A spatial regression analysis of German community characteristics associated with voluntary non-remunerated blood donor rates

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Background and Objectives Previous studies have shown substantial geographical variation in blood donation within developed countries. To understand this issue better, we identified community characteristics associated with blood donor rates in German municipalities in an ecological analysis.

Materials and Methods We calculated an aggregated rate of voluntary blood donors from each of 1533 municipalities in south-west Germany in 2007 from a database of the German Red Cross Blood Service. A multiple linear regression model estimated the association between the municipality-specific donor rate and several community characteristics. Finally, a spatial lag regression model was used to control for spatial autocorrelation that occurs when neighbouring units are related to each other.

Results The spatial lag regression model showed that a relatively larger population, a higher percentage of inhabitants older than 30 years, a higher percentage of non-German citizens and a higher percentage of unemployed persons were associated with lower municipality-specific donor rates. Conversely, a higher donor rate was correlated with higher voter turnout, a higher percentage of inhabitants between 18 and 24 years and more frequent mobile donation sites.

Conclusions Blood donation appears to be a highly clustered regional phenomenon, suggesting the need for regionally targeted recruiting efforts and careful consideration of the value of mobile donation sites. Our model further suggests that municipalities with a decreasing percentage of 18- to 24-year-olds and an increasing percentage of older inhabitants may experience substantial declines in future blood donations.

Key words: blood donor, blood donor recruitment, demography, geographical information systems, Germany, residence characteristics.

Introduction

The WHO Global Database on Blood Safety reports significant differences in blood donor rates and the availability of blood components between developed countries [1,2]. Within developed nations, substantial geographical variation in blood donor rates also exists [3–5], especially in urban settings, where donor commitment and donor rates are generally lower than in rural areas [6]. As the demographics of developed nations change, the proportion of older citizens with health concerns is expected to rise, potentially increasing the demand for blood at a time when...
the healthier younger donor population is decreasing [7,8]. Therefore, the potential for frequent local blood shortages may increase, particularly in regions with low donor commitment and pronounced demographic change [9].

To optimize recruiting strategies and to avoid decreases in blood collection, it is important to identify factors associated with blood donor rates. Although attention in previous studies has focused primarily on the characteristics of those donating blood, several studies point to the potential importance of community characteristics. For example, population composition (e.g., the proportion of younger residents (<30 years) and immigrants), measures of social capital such as voter turnout, and economic indicators (e.g., average income, the proportion of university graduates) [3–6] have been linked to municipality-specific blood donor rates.

While insights from these studies justify continued exploration into the role of community on community-building activities such as voluntary blood donation, it is important to recognize that many of these studies are affected by methodological limitations that undermine the reliability of their results. Either the number of donor clinics or mobile donation sites organized by the blood centres, which have been identified as an important correlate of donor rates [6], were not included in the model [3,5], or potential spatial autocorrelation in the data was not taken into account [3,5,6]. Spatial autocorrelation is present when characteristics, including health-related outcomes, are shared across nearby spatial units. If neighbouring measures are related to each other and residuals of a regression model are as well, coefficients and standard errors of regression analyses may be overestimated [10–12]. At present, the number of studies accounting for spatial autocorrelation is limited to a single report based on data of the Canadian Blood Service [4], even though spatial regression techniques are available and have been applied successfully in several disciplines [11,12].

Reliable studies are needed that guide blood donation recruitment efforts, especially in settings vulnerable to shortages in the blood supply that may arise due to changes in regional demographics. We were particularly interested in assessing these factors within a setting in which one blood service is responsible for collecting most of all blood donations across a large territory characterized by dramatic regional variations in blood donor rates. The states of Baden-Württemberg and Hesse in south-west Germany rely heavily on their Red Cross blood donation system as the primary source of their blood supply. Furthermore, Germany is facing a significant demographic change with major implications for blood supply [9]. The objective of this study, therefore, was to identify community characteristics associated with blood donor rates in German municipalities.

**Materials and methods**

**Study population**

In this study, we analysed 1533 municipalities in south-west Germany (state of Hesse and Baden-Württemberg with 16 million inhabitants). We calculated a donor rate for each of these municipalities, defined as the ratio of inhabitants who successfully donated whole blood at least once in 2007 at the Red Cross Blood Service and the total population. These donations could have been in the municipality of residence or elsewhere in Baden-Württemberg or Hesse. Donations in other states were not included.

As blood donation in Germany is restricted to persons between 18 and 68 years, we included only the population figure in this age group in the denominator when determining the donor rate. We calculated both crude and population-weighted donor rates. Given concern for the effect of outliers on our analysis, we excluded 14 municipalities (0.9%) with donor rates falling more than three standard deviations from the sample mean. The final analytic sample therefore consisted of 1519 municipalities.

In calculating the numerator for each municipality, we used data provided by the German Red Cross Blood Service of Baden-Württemberg–Hesse that identified all voluntary and non-remunerated donors for the year 2007. The German Red Cross Blood Service collects approximately 85–90% of all donations made in Baden-Württemberg and Hesse. Donations that are collected by other organizations were not considered in this study. We included, however, an indicator variable in the statistical analysis that indicated municipalities with an active donor recruitment other than that of the German Red Cross (n = 6). This variable also indicated all direct neighbours of municipalities with a competing donor recruitment (n = 83). We expected lower blood donor rates in these municipalities due to donations made at other organizations.

To calculate municipality-specific donor rates, a federally assigned municipality identification code (ID) was matched against the postal code for each donor’s place of residence. Approximately 93% of all the postal codes could be assigned a unique municipality ID. In cases where a postal code was associated with multiple IDs, we matched the data manually, using the postal code and the name of the municipality. The data set was then collapsed according to municipality ID, and a municipality-specific donor rate was calculated as described previously. We then combined these data with several municipality-specific characteristics (described below) to enable tests of association.

The population figure (total number of inhabitants) and percentage of non-German inhabitants were expected to correlate negatively with the municipality-specific donor rate [4–6]. The percentage of young inhabitants below
30 years was expected to be positively associated with donor rate according to previous studies and a lowered risk of deferral in this age group [4,6,13]. We used data from the Federal Statistical Office to create three demographic indicators to test associations between donor rates and compositional effects of the population: the total population figure at the end of the year 2007, the percentage of inhabitants in four age groups (18–24, 25–29, 30–49 and 50–65 years) and the percentage of inhabitants with non-German citizenship.

Based on previous work, we expected that economic indicators would be associated with different donor rates [4]. We assumed, for example, that higher percentages of unemployed persons and higher purchasing power were both associated with lower donor rates. We therefore obtained data from two sources to create these indicators and to test this assumption. The Federal Statistical Office calculates the percentage unemployed, defined as the ratio of unemployed people living in each municipality and the working age population figure (15–64 years). We also used the purchasing power index provided by the Gesellschaft für Konsumforschung (Society for Consumer Research). The purchasing power index is based on a national survey conducted in 41 European countries that quantifies salaries after tax and social contributions. A mean value of 100 indicates the average value for a German household [14].

Voter turnout in the last federal election (Bundestagswahl 2009) was included as an indicator of institutional trust. Turnout rates in every municipality were obtained from the Statistical Offices of Hessia and Baden-Württemberg. In line with results from the Netherlands, we expected a strong, positive relationship between voter turnout and blood donor rate [6].

Finally, the annual number of mobile donation sites in each municipality organized by the Red Cross in the year 2007 was determined. In mobile donation sites, which often are organized in schools or community centres, most of the blood donors are recruited. We expected a positive but nonlinear association between the number of annual mobile donation sites and the donor rate in each municipality. We assumed that the first donation site was likely to be more closely associated with donor rates than the second, which was more closely associated than a third session. Additionally, we created a variable indicating if a fixed donation site was available in the municipality ($n = 5$) or in a neighbouring municipality ($n = 47$). We expected that the availability of a fixed donor site increased the municipality-specific blood donor rate.

Statistical analyses

First, we calculated univariate statistics of the donor rate in the municipalities and of every independent variable including Moran’s I statistic to measure spatial autocorrelation. Positive values of Moran’s I statistic indicate that neighbouring municipalities have similar donor rates and negative values indicating dissimilar rates [10,11].

Second, we fitted a linear regression based on ordinary least squares (OLS) to estimate the association of community characteristics and blood donor rate. The unit of analysis was the municipality. As the dependent variable, the crude blood donor rate in each of these municipalities, had a skewed distribution, we used a square root transformation instead. The age groups were compared with each other (18–24 years vs. all others, 25–29 years vs. all others, etc.) as this approach has been used in several previous studies to detect age-related compositional effects of the population [4–6]. We both calculated unstandardized ($\beta$) and standardized (Beta) regression coefficients. Unstandardized regression coefficients can be interpreted as the amount of increase in blood donor rate for each one-unit increase in the independent variable. Standardized regression coefficients (Beta) reflects $\beta$ if all variables are standardized and can be used to determine the relative importance of each variable. A tolerance test determined whether the independent variables were correlated as multicollinearity may inflate the standard errors of OLS regression.

Third, we included a quadratic term for the annual number of mobile donation sites (mobile sites × mobile sites) in the regression model. This post hoc test of interaction was conducted to determine whether the relationship between the number of mobile donation sites and blood donor rate was nonlinear.

Fourth, we calculated Moran’s I statistics of the regression residuals to detect spatial autocorrelation in the data and to determine whether the results of the OLS regression were biased.

Fifth, we calculated a spatial lag regression model with the same variables to control for spatial autocorrelation. The spatially lagged dependent variable in the model is an average value of the donor rates in the neighbouring municipalities and reflects the influence of donor rates in neighbouring municipalities [11,12]. Such effects are plausible as blood donation is often a social activity with donors inviting friends and relatives to donate with them [15]. The identification of neighbouring municipalities was based on sharing a common boundary. Both regression models were estimated with GeoDa 0.9.5.i5 [16].

Results

Univariate analyses

The mean value of the crude donor rate in the analytic sample of 1519 municipalities was 5.4% with a standard deviation of 2.7 (Table 1). After adjusting for unequal
municipality sizes by weighting with the population figure, the mean value was 3.5%. This population-weighted mean value of the donor rate is lower than the crude mean value due to the high percentage of small municipalities with high donor rates in the analysis.

We observed that the crude donor rate and its square root transformation both have high spatial autocorrelation (Moran’s I value of 0.59 and 0.61, respectively), suggesting that municipalities with high donor rates tend to be located close to other municipalities with higher rates. The economic indicators also show high spatial autocorrelation, whereas Moran’s I statistics for the demographic characteristics, of voter turnout, and for the number of mobile collecting sessions was much lower (Table 1).

**Multivariate analyses**

In the OLS model, all indicators were significantly related to the square root of the crude donor rate except for the percentage of municipal populations between 25 and 29 years, voter turnout and the availability of a fixed donation site (Table 2, OLS model). The percentage aged 18–24 and the annual numbers of mobile donation sites in each municipality was positively associated with donor rates. In the regression model, for example, an increase of 1% of younger inhabitants was associated with an increase of 0.04 in the square root of the donor rates (Table 2, OLS model, \( \beta = 0.04 \)). In contrast, if the unemployment rate was 1% higher, a decrease in the square root of the donor rate by 0.104 can be expected (Table 2, OLS model, \( \beta = -0.104 \)).

Most of our hypotheses based on previous studies were supported by this analysis, including the expected non-linear association of mobile donation sites and donor rate. The quadratic term for the annual mobile donation sites associated to indicate the relative importance of variables included in the model. It appeared, for example, that the number of collecting sessions had the highest relative importance (\( \beta = 0.471 \)), followed by the percentage of inhabitants without German citizenship (\( \beta = -0.306 \)). The fit of the

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**Table 1** Univariate and spatial statistics of the dependent and independent variables in 1519 municipalities

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
<th>Moran’s I a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude donor rate 2007</td>
<td>0.08</td>
<td>14.04</td>
<td>5.40</td>
<td>2.70</td>
<td>0.59</td>
</tr>
<tr>
<td>Square root of crude donor rate 2007</td>
<td>0.28</td>
<td>3.75</td>
<td>2.24</td>
<td>0.60</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Economic indicators

<table>
<thead>
<tr>
<th>Indicator variable</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population figure (1000)</td>
<td>0.10</td>
<td>659.02</td>
<td>11.05</td>
<td>29.80</td>
</tr>
<tr>
<td>Percentage between 18 and 24 years</td>
<td>0.00</td>
<td>14.48</td>
<td>7.98</td>
<td>1.03</td>
</tr>
<tr>
<td>Percentage between 25 and 29 years</td>
<td>0.00</td>
<td>11.43</td>
<td>5.32</td>
<td>0.85</td>
</tr>
<tr>
<td>Percentage between 30 and 49 years</td>
<td>21.81</td>
<td>41.60</td>
<td>30.16</td>
<td>1.84</td>
</tr>
<tr>
<td>Percentage between 50 and 65 years</td>
<td>4.90</td>
<td>25.64</td>
<td>18.18</td>
<td>1.70</td>
</tr>
<tr>
<td>Percentage of inhabitants without German citizenship</td>
<td>0.00</td>
<td>31.9</td>
<td>7.76</td>
<td>5.38</td>
</tr>
</tbody>
</table>

Social capital

<table>
<thead>
<tr>
<th>Indicator variable</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voter turnout 2005 (%)</td>
<td>61.30</td>
<td>88.70</td>
<td>78.49</td>
<td>3.90</td>
</tr>
</tbody>
</table>

Donation sites

<table>
<thead>
<tr>
<th>Indicator variable</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile donation sites per 1000 inhabitants</td>
<td>0.00</td>
<td>5.86</td>
<td>0.60</td>
<td>0.69</td>
</tr>
<tr>
<td>Competing blood recruitment organization available b</td>
<td>0.00</td>
<td>1.00</td>
<td>0.03</td>
<td>0.18</td>
</tr>
</tbody>
</table>

a All Moran’s I values are significant with \( P < 0.01 \).

b Indicator variable.
OLS regression model was high, and the tolerance values indicated little problem with multicollinearity. However, Moran’s I of the residuals was also high (I = 0.443), indicating positive spatial autocorrelation and potentially biased results.

In the spatial lag regression model, the results changed slightly, especially for the economic indicators, which were affected to a significant extent by spatial autocorrelation (Table 1). The regression coefficient of the purchasing power index no longer achieved statistical significance, and the coefficient for the unemployment rate was attenuated. In contrast, the association with voter turnout increased, becoming significant and positive in accord with our hypothesis (Spatial lag model, Table 2, β = 0.015).

The rank order of the standardized regression coefficients did not change in the lag regression model. The number of local mobile collecting sites was second most important, followed by the percentage of non-German inhabitants. Except for voter turnout and the population figure, the coefficients of all variables were smaller than their counterparts in the OLS regression model.

The spatial lag parameter was significantly related to the municipality-specific donor rate. High donor rates were much better than the OLS regression model (log likelihood value increased from −862.2 to −498.7) with the Moran’s I for residuals reduced substantially and was no longer statistically significant.

**Discussion**

Our study shows that several community characteristics are associated with regional variation in donor rates in Germany, including compositional features of the population such as the total population of municipalities, the

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**Table 2** Association between donor rate (square root transformed) and community characteristics in 1519 municipalities

<table>
<thead>
<tr>
<th>Demographic characteristics</th>
<th>OLS regression model</th>
<th>Spatial lag regression model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.530</td>
<td>0.895</td>
</tr>
<tr>
<td>Population figure (1000)</td>
<td>−0.001***</td>
<td>−0.000***</td>
</tr>
<tr>
<td>Percentage between 18 and 24 years</td>
<td>0.040**</td>
<td>0.029**</td>
</tr>
<tr>
<td>Percentage between 25 and 29 years</td>
<td>−0.019</td>
<td>−0.018</td>
</tr>
<tr>
<td>Percentage between 30 and 49 years</td>
<td>−0.044***</td>
<td>−0.013*</td>
</tr>
<tr>
<td>Percentage between 50 and 65 years</td>
<td>−0.091***</td>
<td>−0.045***</td>
</tr>
<tr>
<td>Percentage of inhabitants without German citizenship</td>
<td>−0.034***</td>
<td>−0.019***</td>
</tr>
<tr>
<td>Economic indicators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage unemployed</td>
<td>−0.104***</td>
<td>−0.053***</td>
</tr>
<tr>
<td>Purchasing power index</td>
<td>−0.004**</td>
<td>0.001</td>
</tr>
<tr>
<td>Social capital</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voter turnout 2005 (%)</td>
<td>0.005</td>
<td>0.015***</td>
</tr>
<tr>
<td>Donation sites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile donation sites per 1000 inhabitants</td>
<td>0.413***</td>
<td>0.343***</td>
</tr>
<tr>
<td>Mobile sites × mobile sites</td>
<td>−0.063***</td>
<td>−0.053***</td>
</tr>
<tr>
<td>Fixed donation site available</td>
<td>−0.096</td>
<td>−0.018</td>
</tr>
<tr>
<td>Competing blood recruitment organization available</td>
<td>−0.531***</td>
<td>−0.173***</td>
</tr>
<tr>
<td>Spatial parameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial lag</td>
<td>0.636***</td>
<td>0.571***</td>
</tr>
</tbody>
</table>

OLS, ordinary least squares.

*P < 0.05; **P < 0.01; ***P < 0.001.

1Quadratic term of mobile donation sites per 1000 inhabitants.

2Indicator variable: fixed donor site available (1) or not available (0).

3Indicator variable: competing blood recruitment organization available (1) or not available (0).

4For the spatial lag regression model, we report pseudo $R^2$. 

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percentage of inhabitants between 18 and 24 as well as between 30 and 65, the percentage of non-German inhabitants and the percentage of unemployed residents. Associations with other characteristics reflective of social capital and the frequency of collecting sessions offered within a municipality appear similarly important. Given consistent findings from studies conducted in other national settings [4–6], our findings suggest that regional variation in blood donation can be explained to some extent by the characteristics of communities in which they take place.

Our analysis, however, also highlights several important new insights into the correlates of voluntary blood donation. First of all, blood donation appears to be a highly clustered regional phenomenon. By this, we mean that municipalities with low donor rates are located close to each other beyond random chance. Our results therefore suggest that regionally targeted recruitment efforts might be very effective. Increasing the donor rate in few municipalities could have a positive effect in several neighbouring municipalities when new donors invite their friends and relatives. This finding suggests that spatial autocorrelation should not be ignored in future studies of behaviours that benefit society. A spatial lag parameter that reflects the neighbouring donor rates can be used to control for spatial autocorrelation and to calculate unbiased estimates. Spatial regression models represent an alternative to regression models based on OLS.

As evidence of the importance of spatial autocorrelation, we observed that economic indicators demonstrated the highest spatial autocorrelation; regression models including unemployment and purchasing power that fail to acknowledge this phenomenon are therefore vulnerable to potential bias. This might explain why the association between average income and donor rate was judged differently in previous studies [4–6]. Our findings observing little association between average purchasing power and unemployment rates in a municipality with the blood donor rate suggest that economic development in communities may have little correlation with future increases in patterns of blood donation.

Furthermore, the number of mobile donation sites (often referred to as ‘bloodmobiles’ in some settings) appears to be an important factor in understanding geographical variation in blood donation. The number of annual mobile donation sites in each municipality was the most important factor in our analyses. These results suggest that the recruitment efforts of the blood services and the way in which blood services are configured and deployed in a municipality are primarily responsible for the substantial geographical variations in blood donor rates reported in this study.

Fortunately, the number of donation sites can be directly influenced by the organizations responsible for providing blood collecting services, in contrast to most of the other characteristics included in our analyses. We demonstrated a positive but nonlinear association between the number of mobile donation sites per thousand inhabitants and the donor rate. We therefore conclude that it may be valuable to distribute mobile donation sites equally according to the population figure of the municipalities. Multiple donation sites in one municipality should be avoided if other municipalities are waiting for the first visit of a bloodmobile.

Surprisingly, we did not find higher blood donor rates in municipalities where a fixed donation site was available. This finding suggests that mobile donation sites may be more important in recruiting German blood donors than fixed sites. Based on this result, we recommend that blood services carefully examine the efficiency of fixed donation sites and should consider increasing the annual number of mobile collecting sites.

Our results underscore the extreme importance of demographic changes: we note, for example, that a shift in the age distribution from younger to older age groups has the potential to result in major effects on the blood supply. In several developed countries, a decrease in this age group is expected or already observable [8,9]. Simultaneously, the proportion of people aged 50 or above associated with a lower donor rate is increasing. Therefore, recruitment strategies that more effectively engage older individuals are urgently needed. The current findings support the potential value of developing predictive models that assess the relationship of demographic changes with local blood supply. Age-specific recruitment strategies can be targeted regionally according to the age structure of the municipalities.

Other demographic changes such as the influx of immigrants into German communities appear important as well. Our results suggest, for example, that the immigration of young foreigners in the last decades has not compensated for the actual decline in blood donation. Indeed, a higher percentage of non-German citizens was associated with lower donor rates. This correlation may partly be explained by different norms governing social participation in areas where non-German citizens live. Activating and engaging communities in which these individuals live may therefore represent a strategy for increasing future donor pools and minimizing blood shortages. Future analyses that explore donation patterns of non-German citizens at the community and individual levels may therefore be useful.

Our findings should be interpreted within the context of several limitations. First, we note that the unit of analysis used in this study makes it impossible to ascribe the associations we observed to individual respondents without risking an ecological fallacy [17]. Second, we considered only donations collected by the German Red Cross, which is the

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most important blood collection service in Germany. To avoid biased results due to donations given to other organizations, we used an indicator variable to account for the average effect of competing donor recruitment activities. Third, we did not include information about municipality-specific recruitment resources or the degree of regional marketing. The German Red Cross Blood Service relies heavily on volunteers to recruit new blood donors, and advertising is usually conducted as part of a pro bono campaign. Inclusion of data on these investment activities may have enhanced model fit and should be explored in future studies. Fourth, we note that blood donor rates may also be affected by geographical variations in blood demand which were not assessed in this report. Fifth, our analysis was somewhat limited by the data available on community characteristics. This may have confounded our results through missing variable bias. Other studies [6], for example, have been better able to assess more accurately the role of socioeconomic status from information on the percentage of university graduates and average income levels in municipalities. Similarly, the availability of data on the proportion of inhabitants belonging to specific religious denominations and indicators of prosocial norms and civic engagement may have provided further useful detail on social features associated with blood donation.

Although data on these characteristics were not available in the current study, we note that our ability to explain variation in blood donation rates at the municipal level was modestly higher than results from previous work (adjusted $R^2$ 0.494 in our OLS model vs. 0.433 in the OLS model of Bekkers and Veldhuizen [6]): 12 parameters available for all the German municipalities included in our study explained half of the geographical variation in blood donor rates. High donor rates can be expected in municipalities with a high percentage of inhabitants between 18 and 24 years, high voter turnout, low unemployment rates and frequent mobile donation sites. Low donor rates are more likely to be found in municipalities with a relatively high populations figure, a high percentage of inhabitants older than 30 years, a high percentage of non-German inhabitants, and with competing blood recruitment organizations. Model fit increased even more following the addition of a spatial lag parameter. These results emphasize the importance of accounting for regional clustering of community-building activities like blood donation.

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Authors’ contribution

CW, SS and HK were responsible for the study design. CW and EW collected the data. CW and DL drafted the manuscript, and all other authors contributed to the interpretation of analyses. All authors approved the submitted version.

References