Sensitivity of hospital-based surveillance for severe disease: a geographic information system analysis of access to care in Kilifi district, Kenya

Jennifer C Moisi,a D James Nokes,a Hellen Gatakaa,a Thomas N Williams,a Evasius Bauni,a Orin S Levineb & J Anthony G Scotta

Objective To explore the relationship between homestead distance to hospital and access to care and to estimate the sensitivity of hospital-based surveillance in Kilifi district, Kenya.

Methods In 2002–2006, clinical information was obtained from all children admitted to Kilifi District Hospital and linked to demographic surveillance data. Travel times to the hospital were calculated using geographic information systems and regression models were constructed to examine the relationships between travel time, cause-specific hospitalization rates and probability of death in hospital. Access to care ratios relating hospitalization rates to community mortality ratios were computed and used to estimate surveillance sensitivity.

Findings The analysis included 7200 admissions (64 per 1000 child-years). Median pedestrian and vehicular travel times to hospital were 237 and 61 minutes, respectively. Hospitalization rates decreased by 21% per hour of travel by foot and 28% per half hour of travel by vehicle. Distance decay was steeper for meningitis than for pneumonia, for females than for males, and for areas where mothers had less education on average. Distance was positively associated with the probability of dying in hospital. Overall access to care ratios, which represent the probability that a child in need of hospitalization will have access to care at the hospital, were 51–58% for pneumonia and 66–70% for meningitis.

Conclusion In this setting, hospital utilization rates decreased and the severity of cases admitted to hospital increased as distance between homestead and hospital increased. Access to hospital care for children living in remote areas was low, particularly for those with less severe conditions. Distance decay was attenuated by increased levels of maternal education. Hospital-based surveillance underestimated pneumonia and meningitis incidence by more than 45% and 30%, respectively.

Abstracts in العربية, 中文, Français, Русский and Español at the end of each article.

Introduction

In addition to a focus on the Millennium Development Goals – specifically Goal 4, which aims for a two-thirds reduction in under-5 mortality between 1990 and 2015 – the child survival agenda in developing countries is increasingly driven by equity considerations.12 Regional and country-level analyses have investigated the socioeconomic and spatial determinants of health inequities and have demonstrated that lower-income and rural populations frequently experience worse child survival rates than their wealthier, more urban counterparts.3–6 However, limited data are available at the district level to help identify geographic inequities in health outcomes and target the delivery of services to disadvantaged populations.7,8

In rural settings with a low density of health facilities, physical access to sources of care is a known determinant of health-care utilization, with substantial decreases in rates of clinic attendance observed with increasing distance from the homestead to the clinic;11–13 this phenomenon is frequently termed “distance decay.” However, studies have not directly linked distance to health facilities to morbidity rates in the community. High utilization rates in areas close to clinics could therefore partially reflect higher rates of disease rather than better access, as would be the case, for example, if deliberately or coincidentally sicker people lived closer to clinics or if clinics were located in areas of higher disease risk.

Moreover, distance decay is generally less marked for hospitals providing inpatient services than for primary care clinics,11,15,20 suggesting that disease severity may modulate the effect of distance on care-seeking and ultimately limit its impact on mortality. In Kilifi district, Kenya, we found no effect of distance to hospitals or vaccine clinics on child mortality,21 a finding consistent with the results of a study from the Gambia,22 but not with analyses from rural areas of Burkina Faso,23 the Democratic Republic of the Congo24 or the United Republic of Tanzania.25

Regardless of their impact on mortality, physical and other barriers to health care seeking are widely assumed to lead to incomplete disease ascertainment in hospital and to limit the sensitivity of hospital-based surveillance. Disease incidence rates observed in sentinel surveillance systems therefore systematically underestimate the true incidence of disease, and this complicates national and global disease burden estimation. Measuring access to care may enable us to evaluate the sensitivity of surveillance and improve on current estimates of disease burden.

In this study we aimed to characterize spatial variations in hospitalization rates in Kilifi district for several diseases, identify areas with low utilization of inpatient services, and link this...
information to mortality rates to define access to care parameters by health condition and geographic area and estimate the sensitivity of hospital-based surveillance.

Methods
This analysis relied on data collected routinely by the Epidemiologic and Demographic Surveillance System (Epi-DSS) of the KEMRI-Wellcome Trust Research Programme in Kilifi district, Kenya. The Epi-DSS includes a demographic surveillance system covering an area measuring 900 km² around Kilifi District Hospital (KDH) linked to hospital-based epidemiological surveillance.

Study site
Kilifi district is a poor, primarily rural district on the Indian Ocean coast of Kenya that enjoys a tropical climate, with two rainy seasons and two dry seasons each year. Mortality in children less than 5 years of age has decreased in recent years but remains high at 65 deaths per 1000 live births.21 KDH serves as a primary care centre and first-level referral facility for the entire district. Inpatient care is available at three other hospitals in Kilifi district, at Malindi District Hospital in Malindi and at Coast Provincial General Hospital in Mombasa. For most residents of the study area, KDH is the nearest facility offering inpatient care.

Demographic and clinical data
Demographic surveillance was initiated in 2000 to track births, deaths and migrations in a target population of 250,000 people. After the initial census, two to three enumeration rounds were conducted each year. Each resident received a unique personal identifier. From 16 April 2002 onwards, hospital and laboratory records including standard clinical data for all admitted children were linked to demographic records for Epi-DSS area residents based on personal identifier. This enabled us to determine the exact residency of each patient at the time of hospitalization. All data were entered into FileMaker 5.5 (FileMaker Inc., Santa Clara, United States of America), and cleaned in Stata 9.2 (StataCorp LP, College Station, USA).

Mapping and travel time
The Epi-DSS area was mapped using Magellan (Magellan Navigation Inc., Santa Clara, USA) and e-Trex (Garmin Ltd, Olathe, USA) geographic positioning systems (GPS) technology, which provided information on topography, footpaths and roads and on the human occupation of the area, including the coordinates of all homesteads. We mapped the location of maternal and child health (MCH) facilities offering inpatient care.

Endpoints and case definitions
We investigated the effects of travel time to KDH on all-cause hospitalization and on hospitalizations for pneumonia and suspected meningitis. Pneumonia was categorized as mild, severe or very severe. Mild pneumonia was defined as a history of acute cough or difficulty breathing plus an elevated respiratory rate (RR) for age (RR ≥ 50 breaths per min in children 0 to 11 months old and ≥ 40 breaths per min in those 12 to 59 months old), severe pneumonia as a history of cough or difficulty breathing plus lower chest wall indrawing, and very severe pneumonia as a history of cough or difficulty breathing plus hypoxia, lethargy, loss of consciousness, prostration or a history of convulsions.26 Suspected meningitis required one or more of the following signs: stiff neck, bulging fontanelle in children < 1 year of age, lethargy, loss of consciousness, prostration or history of convulsions (any seizure in children < 6 months of age; any partial seizure or at least two generalized seizures over the previous 24 hours in children 6–59 months of age).

Other variables of interest
Other variables of interest were ethnicity, maternal education, migration and time. Ethnicity data were collected routinely by the Epi-DSS. The majority ethnic groups in Kilifi district are of Mijikenda origin and include the Giriama and the Chonyi. Ethnic groups with less than 40 deaths during the study period were combined under the category “other.” Maternal education data were collected from all residents in 2004. We calculated the proportion of women 15–49 years old with any schooling in each administrative sublocation and used it to generate a sublocation-level categorical variable (proportion of mothers with any education < 0.5; 0.5 to < 0.6; 0.6 to < 0.7; and ≥ 0.7), which was then applied to individuals based on their residence. For migration, children whose mothers had migrated at least once from outside the Epi-DSS area between 2000 and 2006 were considered migrants. Finally, we analysed seasonal and annual trends in hospitalizations. Mean daily rainfall in Kilifi during the rainy season (April to June and October to November) was ≥ 5 mm between 2000 and 2006.

Data analysis
For each condition, we calculated admission rates per 1000 child-years (allowing multiple admissions per child) by pedestrian and vehicular travel time to hospital and by administrative location, as well as by sex, ethnic group, maternal education, migrant status, season and year for children < 5 years of age. We constructed log-linear regression models to identify predictors of the incidence of admission to KDH and logistic regression models to investigate risk factors for death in admitted children. To account for spatial clustering of disease events in these models, we used a spatial bootstrap method with 50 repetitions, randomly selecting 40 sublocations (with replacement) and estimating the regression model on all data from the selected sublocations in each repetition. The incidence analysis was restricted to 2004 through 2006, a period for which ascertainment of person–time by the Epi-DSS was complete. The case fatality ratio analysis used data from 2002 onwards, since it did not...
Fig. 1. Pedestrian and vehicular travel time to Kilifi District Hospital and incidence of hospitalization for Kilifi Epi-DSS residents less than 5 years of age, by administrative location, Kilifi district, Kenya, 2004–2006.

Epi-DSS, Epidemiologic and Demographic Surveillance System.
Source of map: KEMRI/Wellcome Trust Epi-DSS in Kilifi.
require population-based denominators. All analyses were conducted in Stata 9.2.

For each pedestrian and vehicular travel time stratum we computed the ratios of both the pneumonia and the suspected meningitis hospitalization rate to the all-cause mortality rate measured in the community by the Epi-DSS \( R_p = \text{pneumonia admission rate/all-cause mortality rate} \) and \( R_m = \text{suspected meningitis admission rate/all-cause mortality rate} \). Assuming that children in the lowest stratum (stratum 0) had “perfect” access to care (e.g. that all pneumonia and meningitis cases requiring hospitalization presented to KDH and were admitted) and that the incidence of pneumonia and meningitis requiring hospitalization was directly proportional to the incidence of death, we calculated the stratum-specific probability that a child in need of hospitalization would access care at KDH (“access to care ratios”) as \( R[\text{travel time stratum}] / R[\text{stratum 0}] \) for pneumonia and suspected meningitis separately. We obtained 95% confidence intervals (CIs) by applying the delta method for variance calculation to successive log-transformations of these ratios, under the assumption that stratum-specific rates were independent. We compared the trends in pneumonia and meningitis ratios across travel time strata using the Cuzick extension to the Wilcoxon rank sum test. Access to care ratios for the entire Epi-DSS area were calculated as a weighted average of stratum-specific ratios, with person–years of observation as weights.

Ethical approval
The Kenya Medical Research Institute Ethical Review Committee and the Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved this study.

Results
Median pedestrian and vehicular travel times to hospital were 237 minutes (range: 0–514 minutes) and 61 minutes (range: 0–247 minutes), respectively, and 90% of children lived less than 6.5 hours on foot or 2 hours by vehicle from KDH (Fig. 1).

Hospitalization rates
Between 2004 and 2006, 7200 current Epi-DSS residents less than 5 years of age were admitted to KDH (64 per 1000 child–years), and of these children, 3273 (29 per 1000) had pneumonia and 1758 (16 per 1000) had suspected meningitis. Maps of hospitalization rates by location showed high rates of admission in Kilifi Township (115/1000) and in the two immediately adjacent locations to the north and south (95/1000), accessible by the main coastal road. Hospitalization incidence decreased with increasing distance from the hospital and was lowest in the far northern and southern areas (30 to 35 per 1000). Overall, locations to the north of Kilifi township had higher hospitalization rates than locations to the south. These patterns were replicated for each of the admission endpoints and are reflected in simple graphics of incidence by travel time (Fig. 2).

In univariate log-linear models, the incidence of hospitalization decreased by 15 to 21% per hour of pedestrian travel time to KDH and by 23 to 28% per half hour of vehicular travel time, depending on the endpoint (Table 1). This distance decay was less marked for suspected meningitis than for pneumonia.

Admission rates varied by ethnic group and were significantly lower in females, migrants and the rainy season than in males, non-migrants and the dry season, respectively (Table 1).
Research

In-hospital death risk and travel time

Of the 10 819 admissions to KDH occurring between 2002 and 2006, 647 (6%) resulted in death, as shown in Table 3. Case fatality ratios reached 7.6% for pneumonia and 11.6% for suspected meningitis. The odds of a child dying in the hospital increased by 12% per hour of pedestrian travel time to KDH (odds ratio, OR: 1.12; 95% CI: 1.06–1.18) and 10% per half-hour of vehicular travel time (OR: 1.10; 95% CI: 1.06–1.15). Other covariates affecting the odds of death included age, ethnic group and season. Adjusted ORs for travel time were similar to unadjusted ORs.

Access to care ratios

Community mortality rates in children aged less than 5 years ranged from 11.9 to 15.3 per 1000 and from 11.6 to 13.6 per 1000 across pedestrian and vehicular travel time strata, respectively.21 Pneumonia hospitalization rates varied from 14.5 to 54.9 per 1000 over pedestrian travel time categories and from 15.8 to 50.7 per 1000 over vehicular travel time categories. The corresponding values for suspected meningitis were 10.5 to 25.1 per 1000 and 10.5 to 22.6 per 1000, respectively (Fig. 2). Access to care ratios for pneumonia and meningitis decreased with travel time to hospital (Fig. 3). Access to care ratios were larger for suspected meningitis than for pneumonia and declined less steeply with travel time ($P=0.05$).

Overall access to care ratios for the Epi-DSS area, obtained as weighted averages of the stratum-specific ratios, were 0.51 (pedestrian) and 0.58 (vehicular) for pneumonia and 0.66 (pedestrian) and 0.70 (vehicular) for meningitis.

Discussion

In this study, we used geographic information system methods to estimate pedestrian and vehicular travel time to the main referral hospital in Kilifi district and examined the relationship between travel time, hospital attendance and disease severity in children less than 5 years of age. We established that hospital admission rates in the Kilifi Epi-DSS decrease

---

**Table 1. Univariate all-cause and cause-specific hospitalization rate ratios (RRs) for continuous travel time variables and categorical covariates among children less than 5 years of age admitted to Kilifi District Hospital, Kilifi district, Kenya, 2004–2006**

<table>
<thead>
<tr>
<th>Variable</th>
<th>All admissions</th>
<th>Pneumonia</th>
<th>Suspected meningitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedestrian (60 m)</td>
<td>0.79 (0.76–0.84)</td>
<td>0.79 (0.76–0.82)</td>
<td>0.85 (0.80–0.90)</td>
</tr>
<tr>
<td>Vehicular (30 m)</td>
<td>0.73 (0.68–0.79)</td>
<td>0.72 (0.67–0.77)</td>
<td>0.77 (0.70–0.84)</td>
</tr>
<tr>
<td>Sex (baseline: Female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.22 (1.15–1.30)</td>
<td>1.17 (1.06–1.28)</td>
<td>1.25 (1.15–1.36)</td>
</tr>
<tr>
<td>Ethnic group (baseline: Giriama)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chonyi</td>
<td>0.63 (0.49–0.82)</td>
<td>0.61 (0.47–0.77)</td>
<td>0.66 (0.53–0.84)</td>
</tr>
<tr>
<td>Kauma</td>
<td>0.93 (0.73–1.20)</td>
<td>0.88 (0.70–1.11)</td>
<td>0.93 (0.71–1.22)</td>
</tr>
<tr>
<td>Luo</td>
<td>1.13 (0.81–1.58)</td>
<td>1.07 (0.73–1.60)</td>
<td>1.23 (0.79–1.93)</td>
</tr>
<tr>
<td>Duruma</td>
<td>0.70 (0.50–0.98)</td>
<td>0.76 (0.53–1.11)</td>
<td>0.71 (0.47–1.08)</td>
</tr>
<tr>
<td>Jibana</td>
<td>0.51 (0.36–0.71)</td>
<td>0.59 (0.37–0.95)</td>
<td>0.61 (0.34–1.11)</td>
</tr>
<tr>
<td>Other</td>
<td>1.02 (0.82–1.29)</td>
<td>0.99 (0.78–1.28)</td>
<td>0.93 (0.74–1.17)</td>
</tr>
<tr>
<td>Maternal educationa (baseline: &lt; 0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 to &lt; 0.6</td>
<td>0.58 (0.33–1.02)</td>
<td>0.59 (0.33–1.06)</td>
<td>0.59 (0.35–1.03)</td>
</tr>
<tr>
<td>0.6 to &lt; 0.7</td>
<td>0.62 (0.35–1.12)</td>
<td>0.68 (0.13–1.31)</td>
<td>0.62 (0.36–1.06)</td>
</tr>
<tr>
<td>≥ 0.7</td>
<td>1.21 (0.81–1.82)</td>
<td>1.39 (0.90–2.16)</td>
<td>0.95 (0.58–1.55)</td>
</tr>
<tr>
<td>Migrant status (baseline: non-migrant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migrant</td>
<td>0.87 (0.80–0.96)</td>
<td>0.85 (0.75–0.97)</td>
<td>0.91 (0.76–1.07)</td>
</tr>
<tr>
<td>Season (baseline: dry)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainy</td>
<td>0.83 (0.78–0.88)</td>
<td>0.75 (0.70–0.81)</td>
<td>0.82 (0.73–0.92)</td>
</tr>
<tr>
<td>Year (baseline: 2004)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>0.85 (0.81–0.91)</td>
<td>0.75 (0.68–0.83)</td>
<td>0.76 (0.69–0.85)</td>
</tr>
<tr>
<td>2006</td>
<td>1.10 (1.01–1.20)</td>
<td>1.01 (0.89–1.16)</td>
<td>1.06 (0.93–1.21)</td>
</tr>
</tbody>
</table>

CI, confidence interval.

*a* Categories represent the proportion of women with any education in a child’s sublocation of residence.
roughly exponentially with increases in both pedestrian and vehicular travel time, in line with earlier findings from developing country settings. In a similar study in rural Nigeria, Stock et al. observed a distance decay gradient of 9% per kilometre for inpatient care, which equates to 24% per hour of walking off roads or 45% per hour on roads using our impedance assumptions. This gradient is steeper than the 21% decrease obtained in our pedestrian model, which suggests that children in Kilifi travel farther to access inpatient care. This could be a function of the perceived high quality of services provided at KDH. Alternatively, our travel time analysis may be more accurate than a simple Euclidian distance analysis, as it more closely reflects the physical barriers experienced by families seeking care for a sick child.

We found that three important factors influenced the rate of distance decay in our population. The gradient was steeper for children with pneumonia than for those with suspected meningitis, suggesting that the effect of travel time on hospital care-seeking decreases with increasing disease severity. The findings for meningitis are surprising in a context where 43% of mothers of children with convulsions reported visiting a traditional healer as a first resort, before seeking biomedical therapy. However, if this behaviour were independent of travel time, it would tend to affect overall hospitalization rates for meningitis without biasing the relative rates.

Maternal education was also a key determinant of distance decay: the pedestrian gradient decreased with increasing education and disappeared in the areas.

### Table 2. All-cause and cause-specific hospitalization rate ratios (RRs) for main effects and interaction effects of travel time to Kilifi District Hospital among children less than 5 years of age, Kilifi district, Kenya, 2004–2006

<table>
<thead>
<tr>
<th>Models</th>
<th>All admissions</th>
<th>Pneumonia</th>
<th>Suspected meningitis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pedestrian (per 60 minutes)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel time</td>
<td>0.65 (0.58–0.74)</td>
<td>0.63 (0.57–0.71)</td>
<td>0.62 (0.53–0.73)</td>
</tr>
<tr>
<td>Male sex × travel time</td>
<td>1.06 (1.02–1.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal education × travel time</td>
<td>1.21 (1.03–1.41)</td>
<td>1.28 (1.12–1.46)</td>
<td>1.40 (1.19–1.64)</td>
</tr>
<tr>
<td>Vehicular (per 30 minutes)</td>
<td>0.71 (0.64–0.79)</td>
<td>0.71 (0.64–0.78)</td>
<td>0.75 (0.68–0.83)</td>
</tr>
<tr>
<td>Male sex × travel time</td>
<td>1.11 (1.04–1.18)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Risk of death from all causes in children less than 5 years of age admitted to Kilifi District Hospital, Kilifi district, Kenya, 2002–2006

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unadjusted OR (95% CI)</th>
<th>Adjusted OR, pedestrian (95% CI)</th>
<th>Adjusted OR, vehicular (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time to Kilifi District Hospital</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedestrian (per 60 m)</td>
<td>1.12 (1.07–1.18)</td>
<td>1.14 (1.09–1.19)</td>
<td>–</td>
</tr>
<tr>
<td>Vehicular (per 30 m)</td>
<td>1.10 (1.03–1.18)</td>
<td>–</td>
<td>1.16 (1.07–1.26)</td>
</tr>
<tr>
<td>Age (baseline: &lt; 1 year old)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–4 year old</td>
<td>0.35 (0.29–0.41)</td>
<td>0.34 (0.29–0.41)</td>
<td>0.34 (0.28–0.42)</td>
</tr>
<tr>
<td>Ethnic group (baseline: Giriama)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chonyi</td>
<td>1.07 (0.88–1.29)</td>
<td>0.91 (0.72–1.15)</td>
<td>0.89 (0.67–1.19)</td>
</tr>
<tr>
<td>Kauma</td>
<td>0.70 (0.52–0.95)</td>
<td>0.71 (0.46–1.08)</td>
<td>0.63 (0.37–1.07)</td>
</tr>
<tr>
<td>Luo</td>
<td>2.73 (1.61–4.61)</td>
<td>2.88 (1.48–5.59)</td>
<td>2.88 (1.57–5.26)</td>
</tr>
<tr>
<td>Duruma</td>
<td>1.49 (0.82–2.71)</td>
<td>1.45 (0.81–2.60)</td>
<td>1.45 (0.79–2.66)</td>
</tr>
<tr>
<td>Jibana</td>
<td>1.20 (0.58–2.48)</td>
<td>0.90 (0.41–1.94)</td>
<td>0.91 (0.43–1.94)</td>
</tr>
<tr>
<td>Other</td>
<td>1.02 (0.74–1.40)</td>
<td>1.12 (0.77–1.63)</td>
<td>1.07 (0.72–1.60)</td>
</tr>
<tr>
<td>Season (baseline: dry)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainy</td>
<td>1.21 (1.03–1.42)</td>
<td>1.21 (1.05–1.40)</td>
<td>1.21 (1.02–1.44)</td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio.

* Sex, maternal education and migrant status were not significant in univariate or multivariable models and are not presented here.
with the highest maternal education levels. Finally, among boys distance decay was less steep than among girls in the vehicular models. Sex was not an explanatory factor in the modelling of access to care ratios for pneumonia and meningitis. Access to care ratios were based on local mortality rates and throughout the area males had higher mortality than females. The sex differential in mortality rates increased with distance from hospital. Therefore, the relative distance decay by sex may simply reflect worsening male health relative to female health with distance from hospital rather than a decrease in the willingness of parents with female children to present them to hospital. Unlike other studies, ours identified no differences in distance decay by age group (infants versus older children) or by sex when pedestrian travel was considered. Detailed, individual-level socioeconomic data are required to examine possible interactions between travel time and socioeconomic factors that influence care-seeking behaviour, including the effect of wealth on mode of transport choice. Such data are not currently available for our study area, justifying our use of sublocation-level maternal education variables as the best available proxy: this is an important limitation in a setting where household finances are likely to be a key determinant of access to hospital care. We do not expect any confounding by immunization status given the high levels and limited geographic variations in vaccination coverage in Kilifi.

This study allowed us to assess whether the decrease in admission rates associated with travel time to hospital could reflect lower rates of disease in outlying areas, rather than a lower propensity to seek care. We found that distance to hospital correlated with disease severity in admitted children, as evidenced by increases in the odds of dying with increasing travel time: delays in care-seeking may lead to more severe disease in children who ultimately reach the hospital; alternately, families may be more willing to travel to hospital for more severe conditions. Access to care ratios decreased with distance to hospital and was higher for suspected meningitis than pneumonia, buttressing the concept of distance as a barrier to health care utilization particularly for less severe syndromes. Based on these ratios, we estimated that over 45% of pneumonia cases and over 30% of suspected meningitis cases in the Epi-DSS area would be missed using hospital surveillance alone. Though our analysis included only children less than 5 years of age, previous studies suggest that our conclusions may also hold true among adults.

In this detailed analysis of linked hospitalization and demographic surveillance data sets from the Kilifi Epi-DSS, we showed that pneumonia admission rates decline exponentially with travel time to hospital and drop by three-quarters at six or more hours of travel on foot (or two or more hours of travel by vehicle) compared to baseline against nearly constant background mortality. The effect is less pronounced for meningitis, but there is nevertheless a twofold decline in admission rates over the observed range of travel times. This suggests that a substantial proportion of children with severe diseases fail to present to hospital for life-saving treatment, at least in part because of geographic access barriers. Our approach to calculating surveillance sensitivity can be applied to other settings with data on both hospital morbidity rates and community mortality rates. These novel findings and the accompanying methodology can help scientists and
public health practitioners interpret sentinel surveillance data and improve on current disease burden estimates for policy decision-making.

Acknowledgements
The authors thank the Epi-DSS field team, led by Arthurnas Ngala, for diligent work in collecting the demographic data; Christopher Nyundo for help with geographic information system mapping; Mike Kahindi for support with Epi-DSS data management and cleaning; and Scott Zeger for expert advice on the statistical analysis. This study was published with the permission of the director of the Kenya Medical Research Institute (KEMRI), Nairobi.

Funding: The Kilifi Epi-DSS is part of the INDEPTH network of demographic surveillance sites and is supported by the Wellcome Trust. The study sponsors played no role in designing the study, collecting and analysing the data, writing the final report or deciding to submit for publication.

Competing interests: None declared.

ملخص
حساسية الترصد المستند على المستشفى للمرض الوخيم: تحليل نظام المعلومات الجغرافي للوصول إلى الرعاية في مقاطعة كيليفي في كينيا

الغرض: استكشاف العلاقة بين المسافة المستقلة بين المنزل والأسرة والمستشفى والمقدرة على الوصول إلى الرعاية، وتقييم حساسية الترصد المستند على المستشفى في مقاطعة كيليفي في كينيا.

الطريقة: في الأعراض 2002 حتى 2006، تم قياس معلومات إكلينيكية من جميع الأطفال الذين أدخلوا في المستشفى، وتم ربط البيانات السكانية لل الوصول إلى الرعاية في المستشفى، والتي تم التحقق من معادل مالطخ في الوقت المستمر في المستشفى، على الرضاية والمعدلات المختلفة في المستشفى. وتم استخدام نظام الحساب لتقدير حساسية الترصد.

المستخدم: في هذا الموقع، استخدموا 7200 حالة (إدخال 64 حالة لكل 1000-1000 حالة) عبر النطاق الزمني في الوصول إلى المستشفى، وتم استخدام نقاط الموثوقية في ونحو 237 دقيقة، وكوبية للسنا 61 دقيقة.

النتائج: وضعت محاولات الدقة في المستشفى بنسب 21% لكل 28% لكل نصف ساعة تستغرق للانتقال. وتم التأكد من الرضاية على الأقدام، ونسبة 30% لكل نصف ساعة تستغرق للانتقال.

الاستنتاج: في هذا الموقع، استعملوا معدلات الانتقاء في المستشفى لارتفاع وانخفاض معدلات الانتقاء من المستشفى. وكان وصول الأطفال الذين يعيشون في مناطق نائية من المستشفى، وأقل معا بال的距离 لل的距离 والمعدلات المختلفة في المستشفى، وتم استخدام نظام الحساب لتقدير حساسية الترصد.

الاستنتاج: في هذا الموقع، استعملوا معدلات الانتقاء في المستشفى لارتفاع وانخفاض معدلات الانتقاء من المستشفى. وكان وصول الأطفال الذين يعيشون في مناطق نائية من المستشفى، وأقل معا بال的距离 للระยะية في مستشفى كل مكمNA (100 متر) في المستشفى.

النفي: وضعت محاولات الدقة في المستشفى بنسب 21% لكل 28% لكل نصف ساعة تستغرق للانتقال. وتم التأكد من الرضاية على الأقدام، ونسبة 30% لكل نصف ساعة تستغرق للانتقال.

Résumé
Sensibilité de la surveillance hospitalière des maladies graves: une analyse du système d’information géographique de l’accès aux soins dans le district Kilifi au Kenya

Objectif: Explorer la relation entre la distance du domicile à l’hôpital et l’accès aux soins, mais aussi évaluer la sensibilité de la surveillance hospitalière dans le district de Kilifi au Kenya.

Méthodes: Sur la période 2002–2006, des informations cliniques ont été obtenues pour tous les enfants admis au Kilifi District Hospital, puis elles ont été liées aux données relatives à la surveillance démographique. Les temps de trajet vers l’hôpital ont été calculés à l’aide de systèmes d’information géographique, et des modèles de régression ont été créés afin d’examiner les relations entre le temps de trajet, les taux d’hospitalisation par cause et la probabilité de décès à l’hôpital. Les taux


109

Jennifer C Moïsi et al.
Hospital-based severe disease surveillance sensitivity in Kenya

Mike Kahindi for support with Epi-DSS data management and cleaning; and Scott Zeger for expert advice on the statistical analysis. This study was published with the permission of the director of the Kenya Medical Research Institute (KEMRI), Nairobi.

Funding: The Kilifi Epi-DSS is part of the INDEPTH network of demographic surveillance sites and is supported by the Wellcome Trust. The study sponsors played no role in designing the study, collecting and analysing the data, writing the final report or deciding to submit for publication.

Competing interests: None declared.

ملخص
حساسية الترصد المستند على المستشفى للمرض الوخيم: تحليل نظام المعلومات الجغرافي للوصول إلى الرعاية في مقاطعة كيليفي في كينيا

المبحث
حساسية الترصد المستند على المستشفى للمرض الوخيم: تحليل نظام المعلومات الجغرافي للوصول إلى الرعاية في مقاطعة كيليفي في كينيا

الغرض: استكشاف العلاقة بين المسافة المستقلة بين المنزل والأسرة والمستشفى والمقدرة على الوصول إلى الرعاية، وتقييم حساسية الترصد المستند على المستشفى في مقاطعة كيليفي في كينيا.

الطريقة: في الأعراض 2002 حتى 2006، تم قياس معلومات إكلينيكية من جميع الأطفال الذين أدخلوا في المستشفى، وتم ربط البيانات السكانية لل الوصول إلى الرعاية في المستشفى، والتي تم التحقق من معادل مطخ في الوقت المستمر في المستشفى، على الرضاية والمعدلات المختلفة في المستشفى. وتم استخدام نظام الحساب لتقدير حساسية الترصد.

المستخدم: في هذا الموقع، استعملوا معدلات الانتقاء في المستشفى لارتفاع وانخفاض معدلات الانتقاء من المستشفى. وكان وصول الأطفال الذين يعيشون في مناطق نائية من المستشفى، وأقل معا بال的距离 للระยะية في مستشفى كل مكمNA (100 متر) في المستشفى.

النفي: وضعت محاولات الدقة في المستشفى بنسب 21% لكل 28% لكل نصف ساعة تستغرق للانتقال. وتم التأكد من الرضاية على الأقدام، ونسبة 30% لكل نصف ساعة تستغرق للانتقال.

Résumé
Sensibilité de la surveillance hospitalière des maladies graves: une analyse du système d’information géographique de l’accès aux soins dans le district Kilifi au Kenya

Objectif: Explorer la relation entre la distance du domicile à l’hôpital et l’accès aux soins, mais aussi évaluer la sensibilité de la surveillance hospitalière dans le district de Kilifi au Kenya.

Méthodes: Sur la période 2002–2006, des informations cliniques ont été obtenues pour tous les enfants admis au Kilifi District Hospital, puis elles ont été liées aux données relatives à la surveillance démographique. Les temps de trajet vers l’hôpital ont été calculés à l’aide de systèmes d’information géographique, et des modèles de régression ont été créés afin d’examiner les relations entre le temps de trajet, les taux d’hospitalisation par cause et la probabilité de décès à l’hôpital. Les taux


109

Jennifer C Moïsi et al.
Hospital-based severe disease surveillance sensitivity in Kenya

Mike Kahindi for support with Epi-DSS data management and cleaning; and Scott Zeger for expert advice on the statistical analysis. This study was published with the permission of the director of the Kenya Medical Research Institute (KEMRI), Nairobi.

Funding: The Kilifi Epi-DSS is part of the INDEPTH network of demographic surveillance sites and is supported by the Wellcome Trust. The study sponsors played no role in designing the study, collecting and analysing the data, writing the final report or deciding to submit for publication.

Competing interests: None declared.
d’access aux soins reliant les taux d’hospitalisation aux taux de mortalité de la communauté ont été calculés et utilisés afin d’évaluer la sensibilité de la surveillance.

**Résultats** L’analyse a inclus 7 200 admissions (64 pour 1 000 enfants–années). Les temps de trajet moyens à pied et en véhicule vers l’hôpital étaient respectivement de 237 et de 61 minutes. Les taux d’hospitalisation ont diminué de 21 % par heure de trajet à pied et de 28 % par demi-heure de trajet en véhicule. L’impact de la distance a été plus élevé pour la méninge que pour la pneumonie, pour les filles que pour les garçons, mais aussi pour les zones où l’éducation des mères était en moyenne inférieure. La distance était fortement associée à la probabilite de mourir à l’hôpital. Les taux globaux de l’accès aux soins, qui représentent la probabilité qu’un enfant nécessitant une hospitalisation puisse accéder aux soins hospitaliers, étaient de 51–58 % pour la pneumonie et de 66–70 % pour la méninge.

**Conclusion** Dans ce contexte, les taux d’utilisation de l’hôpital ont diminué et la gravité des cas admis à l’hôpital a augmenté lorsque la distance entre le domicile et l’hôpital augmentait. L’accès aux soins hospitaliers pour les enfants vivant dans les zones éloignées était faible, en particulier pour ceux dont l’état de santé était grave. L’impact de la distance a été atténué par l’élévation des niveaux d’éducation maternelle. La surveillance hospitalière a sous-estimé l’incidence de la pneumonie et de la méninge de plus de 45 % et 30 %, respectivement.

### Resumen

**Sensibilidad de la vigilancia hospitalaria de enfermedades graves: análisis del sistema de información geográfica del acceso en el distrito de Kilifi, Kenya**

**Objetivo** Investigar la relación existente entre la distancia desde el hogar del paciente al hospital y el acceso a la asistencia. Valorar la sensibilidad de la vigilancia hospitalaria en el distrito de Kilifi, Kenya.

**Métodos** Entre 2002 y 2006 se obtuvo la información clínica de todos los niños ingresados en el Hospital del Distrito de Kilifi y dicha información se vinculó a los datos de vigilancia demográfica. Se calcularon los trayectos al hospital, empleando los sistemas de información geográfica, y se diseñaron modelos de regresión para analizar las relaciones entre la duración del trayecto, las tasas de hospitalización para cada causa específica y la probabilidad de muerte hospitalaria. Los porcentajes de acceso a la asistencia, que relacionaban las tasas de hospitalización con las tasas de mortalidad en la comunidad, se informatizaron y se emplearon para calcular la sensitividad de la vigilancia.

**Resultados** El análisis incluyó 7 200 ingresos (64 por cada 1000 niños–años). La duración media de los trayectos al hospital fue de 237 minutos caminando y de 61 minutos en coche u otro vehículo. Las tasas de hospitalización descendieron en un 21% por cada hora de trayecto a pie y en un 28% por cada hora de trayecto en coche u otro vehículo. La influencia de la distancia fue más pronunciada para la meningitis que para la neumonía, para las mujeres que para los hombres y para las áreas en las que las madres contaban con un nivel inferior de educación. La distancia se asoció categóricamente con la probabilidad de morir en el hospital. Los porcentajes generales de acceso a la asistencia, que representan la probabilidad de que un niño que requiera hospitalización tenga acceso a la asistencia hospitalaria, fueron de un 51–58% para la neumonía y de un 66–70% para la meningitis.
Conclusión En esta situación, las tasas de utilización del hospital descendieron y la gravedad de los casos de los ingresados en el hospital aumentó conforme aumentaba la distancia entre el hogar del paciente y el hospital. El acceso a la asistencia hospitalaria de los niños que vivían en las áreas alejadas fue bajo, especialmente para aquellos que presentaban afecciones de menor gravedad. La influencia de la distancia se atenuó por el aumento del nivel de educación materna. La vigilancia hospitalaria infravaloró la incidencia de la neumonía y de la meningitis en más de un 45% y de un 30%, respectivamente.

References


