blocks' to EID detection, prevention and response (e.g. health workforce, essential medicines, information systems and governance), findings highlight the system 'software' as holding the key to achieving and maintaining preparedness. Specifically, the evidence base exposes trust, throughout all levels of the health system, as a fundamental element to effective EID prevention and response.

Several reviews and critiques have previously examined links between health system functionality and EID outbreaks (Alexander et al., 2015; Buseh et al., 2015; Fineberg, 2014; Jacobsen et al., 2016; Regmi et al., 2015; Shoman, Karafillakis, & Rawaf, 2017). To the authors' knowledge, however, no previous study has applied a preparedness lens to health system responses to EID threats on a global scale. The work reported here also differs from these past approaches in other ways. Firstly, we did not limit our search to outbreaks of a specific EID (e.g. Influenza), enabling a broader scope to the characterisation of preparedness than has been employed previously (evident in over 60% of included articles being published in response to the 2014–15 West African Ebola epidemic). Secondly, in including literature from any LMIC, we have been able to compare and contrast evidence from a variety of health systems, including those in Africa, Asia and South America. In doing so, this review provides a more comprehensive synthesis of evidence from global responses to EID outbreaks to identify common characteristics of preparedness across LMIC settings.

A further differentiating feature of this work is our application of the health system hardware–software model to conceptually frame EID preparedness. It has been more than seven years since Sheikh et al. (2011) theorised that overall health system performance is a product of the dynamic interactions between system 'software' (intangible health system components such as human values, power dynamics and norms) and system 'hardware' (tangible or material resources, such as infrastructure, drugs, information systems and health workforce). While the critical role of hardware–software interaction has gained some recognition in the health systems literature in recent years (e.g. framing of health system governance (Abimbola et al., 2017a); evaluation of the drivers of quality and responsiveness in frontline health services (Topp, Black, Morrow, Chipukuma, & Van

Damme, 2015)), analytical health system frameworks – including those specific to public health threats – remain largely unadapted to reflect these interactions. Applying a hardware–software lens to characterising an EID prepared health system here draws attention to the mismatch between the traditional 'mechanistic' health system formulations and EID preparedness. Instead, we highlight the relevance of a new generation of health system frameworks that recognise the importance of the system software as binding components (as represented in Figure 2).

There are limitations to this review that should be noted. The literature search, screening and data abstraction were carried out by a single researcher (AP), which may influence the objectivity and interpretation of findings. However, all authors were involved in determining a final set of health system constructs and the conceptual framing and categorisation of sub-elements. Although we searched a number of online databases of peer-reviewed literature, and applied a snowballing technique to identify additional literature from reference lists, it is possible that the search strategy missed some relevant literature. In particular, the exclusion of grey literature sources prevents evaluation of post-event review reports from both government and non-government sources; further research seeking to access and synthesise these documents may provide additional valuable practical learnings from localised EID preparedness and response initiatives. Identified articles were of varying format and study design; consequently we did not conduct a formal evaluation of evidence quality. Instead, all relevant articles were included and the review is narrative rather than systematic in nature. Finally, the peer-reviewed literature was dominated by evidence from Ebola preparedness and response activities in West Africa. Health systems analyses from LMICs of the Asia-Pacific region remain rare, limiting practice-based learnings from small island nations with complex health system challenges, such as those posed by geographically dispersed populations (amplifying issues with communications, access and inter-island travel) and frequent natural events. Sharing and synthesis of case studies that document processes and challenges of health system EID preparedness in these settings will promote intra-regional learning to draw out best practices.

While the resulting conceptual framework characterising health system preparedness for EIDs in LMICs (Tables 1 and 2) represents a literature-informed group of elements, this list is by no means exhaustive. Despite the widespread attention now given to the need for sustainable financial investments to strengthen national and regional preparedness capacities for health emergencies (Fryatt & Bhuwanee, 2017; World Bank, 2017), just two articles discussed aspects of health security financing in relation to past outbreaks, limited to the presence of a global health emergency fund (Cancedda et al., 2016; Siedner et al., 2015). No study drew lessons from the relationship between national health security financing and EID preparedness, rendering synthesis of aspects of health system financing unfeasible. And although the importance of EID risk prediction modelling was mentioned in several articles, there was no comment on the need to expand modelling capabilities to include mapping and overlay of health system performance indicators, including health infrastructure and service functionality. Interactive visual representations of health system data allow users to interact with information systematically and can support decision- and policy-making activities for preparedness planning (Carroll et al., 2014; Zakkar & Sedig, 2017). Perhaps most notably, there was very little reported from past outbreaks on the ecological aspects of health and disease, including zoonoses, animal health and environmental hazards, and their interplay with the broader human health system. All are of critical concern to EID prevention efforts (Caceres, Awada, Barboza, Lopez-Gatell, & Tizzani, 2017; Edmunds, Hunter, Few, & Bell, 2013; Rabinowitz & Conti, 2013), and represent areas where there is urgent need for future translational and implementation science research to understand how best they can or should be conceptualised within a preparedness framework.

The IHR (World Health Organization, 2005) presently guide global EID preparedness efforts by providing a governing framework of 'essential' capacities required by nations to prevent, detect, and rapidly respond to public health threats. Co-ordinated by WHO, the IHR is a legally binding mechanism, with member states expected to report IHR compliance annually, determined through a process of self-assessment guided by a checklist of indicators. However, IHR compliance remains low: by

the end of 2017 just 14% ($n = 20$) of 139 LMIC member states reported more than 50% compliance across all core capacities (World Health Organization Global Health Observatory, 2018), raising questions about the ability of LMICs to meet IHR obligations in the absence of adequate resourcing and financial support (Gostin et al., 2016), and the prioritisation of IHR capacities over basic health system functionality (Fidler, 2015a).

Both the 2009 influenza A (H1N1) pandemic and the 2014–15 West Africa Ebola outbreak not only exposed weaknesses in IHR implementation (Fidler, 2015b; Wilson, Brownstein, & Fidler, 2010), but showed how weak health systems are incapable of fulfilling the capacities of the IHR. This review provides a comprehensive assessment of the broader health system foundations required for EID preparedness, many of which do not map perfectly onto the present IHR capacities. Current IHR omissions include the core construct of *trust*, the cross-cutting element of *community engagement and empowerment*, the binding glue of *governance* in the form of health leadership, multisectoral coordination, partnership and health worker management and support, and the necessity to differentiate *subnational capacities* from those at a national level. A 2018 revision of the IHR self-assessment annual reporting tool (Kluge et al., 2018) takes a worthwhile step towards acknowledging the vital importance of strong resilient health systems for the implementation of the IHR, along with a need to integrate core capacities with essential public health functions. Further work engaging governments of LMICs is necessary to not only ensure identification of relevant preparedness capacities, but that national health system data applicable to capacity indicators are available, accessible and complete (Abimbola et al., 2017b). Developing human and institutional resources to ensure that civil servants and policy-makers are able to collect and interpret this information, and act on assessment outcomes, is also crucial.

This review suggests that important changes to health system strengthening (HSS) frameworks are needed to ensure that they reflect current challenges including health security and, at its foundation, achievement of universal health coverage (UHC). The WHO building blocks framework (World Health Organization, 2007; World Health Organization, 2010) has served a strong purpose over the last 12 years but fails to account for some critical elements identified in this research. The issue of trust has been highlighted in this review; this accords with the revised building blocks framework of de Savigny and Adam which puts 'people' at the centre (de Savigny & Adam, 2009). Our emphasis on communication mechanisms is not currently captured under any building block and also highlights the need for a more person-centred framing of HSS that aligns better with UHC. This review also frames governance as the mortar that binds all other components together – rather than as a standalone building block – acknowledging that HSS is not an apolitical technical exercise but rather intensely complex. Kieny and colleagues (Kieny, Evans, Schmets, & Kadandale, 2014) added additional intermediary objectives to HSS including resilience and sustainability to try to integrate health security challenges; while those terms are somewhat contested (Abimbola & Topp, 2018), they do reflect the need for revamping HSS frameworks to better reflect the complex and dynamic interactions driving health systems performance. Encouragingly, public health preparedness is now firmly placed within the 'sustainability and resilience' action domain of the UHC Action Framework of the WHO Western Pacific Regional Office (World Health Organization, 2016), signalling the transition to embedding health security into the strengthening of health systems more broadly.

Conclusion

The critical next step for EID preparedness is occurring in LMICs as they grapple with how to strengthen their health systems to prevent and respond to outbreaks in the context of significant resource constraints. The revised IHR self-assessment tool (Kluge et al., 2018) helps in this regard, and we believe that the emphasis on system 'software' that was highlighted by this review of the literature provides an important additional element for success. Indeed, the findings presented here may provide the basis for refining a set of indicators for an 'optimised', context-adaptable EID health system preparedness tool able to be used by governments for monitoring and planning

health system strengthening efforts at both national and sub-national levels. To this end, the research team involved in this review is now working with partners in the Pacific region to refine and adapt this framework to aid IHR compliance and sub-national system strengthening for EID preparedness.

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