CO-ACTION PUBLISHING

First experiences in the implementation of biometric technology to link data from Health and Demographic Surveillance Systems with health facility data

Adwoa Serwaa-Bonsu[1], Abraham J. Herbst[2]*, Georges Reniers[3,4], Wilfred Ijaa[5], Benjamin Clark[3], Chodziwadziwa Kabudula[3] and Osman Sankoh[6]

[1]School of Technology, Ghana Institute of Management and Public Administration, Accra, Ghana; [2]Africa Centre for Health and Population Studies, UKZN, South Africa; [3]Agincourt HDSS, South Africa; [4]Office of Population Research, Princeton University, Princeton, NJ, USA; [5]Kisumu HDSS, Kenya; [6]INDEPTH Network Secretariat, Accra, Ghana

Background: In developing countries, Health and Demographic Surveillance Systems (HDSSs) provide a framework for tracking demographic and health dynamics over time in a defined geographical area. Many HDSSs co-exist with facility-based data sources in the form of Health Management Information Systems (HMIS). Integrating both data sources through reliable record linkage could provide both numerator and denominator populations to estimate disease prevalence and incidence rates in the population and enable determination of accurate health service coverage.

Objective: To measure the acceptability and performance of fingerprint biometrics to identify individuals in demographic surveillance populations and those attending health care facilities serving the surveillance populations.

Methodology: Two HDSS sites used fingerprint biometrics for patient and/or surveillance population participant identification. The proportion of individuals for whom a fingerprint could be successfully enrolled were characterised in terms of age and sex.

Results: Adult (18–65 years) fingerprint enrolment rates varied between 94.1% (95% CI 93.6–94.5) for facility-based fingerprint data collection at the Africa Centre site to 96.7% (95% CI 95.9–97.6) for population-based fingerprint data collection at the Agincourt site. Fingerprint enrolment rates in children under 1 year old (Africa Centre site) were only 55.1% (95% CI 52.7–57.4). By age 5, child fingerprint enrolment rates were comparable to those of adults.

Conclusion: This work demonstrates the feasibility of fingerprint-based individual identification for population-based research in developing countries. Record linkage between demographic surveillance population databases and health care facility data based on biometric identification systems would allow for a more comprehensive evaluation of population health, including the ability to study health service utilisation from a population perspective, rather than the more restrictive health service perspective.

Keywords: *biometrics*; *fingerprint*; *Health and Demographic Surveillance Systems*; *record linkage*; *INDEPTH Network*

Received: 26 October 2009; Revised: 26 January 2010; Accepted: 26 January 2010; Published: 24 February 2010

Health and Demographic Surveillance Systems (HDSSs) provide a useful framework for tracking demographic and health dynamics over time in a defined geographical area. HDSSs capture information on residence, update vital events and cover the whole or part of a district where data on all individuals, their relationships, ages as well as other attributes, are recorded longitudinally along with events affecting population dynamics including births, deaths and migrations (in and out) (1, 2). In addition, most HDSS sites monitor causes of death as a major indicator of population health (1), and capture several types of socio-economic data, including household wealth and education status, as additional information for evaluating population health profiles (3).

In most cases, health care facilities are located within the HDSS surveillance areas. In some cases, facility-based data sources in the form of Health Management Information Systems (HMIS), which capture health services attendance, diagnosis, service and treatment data as individuals come in contact with the formal health system for either preventive or curative services, exist in these health facilities (1, 4, 5). Although the HDSS and HMIS co-exist within the same population, they do so independently of each other. This limits the ability to use the HDSS population as denominator and source of explanatory variables when analysing health facility-based observations. Integrating the two data sources would provide the numerator and the denominator populations for computation of disease incidence and prevalence rates in the population. It would also assist in calculating accurate health service coverage. The HDSS also provides information at individual, household and community levels to serve as explanatory variables when analysing health facility-based data. These are essential ingredients for health system analysis, health planning and policy formulation, but are currently lacking (6, 7), particularly in developing countries (2, 8, 9).

This paper describes an approach to link HDSS and HMIS data systems to improve the utility and value of data from both systems to evaluate health interventions, and to eventually gain a deeper understanding of the impact of district health systems on the health of populations in low- and middle-income countries.

Record linkage

Record linkage (10) is the bringing together from different sources of two or more records relating to the same individual, family, event or entity and is widely used in health research (11–18). There are two main types of record linkage: deterministic record linkage links pairs of records on the basis of whether they agree on specific identifiers, and is possible whenever there is a unique identifier, such as a personal identification code in both sources (13). Probabilistic record linkage uses probabilities to determine whether a pair of records refers to the same individual (19), based on the degree of matching between several individual characteristics, such as names, sex, date of birth and address.

In some developed countries, social security numbers are used as the principal means of deterministic record linkage, in addition to demographic information such as names, date of birth, sex and address for probabilistic record linkage purposes (20–22). However, in developing countries these techniques for record linkage are not appropriate as most of these countries do not have any standardised form of identification such as social security numbers. Moreover, due to the high rates of illiteracy in these parts of the world it is difficult for a person to provide accurate information regarding date of birth, address or standardised form and spelling of names. The majority of developing countries do not have a proper house and street addressing system in place, especially in rural areas. High migration rates further complicate matters.

Biometric technologies have been proposed as a possible technological solution for these issues due to its ability to provide a mechanism for unique verification of an individual's identity (23, 24). Biometrics refers to the automatic identification of a person based on his/her physiological (e.g. face, fingerprint, iris, retina, hand geometry) or behavioural characteristics (e.g. signature, gait) (25). Biometrics is gradually becoming an essential part of effectively identifying a person because biometric identifiers cannot be shared, exchanged with another individual or misreported, and they essentially represent the individual's bodily identity. Due to its convenience, individuality and efficiency, fingerprint recognition has become the identification method of choice (26). Example applications of fingerprint-based biometric systems include building access systems, automated teller machine (ATM) authentication and welfare disbursements (27, 28).

There are a few reports of fingerprint biometrics use in the health field: the SonLa Study Group (24) used fingerprint recognition technology for the identification of clinical trial participants among teachers and students at a nursing college in Vietnam. They found the system simple to use and recommended that fingerprint recognition should become the standard technology for identification of participants in field trials. Weibel reported the use of fingerprint biometrics to identify mobile pastoralists in Chad and obtained a fingerprint enrolment rate of 89.9% among adult women (29). Yu reported the use of fingerprint biometrics in antiretroviral therapy (ART) patients, but gave no details on fingerprint enrolment rates (30).

INDEPTH is an international network of 34 HDSS sites in 17 countries in sub-Saharan Africa, Asia and Oceania (31). INDEPTH funded a workshop on the application of biometric technology in early March 2009 at the Africa Centre for Health and Population Studies in Somkhele, South Africa, during which the sites shared their plans and experience in using biometric technology for individual identification and record linkage. The discussion in this paper is a result of the workshop and we analyse the experience at three INDEPTH sites that have used fingerprint biometrics to show the range of

Citation: Global Health Action 2010, **3**: 2120 - DOI: 10.3402/gha.v3i0.2120

intended use of this technology as well as results to explore its acceptability and technical value.

Methodology

Three INDEPTH member sites (Africa Centre, South Africa (32), Agincourt, South Africa (33) and Kisumu, Kenya (34)) have used fingerprint biometrics for patient and/or surveillance population participant identification. At two of the sites (Africa Centre and Agincourt), sufficiently detailed data were collected to assess the feasibility and acceptability of electronically collected fingerprints as a means of identification. The general approach to individual identification followed by these sites was as follows:

(1) *Patient registration and fingerprint capture at health care facility.* A fingerprint reader was used to scan and enrol the patient's fingerprints. Before patient registration was done, the system searched the database for a matching fingerprint, and if the record existed, the system prompted the health worker that the patient in question was already in the system. If no such record existed, the system generated a unique identifier linked with the scanned fingerprint. This identifier allowed the anonymised confidential matching at a later stage to individuals in the HDSS population database, by eliminating the need to use names or other personally identifiable information in the record linkage process.
(2) *Fingerprint collection from HDSS population.* Fingerprints were recorded from individuals during routine surveillance visits using handheld computers.
(3) *Consent for record linkage.* Consent was obtained from the individuals at the time of fingerprint collection to link their HDSS data to their health care data based on the fingerprint scan.
(4) *Link HDSS ID (and consequently HDSS information) with health facility data.* By using the fingerprint templates collected both at the health care facilities and during population surveillance visits, individual records could be linked. None of the three participating sites have reached this phase of the record linkage process at the time of writing.

Fingerprint enrolment rates (35) are used to report the proportion of participants eligible for fingerprint collection where a fingerprint is successfully recorded. Failure to enrol could be due to the following:

(1) Although eligible, the participant was not requested to provide a fingerprint, e.g. a patient attending a health care facility bypassed the patient registration process, or in the case of HDSS surveillance, the individual could not be contacted.
(2) The participant refused to provide a fingerprint.
(3) The participant was unable to present the required finger/s for enrolment due to physical constraints, such as finger amputations or injuries.
(4) The fingerprint reader or computer system malfunctioned due to hardware of software failures.
(5) The fingerprint reader was unable to capture an image of sufficient quality for successful fingerprint template extraction.

In the reported case studies, failure to enrol fingerprints was due to a combination of these factors and the particular cause was not recorded in all cases. Due to the requirement for portability and independence from electrical power, fingerprint collection during household surveillance presents additional technical challenges, such as limited support for fingerprint readers and proprietary software on handheld computers. However, the availability of cheap and lightweight netbook portable computers running standard operating systems and with adequate battery life allows the use of devices and software similar or identical to those deployed in health care facilities.

The Africa Centre for Health and Population Studies, South Africa

The Africa Centre, University of KwaZulu-Natal, is a demographic surveillance site in the southern part of the Umkhanyakude district of the KwaZulu-Natal province of South Africa (32). The Africa Centre has been using fingerprint biometrics for patient identification in an electronic medical record system since 2007 and is currently evaluating its potential use to link the records of surveillance participants and health care service users.

The Africa Centre has developed a primary care information system (PCIS) based on the OpenMRS electronic medical record specification. OpenMRS is a collaborative open source project to develop software to support the delivery of health care in developing countries (36, 37). The PCIS system is used in all six of the primary health care clinics serving the surveillance population and is part of the routine recordkeeping system in those clinics.

Upon registration at the clinic, fingerprint scans of the left and right thumbs are obtained from the patient. Alternative fingers are used if either of the thumbs cannot be scanned successfully. In children under 3 years of age, heels are scanned using the same fingerprint reader used for older patients, if their thumbs cannot be scanned successfully. Heels have similar ridge patterns to fingers, but in young children offer a larger surface area and more prominent ridges than finger tips, increasing the chances for successful enrolment.

The reported enrolment rates refer to the proportion of patients with a valid fingerprint record of all patients registered at the participating clinics over the period 1 January 2009 to 30 September 2009. No patient refusals were reported and inability to enrol was due either to failure to successfully scan a finger or to system failures. System failures were due mainly to fingerprint device driver incompatibilities, fingerprint reader hardware malfunction or operator failure to request and record a fingerprint. The reason for failure to enrol fingerprints in individual cases was not recorded because the PCIS, as a routine health information system, does not make provision for the capture of this information.

Agincourt, South Africa

Agincourt is a health and demographic surveillance site in the north-eastern part of the Mpumalanga province of South Africa (33). The main purpose of their use of fingerprint biometrics is the linkage of health facility records and the Agincourt Health and Demographic Surveillance System (AHDSS) database. The research infrastructure is being developed to study the coverage of health services programmes and the (self-) selection of individuals under demographic surveillance into seeking care. Linked databases will be used to study the utilisation of voluntary counselling and testing (VCT) and ART services, but the record linkage methodology is generic and can be extended to other services. The AHDSS-clinic link provides the data platform to conduct and evaluate community-based interventions to increase the uptake of medical services. The data-linkage methodology and experiences with collecting fingerprints at the household level will later be used to inform other AHDSS projects (e.g., migration reconciliation).

The fingerprint technology was utilised to construct a gold standard of matched records across data collection systems against which probabilistic record linkage on ordinary identifiers (e.g. name, sex, date of birth, village) could be validated.

The community-based fingerprinting in Agincourt village section of the surveillance area started in November 2008 and ran through February 2009. Fingerprinting in the Agincourt Health Centre is ongoing. In what follows, we only report on the fieldwork experience of the community-based fingerprinting.

For the enrolment process, fingerprints of the left and right index fingers and thumbs were collected. The reported enrolment rate is the proportion of participants where a valid fingerprint was recorded for all participants older than 18 years of age who were contacted for fingerprint collection. Failure to enrol was due to participant refusal and the inability to successfully scan any finger.

Kisumu, Kenya

Kisumu is a health and demographic surveillance site (HDSS) in the Siaya and Bondo districts of Western Kenya (34). The US Center for Disease Control and Prevention and Kenya Medical Research Institute (CDC/KEMRI) organisation has several studies of diseases such as malaria and tuberculosis, with thousands of participants enrolling in those studies. Kisumu investigated the use of fingerprint-based identification systems as a potential solution to the following situations:

(1) Each study assigns its participants a study number (identification number). Individuals can be enrolled in more than one study. It is difficult to consistently identify study participants due to misplaced identity cards, identifying and searching non-study participants and name similarities. Some clinical trial studies do not allow cross-study participation, and in these cases limitation in participant identification compromised the process.
(2) The high rate of migration in the demographic surveillance area creates a problem to reconcile in-migrants with their surveillance records in cases where they were former residents in the surveillance area. A more reliable means of identification would reduce duplication of surveillance records.
(3) The need to link the patients in the hospitals with the HDSS participants for studies of health service utilisation.

At the time of writing, fingerprint-based identification was collected in three health care facilities. For the fingerprint enrolment process, the left thumb print is enrolled first, if enrolment fails, the right thumb print is enrolled. Lack of sufficiently detailed denominator data prevented the data from this site from being included in the analysis.

The equipment and software used by each site is summarised in Table 1.

In all three sites, ethical clearance for the studies was obtained from their respective ethics review committees and the relevant health authorities.

Results

In the health care facility-based data collection at the Africa Centre, an average enrolment rate of 88.1% (95% CI 87.6–88.6) was achieved, with the lowest enrolment rate in children under the age of 1 year (55.1% CI 52.7–57.4), in 17,031 patients attending the six study clinics between 1 January and 30 September 2009 (Fig. 1). Enrolment rates increased with age, but decreased again in the older age groups, reaching 88.9% (CI 86.3–91.5) in the 65 years and older age group (Table 2). The only significant difference in enrolment rates by sex was in the age group 18–64, where the enrolment rate in women (95.2% CI 94.7–95.7) was higher than that in men (91.1% CI 90.0–92.2). The proportion of children where finger scans were unsuccessful and where heel scans were

Citation: Global Health Action 2010, 3: 2120 - DOI: 10.3402/gha.v3i0.2120

Table 1. System specifications

Site	Country	Population under surveillance	Fingerprint scanning device	Fingerprint processing library	Host computer
Africa Centre	South Africa, Northern Kwazulu-Natal	95,000	Secugen Hamster Plus and IV	Griaule Fingerprint SDK 2009	Microsoft Windows XP Tablet Edition and Microsoft Vista, SQL Server database
Agincourt	South Africa, Mpumalanga	85,000	Sagem MorphoSmart CBM	Proprietary Sagem Library	Tripod Data Systems Recon, operating system Windows Mobile 6.0 and SQL Server CE database
Kisumu	Kenya	135,000	Microsoft Fingerprint Reader	Griaule Fingerprint SDK 2009	Laptop computer, Windows XP SP2, SQL Server database

required decreased with age, with the highest proportion requiring heel scans in children under two months of age (96.6% CI 94.4–99.3). By age 4, heel scans were no longer required and by age 5, enrolment rates approached those of adults.

Civilian identity numbers were recorded in the PCIS for 3% of children under 18 years and in 26.3% of adults 18 years and older, limiting the use of identity numbers for deterministic record linkage. Experience with probabilistic record linkage between clinic records and demographic surveillance records in a mostly adult population in another study at the Centre indicated that approximately 30% of cases could be matched directly based on names, sex and date of birth, with a further 20–30% matched after further inspection by an operator (C. Newell, Personal communication, October 2009). In another exercise, matching mothers and infants enrolled in a study of mother-to-child transmission of HIV-1 (38) to their demographic surveillance records, 52% of women were matched. In matched women, 86% of the infants could be matched (R. Bland, Personal communication, October 2009).

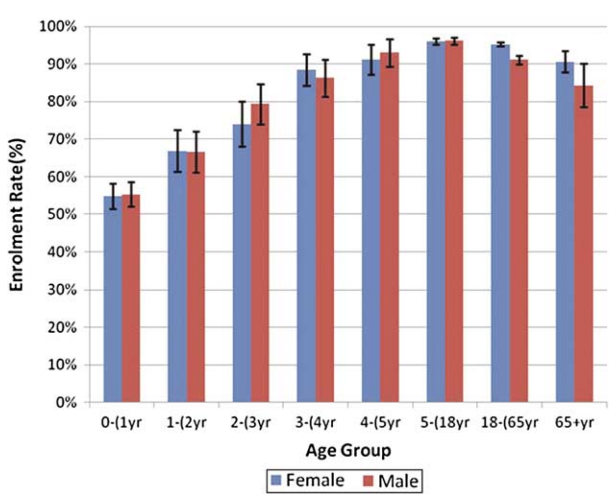

Fig. 1. Fingerprint enrolment rates by age group and sex at Africa Centre ($n = 17{,}031$).

In a population-based data collection at Agincourt, there were 2,584 eligible individuals aged 18 years and older, of whom 2,145 (83%) were contacted. The overall fingerprint enrolment rate among those contacted was 96.6% (95% CI 95.8–97.4). A significant difference was also found in the enrolment rates of women and men aged 18–64 years, with an enrolment rate in women of 97.8% (CI 96.9–98.6) compared to 94.7% (CI 92.7–96.5) in men (Table 3). Failure to enrol was due to refusal (3% of males and 1% of females), and technical problems with the collection of the fingerprint itself prevented enrolment in 2.1 and 1.5% of males and females, respectively. During fieldwork it was noted that direct sunlight negatively affected the ability to obtain a successful fingerprint scan, this was subsequently addressed by recording the finger in a shady area.

Discussion

The results from the South African sites show that high levels of fingerprint enrolment can be obtained both in the health care context (Africa Centre) and at community level during routine surveillance visits (Agincourt). Although none of the sites has yet progressed to actual record linkage based on the collected fingerprint templates, the technical feasibility and acceptability of collecting fingerprints in health care facility and household contexts have been confirmed. At the Africa Centre, the availability of valid fingerprint identification outstripped the availability of civilian identity numbers as a basis for deterministic record linkage. In adults and older children, where the enrolment rates were uniformly high, fingerprint matching has the potential to outperform probabilistic record linkage based on individual demographic information hitherto used for record linkage. Contrary to the belief expressed by the SonLa Group regarding the potential of fingerprint identification in paediatric populations (24), we found lower enrolment rates in young children and infants. However, fingerprint identification could be a

Table 2. Fingerprint enrolment rates at the Africa Centre

	Population			Enrolment rate	
Age group (years)	Females	Males	Total	Females (95% CI)	Males (95% CI)
0–<1	844	918	1,762	54.7% (51.4–58.1)	55.3% (52.1–58.6)
1–<2	284	293	577	66.9% (61.4–72.4)	66.6% (61.1–72.0)
2–<3	208	218	426	74.0% (68.1–80.0)	79.4% (74.0–84.7)
3–<4	226	190	416	88.5% (84.3–92.7)	86.3% (81.4–91.2)
4–<5	193	186	379	91.2% (87.2–95.2)	93.0% (89.3–96.7)
5–<18	1,830	1,484	3,314	96.1% (95.2–97.0)	96.2% (95.2–97.1)
18–<65	6,891	2,709	9,600	95.2% (94.7–95.7)	91.1% (90.0–92.2)
65+	404	153	557	90.6% (87.7–93.4)	84.3% (78.5–90.1)
Total	10,880	6,151	17,031	90.2% (89.6–90.7)	83.9% (83.5–85.3)

useful adjunct to other means of identification, such as patient demographic details, especially when combined with fingerprint-based identification of accompanying adults (29).

In the South African HDSS sites, the acceptability of fingerprint identification has been high, perhaps because the government uses the same technology to identify grantees in its old-age pension grant scheme, thereby reducing any negative connotations fingerprinting may carry. The acceptability of the use of fingerprint technology in health and demographic research will increase as countries continue to apply the technology to other uses, such as electronic payment systems, which require fingerprints. For instance, in Ghana (39), the use of a nationwide electronic payment system, called E-ZWICH, is being implemented for which fingerprints of users are stored on a smart card. The possibility of forensic use of the recorded fingerprint templates exists, even though no actual fingerprint image is stored, it might be possible to derive a fingerprint template from a latent fingerprint image and match such a template to the stored templates.

Difficulties encountered in successful enrolment included scars and cuts of the fingers, limiting the ability to scan multiple fingers (5.9 and 3.6% of contacted males and females, respectively, at Agincourt). In concert with information technology in general, fingerprint scanning technology is developing rapidly, with new scanning technology released frequently. This complicates the operational requirement to maintain stable systems due to device and software incompatibilities, with subsequent negative impact on enrolment rates as experienced at the Africa Centre.

Fingerprints are generally accepted as unique between individuals, although this assertion has been questioned (40), the probability of two different individuals having identical fingerprints is extremely low (41) and of little practical significance for record linkage. Of greater relevance are the effects of fingerprint image quality, variability in fingerprint scans between different operators and at different time points and the performance of the fingerprint matching algorithms on the sensitivity and specificity of fingerprint matching (26). As a result, the high fingerprint enrolment rates reported for certain age groups in this research will not necessarily translate into high record linkage rates, and further research is required to assess the implication of these factors on the performance of fingerprint biometrics for record linkage and individual identification in health and demographic research.

Conclusion

The experiences of the three INDEPTH sites presented in this paper have demonstrated the potential uses of biometric technology in health and demographic surveillance research in the developing world and its feasibility as a means of individual identification. Improved

Table 3. Fingerprint enrolment rates at Agincourt

	Population			Enrolment rate	
Age group (years)	Females	Males	Total	Females (95% CI)	Males (95% CI)
18–64	1,203	602	1,805	97.8% (96.9–98.6)	94.7% (92.9–96.5)
65+	233	107	340	95.7% (93.1–98.3)	96.3% (92.7–99.9)
Total	1,436	709	2,145	97.4% (96.6–98.2)	94.9% (93.3–96.5)

Citation: Global Health Action 2010, **3**: 2120 - DOI: 10.3402/gha.v3i0.2120

individual identification in health and demographic surveillance sites will improve data quality and will facilitate the linking of HDSS and health facility data. This will allow for a more comprehensive evaluation of the health of the people under surveillance, including the ability to study health service utilisation from a population perspective, rather than the more restrictive health service perspective. As electronic medical record systems find broader acceptance in the developing countries, the potential of record linkage based on patient biometrics will increase. The INDEPTH Network will continue to collect evidence on effective surveillance technologies and to support their introduction at member sites.

Acknowledgements

This paper is a result of a workshop on biometrics held at the Africa Centre in South Africa, funded by the INDEPTH Network. INDEPTH acknowledges support from its core funders: Sida/GLOBFORSK, Bill & Melinda Gates Foundation, Rockefeller Foundation, The Wellcome Trust and The William & Flora Hewlett Foundation. The contribution of the following workshop participants in formulating the ideas expressed in this paper is acknowledged: Henry Mwanyika, Felix Kondayire, Cheik Bagagnan, Delino Nhalungo, Messias Mandua, Somnath Sambhudas, Kwabena Owusu-Boateng, Samuel Danso, Nkosinathi Ngwane and Francis Ameni. Thanks to Marie-Louise Newell for her comments on drafts of the paper.

Conflict of interest and funding

The biometrics research at the Africa Centre is funded by the Atlantic Philanthropies and the demographic surveillance by the Wellcome Trust. The Agincourt HDSS is supported by the Wellcome Trust (Grant No. 085477/Z/08/Z), the Andrew W. Mellon Foundation, the University of the Witwatersrand and the South African Medical Research Council. The AHDSS-clinic link pilot is funded in part through two grants to the University of Colorado, a US National Institutes of Health Grant (NIH 1R24AG032112) with subcontract to the University of the Witwatersrand, and a William & Flora Hewlett Foundation Grant (2006-8377). The Kisumu HDSS is funded by the US Centers for Disease Control and Prevention (CDC), Bill & Melinda Gates Foundation, EDCTP, Aeras Global TB Foundation, in collaboration with the Kenya Medical Research Institute (KEMRI).

References

1. INDEPTH Network. Population and health in developing countries. Population, health and survival at INDEPTH sites. Vol. 1. Ottawa: International Development Research Centre; 2002.
2. Sankoh O, Binka F. INDEPTH Network: generating empirical population and health data in resource-constrained countries in the developing world. In: Becher H, Kouyaté B, eds. Health research in developing countries: a collaboration between Burkina Faso and Germany. Berlin: Springer; 2005, pp. 21–32.
3. INDEPTH Network. Measuring health equity in small areas: findings from demographic surveillance systems. Aldershot, UK and Burlington, VT: Ashgate; 2005.
4. Adazu K, Lindblade KA, Rosen DH, Odhiambo F, Ofware P, Kwach J, et al. Health and demographic surveillance in rural western Kenya: a platform for evaluating interventions to reduce morbidity and mortality from infectious diseases. Am J Trop Med Hyg 2005; 73: 1151–8.
5. Tanser F, Gijsbertsen B, Herbst K. Modelling and understanding primary health care accessibility and utilization in rural South Africa: an exploration using a geographical information system. Soc Sci Med 2006; 63: 691–705.
6. Brownson RC, Fielding JE, Maylahn CM. Evidence-based public health: a fundamental concept for public health practice. Annu Rev Public Health 2009; 30: 175–201.
7. Handler A, Issel M, Turnock B. A conceptual framework to measure performance of the public health system. Am J Public Health 2001; 91: 1235–9.
8. McMichael C, Waters E, Volmink J. Evidence-based public health: what does it offer developing countries? J Public Health (Oxf) 2005; 27: 215–21.
9. Wynn BO, Dutta A, Nelson MI, RAND Center for Domestic and International Health Security. Challenges in program evaluation of health interventions in developing countries. Santa Monica, CA: RAND Center for Domestic and International Health Security; 2005.
10. Winkler WE. The state of record linkage and current research problems. Washington, DC: Statistical Research Division, US Bureau of the Census; 1999.
11. Chamberlayne R, Green B, Barer ML, Hertzman C, Lawrence WJ, Sheps SB. Creating a population-based linked health database: a new resource for health services research. Can J Public Health 1998; 89: 270–3.
12. Clark DE. Practical introduction to record linkage for injury research. Inj Prev 2004; 10: 186–91.
13. Machado JC. A literature review of record linkage procedures focusing on infant health outcomes. Cad Saude Publ 2004; 20: 362–71.
14. Schneeweiss S, Avorn J. A review of uses of health care utilization databases for epidemiologic research on therapeutics. J Clin Epidemiol 2005; 58: 323–37.
15. Wirehn AB, Karlsson HM, Carstensen JM. Estimating disease prevalence using a population-based administrative healthcare database. Scand J Public Health 2007; 35: 424–31.
16. Connell FA, Diehr P, Hart LG. The use of large data bases in health care studies. Annu Rev Public Health 1987; 8: 51–74.
17. Sibthorpe B, Kliewer E, Smith L. Record linkage in Australian epidemiological research: health benefits, privacy safeguards and future potential. Aust J Public Health 1995; 19: 250–6.
18. Sorensen HT, Sabroe S, Olsen J. A framework for evaluation of secondary data sources for epidemiological research. Int J Epidemiol 1996; 25: 435–42.
19. Fellegi IP, Sunter AB. A theory for record linkage. J Am Stat Assoc 1969; 64: 1183–210.
20. Sorensen HT, Sabroe S, Olsen J, Rothman KJ, Gillman MW, Fischer P. Birth weight and cognitive function in young adult life: historical cohort study. BMJ 1997; 315: 401–3.
21. Weber GI, ed. Achieving a patient unit record within electronic record systems. Toward an electronic patient record, 14–19 March 1995, Orlando, FL.
22. Bakketeig LS. Perinatal epidemiology – a Nordic challenge. Scand J Soc Med 1991; 19: 145–7.
23. Zuniga AEF, Win KT, Susilo W. Biometrics for electronic health records. J Med Sys 2009. DOI: 10.1007/s10916-009-9313-6.

24. The SonLa Study Group. Using a fingerprint recognition system in a vaccine trial to avoid misclassification. Bull World Health Organ 2007; 85: 64–7.
25. Jain AK, Pankanti S, Prabhakar S, Hong L, Ross A, Wayman JL. Biometrics: a grand challenge. International Conference on Pattern Recognition, Cambridge, UK, 23–26 August 2004, pp. 935–42.
26. Maltoni D, Jain AK, Prabhakar S. Handbook of fingerprint recognition, 2nd ed. London: Springer; 2009.
27. Yager N, Amin A. Fingerprint verification based on minutiae features: a review. Pattern Anal Appl 2004; 7: 1433–7541.
28. Stone M. Talking body language. Brainstorm Magazine; February 2005.
29. Weibel D, Schelling E, Bonfoh B, Utzinger J, Hattendorf J, Abdoulaye M, et al. Demographic and health surveillance of mobile pastoralists in Chad: integration of biometric fingerprint identification into a geographical information system. Geospat Health 2008; 3: 113–24.
30. Yu KL, Chen CC, Chang WS, Juma H, Chang CS. Fingerprint identification of AIDS patients on ART. Lancet 2005; 365: 1466.
31. INDEPTH Network 2009 [updated 2009]. Available from: http://www.indepth-network.org/ [cited 14 August 2009].
32. Tanser F, Hosegood V, Barnighausen T, Herbst K, Nyirenda M, Muhwava W, et al. Cohort profile: Africa Centre Demographic Information System (ACDIS) and population-based HIV survey. Int J Epidemiol 2008; 37: 956–62.
33. Kahn K, Tollman SM, Collinson MA, Clark SJ, Twine R, Clark BD, et al. Research into health, population and social transitions in rural South Africa: data and methods of the Agincourt Health and Demographic Surveillance System. Scand J Public Health Suppl 2007; 69: 8–20.
34. HDSS K. Kisumu profile. Available from: www.indepth-network.org/dss_site_profiles/kisumuprofile.pdf [cited 21 August 2009].
35. Mansfield AJ, Wayman JL. Best practices in testing and reporting performance of biometric devices. Ver 2.01. National Physical Laboratory; 2002.
36. Seebregts CJ, Mamlin BW, Biondich PG, Fraser HS, Wolfe BA, Jazayeri D, et al. The OpenMRS Implementers Network. Int J Med Inform 2009; 78: 711–20.
37. Wolfe BA, Mamlin BW, Biondich PG, Fraser HS, Jazayeri D, Allen C, et al. The OpenMRS system: collaborating toward an open source EMR for developing countries. AMIA Annu Symp Proc 2006: 1146.
38. Coovadia HM, Rollins NC, Bland RM, Little K, Coutsoudis A, Bennish ML, et al. Mother-to-child transmission of HIV-1 infection during exclusive breastfeeding in the first 6 months of life: an intervention cohort study. Lancet 2007; 369: 1107–16.
39. France F, Selormey D. Biometrics improving financial accessibility. Biometr Technol Today 2009, 2009: 10–11.
40. Kaye DH. Questioning a courtroom proof of the uniqueness of fingerprints. Int Stat Rev 2003; 71: 521–33.
41. Cole SA. History of fingerprint pattern recognition. In: Ratha N, Bolle R, eds. Automatic fingerprint recognition systems. Berlin: Springer; 2003, pp. 1–25.

***Dr Abraham J. Herbst**
The Africa Centre for Health and Population Studies
UKZN, PO Box 198
Mtubatuba
3935, South Africa
Email: kherbst@africacentre.ac.za

Citation: Global Health Action 2010, **3**: 2120 - DOI: 10.3402/gha.v3i0.2120