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# Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study

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## ABSTRACT

**Objectives:** To determine whether stroke patients' acute hospital length of stay (AHLOS) varies between hospitals, over and above cases mix differences, and to investigate the hospital-level factors driving such hospital variations in AHLOS.

**Design:** A multicentre prospective cohort study.

**Setting:** Eight National Health Service acute hospital trusts within the Anglia Stroke & Heart Clinical Network in the East of England, UK.

**Participants:** The study sample was systematically selected to include all consecutive patients admitted to any of the eight hospitals, diagnosed with stroke by an admitting clinician, every third month between October 2009 and September 2011.

**Primary and secondary outcome measures:** AHLOS was defined as the number of days between date of hospital admission and discharge or death, whichever came first. We used a multiple linear regression model to investigate the association between hospital (as a fixed-effect) and AHLOS, adjusting for a number of important patient covariates. Exploratory data analysis was utilized to gain insight into the hospital-level characteristics which may contribute to the hospital-level variance.

**Results:** A total of 2233 stroke admissions (52% female, median age (interquartile range (IQR)) 79 (70 to 86) years, 83% ischaemic stroke) were included in the study analysis. The overall median AHLOS (IQR) was 9 (4 to 21) days. After adjusting for patient covariates and confounding factors, AHLOS still differed significantly between hospitals ($p<0.001$; $R^2=2.4\%$). Furthermore, hospitals with the longest adjusted AHLOS's were predominantly secondary and in which stroke volumes were lower.

**Conclusions:** We have clearly demonstrated that AHLOS varies at the hospital-level and, have highlighted the potential importance of hospital type and volume of stroke patients as the hospital factors influencing these differences.

## ARTICLE SUMMARY

### Strengths and limitations of this study

- This is a comprehensive study that has used multi-centre data to determine whether acute hospital length of stay of stroke patients varies across hospitals in the UK, after adjustment for patient-level covariates.
- With a wealth of detailed patient data we were able to adjust for the important covariates, inpatient complications and discharge destination, which previous studies have not addressed.
- Hospital-level effects were not estimated due to the limited hospital sample size of eight.
- Although National Institute for Health Stroke Scale (NIHSS) stroke patients' scores are known to be associated with acute hospital length of stay, we were unable to adjust for this as this was only calculated for patients who were potentially eligible for thrombolysis and would have introduced collection bias.

## INTRODUCTION

Stroke is the second leading cause of mortality and the third leading cause of disability in the world, with a global incidence of 16.9 million in 2010.[1-2] While acute hospitalization for stroke in the US has been estimated at a cost of $31,667, total direct stroke-related annual medical costs are expected to triple, from $71.6 billion in 2012 to $184.1 billion by 2030.[3-4] Considerable differences in stroke-related outcomes exist worldwide, with the highest age-standardized stroke-related mortality and disability adjusted life-years rates observed in Russia and Eastern European countries.[1] Stark regional disparities within countries are also apparent. In the UK, for example, there exists a clear north-south divide where the lowest stroke-related mortality rates are observed almost exclusively in the South of England.[5] Such differences in outcomes likely reflect underlying stroke incidence rates and variations in exposure to relevant risk factors.[5-6] However, we and others have demonstrated that some of the differences in post-stroke survival have also been explained by disparities in available resources and medical care.[7-11] Studies assessing the effect of stroke care heterogeneities have largely focused on mortality as the primary outcome.

However, it is possible that heterogeneities in stroke care also impact other important stroke-related outcomes, such as a patient's acute hospital length of stay (AHLOS). To date, studies have mainly identified patient-related determinants of AHLOS,[12-15] with little exploration into hospital-level influences.

During acute hospitalization, AHLOS is the main driver of acute care costs.[16] Determining the hospital-level factors influencing AHLOS therefore provides invaluable information to service providers and policymakers who can develop optimal management strategies and enhance patient care by minimizing service deficiencies, costs and bed shortages.

The aim of this study is to investigate whether there are variations in stroke patients' AHLOS which can be partly explained by heterogeneities in characteristics of stroke care between

hospitals in a UK National Health Service (NHS) setting. We also aimed to explore which hospital-level factors drive such hospital variations in AHLOS.

## METHODS

### *Study design*

A multi-centre prospective cohort study was conducted at eight acute NHS Trusts within the Anglia Stroke & Heart Clinical Network (ASHCN) which covers the three counties of Suffolk, Norfolk and Cambridgeshire, in the East of England with a catchment population of approximately 2.5 million. The detailed study protocol has previously been published (see supplementary document 1).[17] Ethical approval was obtained from the NRES Committee East of England – Norfolk (REC Reference number 10/H0310/44).

### *Participants*

The study population included all patients, aged 18 years or older, admitted to any of the eight hospitals within the ASHCN diagnosed with stroke by an admitting clinician between October 2009 and September 2011. Stroke was defined as a focal neurological impairment of sudden onset, and lasting more than 24 hours (or leading to death) as a consequence of an intracerebral ischemic or haemorrhagic event. This definition excludes diagnoses of transient-ischemic attacks, subdural hematomas and subarachnoid haemorrhages. The study sample was systematically selected to include all consecutive stroke patients admitted every third month of this 2-year period, resulting in a total of eight study months and sample size of 2656. The robustness of this sampling technique has been confirmed.[18]

### *Data collection*

Clinical teams responsible for the care of stroke patients in each of the hospitals prospectively recorded individual patient data. Patient data routinely collected by each participating site for the ASHCN surveys was used in this study. Additional baseline patient and outcome data were also retrieved from case records, discharge summaries and Patient Administrative Systems by the clinical teams. Data was anonymized and sent to the ASHCN coordinating

centre where it was collated and sent to the research team. Any identifiable patient information was held only at the local NHS Trusts - the network and investigators did not have access to these details.

Data on health service characteristics were collected from clinical leads or service managers at each stroke unit and updated every six months over the 2-year study period by research staff.[17]

***Definition of variables***

Our outcome measure, AHLOS, was treated as a continuous variable and defined as the number of days from, and including, the patients' date of hospital admission to their date of discharge or death, whichever came first.

Patient level covariates adjusted for were: age (treated as a continuous variable), sex, pre-stroke Rankin Scale (mRS) as an indicator of pre-stroke frailty, pre-stroke residence status, stroke type, Oxfordshire Community Stroke Project (OCSP) (a stoke classification system), presence or absence of lateralisation signs, acute inpatient complications, established comorbidities (including previous stroke/transient ischaemic attack, previous myocardial infarction or ischaemic heart disease, previous cancer), presence of other relevant comorbidities (including diabetes mellitus, dementia, hypercholesterolemia, hypertension, cancer, depression, rheumatoid arthritis and chronic obstructive pulmonary disease), day and season of admission and, discharge destination (including in-hospital death).

Independent hospital-level variables of interest were: hospital type (secondary or tertiary), hospital stroke volume (mean number of stroke patients admitted and treated in hospital per month), presence of vascular surgery onsite, distance to neurosurgical facility, onsite rehabilitation service provision, presence of early supported discharge scheme, number of full-time equivalent (fte) staff per five beds (senior doctors and junior doctors available

during weekdays, healthcare associates and nurses, occupational therapists, physiotherapists and, speech and language therapists), number of total beds present on the stroke unit per 100 stroke admissions, total number of hospital beds per CT scanner, number of non-stroke patients treated daily on the stroke unit per five beds and number of stroke patients treated daily on wards outside the stroke unit per day per five beds.

***Statistical analyses***

Data were available from only eight hospitals which is below the suggested critical number required to reliably estimate hospital effects through multi-level modelling.[19] Therefore, a single-level multiple linear regression model using ordinary least squares was conducted with hospital as a fixed-effect and AHLOS as the outcome. To qualify for inclusion in the multivariable model, patient-level variables had to have a p-value<0.3 in univariable analysis. The standardized residuals of the model were positively skewed. However, a logarithmic transformation of AHLOS subsequently removed the skewness. Before reporting, we transformed the predicted logarithmic AHLOS values back to AHLOS, with exponentiated regression coefficients representing geometric means of AHLOS.

To explore hospital-level predictors, we plotted the hospital intercept estimates of AHLOS from the regression model (mean baseline AHLOS of each hospital), against the hospital-level characteristics of interest. This is the recommended method to use on clustered data to explore hospital effects when the number of higher level units is small and hence are not interpretable in likelihood estimation.[19-20]

***Multiple imputation***

To increase power and reduce potential bias of complete case analysis, we performed multiple imputation by chained equations using the MICE package in R.[21] All the independent variables of interest, AHLOS and a number of auxiliary variables (i.e. variables

in our dataset that were not used in our model) (Table S1 in the online supplementary document 2) informed the imputation. Sixty-four datasets were imputed as the inclusion of auxiliary variables increased the case wise missingness to 64%. Each dataset was pooled together using Rubin's rules. The distribution of sample characteristics between individuals with complete and incomplete data were compared.

All analyses were performed using R version 3.3.1 for Windows.[22]

**Patient and public involvement**

The project was managed by project leader (PKM) who worked in close partnership with the project group of the study and the project steering group. The project steering group included public and patient representatives, recruited through Patient and Public Involvement in Research (PPIRes). PPIRes members were invited to attend research steering group meetings over the study duration to oversee the project.

## RESULTS

### *Description of sample characteristics*

Of the 2656 patients admitted consecutively to the eight NHS hospitals during the inclusion period with an initial diagnosis of stroke, 278 were excluded for the following reasons: eventually diagnosed with a condition other than stroke (n=179), transferred between hospitals (both among the eight study hospitals and from or to outside the region) (n=101), had missing data for admission and discharge dates (n=8). This left a total of 2233 patients for the study analysis (Figure 1).

The median age (interquartile range (IQR)) of our cohort was 79 (70 to 86) years, 52% were female, and 83% had an ischaemic stroke (Table 1). The distributions of patient characteristics did not seem to differ greatly between hospitals (Table S2 in the online supplementary document 2). Although there were low proportions of missing data for each independent variable (Table 1), this compounded to 31% of patients having at least one variable missing. Hospital 4 did not collect data on pre-stroke mRS. Hospital 2 only collected data for two study months due to limited resources and 30 cases from Hospital 3 had missing data on all comorbidities. Complete cases and cases with at least one missing variable had similar characteristic distributions (Table S3 in the online supplementary document 2).

**Table 1** Sample characteristics of patients included in analysis (n=2333) and missing data

| Patient Characteristic | Median (IQR) or No. (%) | Missing Data (%) |
|---|---|---|
| Age, y | 79 (70 to 86) | 2 (0.1) |
| Sex, female | 1165 (52) | 2 (0.1) |
| Recurrent Stroke* | 448 (20) | 30 (1) |
| Diabetes Mellitus* | 370 (17) | 30 (1) |
| Dementia* | 207 (9) | 30 (1) |
| Hypercholesterolemia* | 355 (16) | 30 (1) |
| Hypertensive* | 1483 (66) | 30 (1) |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 (23) | 30 (1) |
| TIA* | 340 (15) | 30 (1) |
| Previous Cancer* | 195 (9) | 30 (1) |
| Active Cancer* | 137 (6) | 30 (1) |
| Depression* | 137 (6) | 30 (1) |
| Rheumatoid Arthritis* | 154 (7) | 30 (1) |
| COPD* | 116 (5) | 30 (1) |
| Pre-stroke Rankin Score | | 442 (20) |
| 0 | 914 (41) | |
| 1 | 335 (15) | |
| 2 | 191 (9) | |
| 3 | 184 (8) | |
| 4 & 5 | 167 (7) | |
| Pre-Stroke Residence | | 51 (2) |
| Independent living with formal care | 210 (9) | |
| Independent living without formal care | 1752 (78) | |
| Institution | 220 (10) | |
| Stroke Type | | 96 (4) |
| Ischaemic | 1864 (83) | |
| Haemorrhagic | 273 (12) | |
| Oxford Community Stroke Project Classification | | 260 (12) |
| LACS† | 503 (23) | |
| PACS† | 784 (35) | |
| POCS† | 279 (12) | |
| TACS† | 407 (18) | |
| No Brain Lateralisation | 244 (12) | 167 (8) |
| Inpatient Complication* | 655 (29) | 0 (0) |
| Discharge Destination | | 50 (2) |
| Death | 414 (19) | |
| Independent living with formal care | 224 (10) | |
| Independent living without formal care | 1006 (45) | |
| Institution | 252 (11) | |
| Interim/Rehab Setting | 287 (13) | |
| Winter Admission | 1159 (52) | 0 (0) |
| Weekend Admission | 614 (27) | 0 (0) |

*No information was assumed to indicate absence of condition or complication

† LACS= Lacunar Anterior Circulation Stroke; PACS= Partial Anterior Circulation Stroke; POCS= Posterior Circulation Stroke; TACS = Total Anterior Circulation Stroke

***Hospital service characteristics***

Service characteristics of each hospital are outlined in Table 2, with median AHLOS. After standardization there was still extensive heterogeneity in staffing levels, bed capacity and the provision of services and facilities. The overall median AHLOS (IQR) was 9 (4 to 21) days and there appeared to be crude variations in this outcome between hospitals.

**Table 2** Hospital characteristics per individual hospital

| Hospital Characteristics | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| General Characteristics | | | | | | | | |
| Catchment Population | 400,000 | 160,000 | 350,000 | 230,000 | 680,000 | 300,000 | 240,000 | 275,000 |
| Hospital Type | Tertiary | Secondary | Secondary | Secondary | Tertiary | Secondary | Secondary | Secondary |
| Hospital Stroke Volume (No. of ASCNES admissions per month) | 52 | 13 | 46 | 19 | 88 | 57 | 35 | 31 |
| Facilities and Services | | | | | | | | |
| No. of hospital beds | 1000 | 304 | 800 | 500 | 1237 | 611 | 488 | 460 |
| No. of stroke unit beds (per 100 admissions) | 71 | 77 | 54 | 138 | 41 | 55 | 83 | 65 |
| No. of hospital beds per CT scanners | 500 | 304 | 400 | 250 | 518 | 306 | 244 | 230 |
| Distance to Vascular Surgery (miles) | 0 | 18 | 0 | 25 | 0 | 0 | 43 | 30 |
| Distance to Neurosurgery (miles) | 0 | 18 | 58 | 89 | 61 | 38 | 48 | 30 |
| Rehabilitation Provision | Onsite | Onsite | Offsite | Offsite | Offsite | Onsite | Offsite | Onsite |
| Early Supported Discharge Provision | No | Yes | No | Yes | Yes | Yes | No | No |
| Stroke Unit Staffing Levels* | | | | | | | | |
| Senior doctors† | 0.34 | 0.25 | 0.49 | 0.47 | 0.42 | 0.31 | 0.62 | 0.87 |
| Junior doctors † | 0.55 | 0.65 | 0.72 | 0.59 | 0.56 | 0.64 | 0.12 | 0.25 |
| Health care associates and nurses (band 5-7) | 9.2 | 8 | 6 | 7.4 | 7 | 5.3 | 6.5 | 10 |
| Physiotherapists (band 2-8) | 0.55 | 1 | 0.79 | 0.4 | 0.91 | 0.78 | 0.69 | 1 |
| Occupational Therapists (band 3-8) | 0.49 | 0.5 | 1.4 | 0.59 | 0.6 | 0.58 | 0.52 | 1.1 |
| Speech and Language Therapists | 0.39 | 0.15 | 0.2 | 0.18 | 0.35 | 0.03 | 0.26 | 0.1 |
| No. of non-stroke patients treated daily on stroke unit (per five stroke unit beds) | 0.27 | 0 | 0.10 | 0.47 | 0.05 | 0.31 | 0.17 | 0 |
| No. of stroke patients treated daily outside stroke unit (per five stroke unit beds) | 0.14 | 5 | 0 | 0.30 | 0.01 | 0.41 | 0 | 0 |
| Median AHLOS (IQR) | 8 (4 to 20) | 29 (24 to 42) | 11 (5 to 27) | 14 (4 to 30) | 8 (4 to 14) | 10 (5 to 22) | 11 (6 to 23) | 7 (3 to 20) |

*Number of fte staff per five stroke unit beds (weighted average for the four study periods taken)

† Weekday numbers only

*Univariable linear regression*

In univariable linear regression (Table S4 in the online supplementary document 2), patients who were older, female, had previous cancer, a previous stroke, had diabetes mellitus, had dementia or were a winter admission had a significantly longer AHLOS ($p<0.05$). Patients who had a haemorrhagic stroke, hypercholesterolemia, pre-stroke Rankin score of 0, no signs of brain lateralisation, lacunar stroke and who lived independently at home without formal care (compared to those who had formal care) prior to stroke were all shown to be significantly associated with a shorter AHLOS ($p<0.01$).

The strongest associations with AHLOS were seen for inpatients who developed a complication, who were admitted to hospital 2 and who were institutionalized after discharge. Inpatient complications were associated with twice as long an AHLOS compared to those without a complication. Patients admitted to hospital 2 had triple the AHLOS of those admitted to hospital 1. Institutionalization quadrupled a patients' AHLOS compared to those who were discharged to home without formal care.

Finally, compared to being admitted to hospital 1 of our study, admission to hospitals 3, 4 and 7 were also significantly associated with an increasing AHLOS, whereas hospital 5 was associated with a decreasing AHLOS ($p<0.05$; $R^2=2.4$).

*Multiple linear regression*

Multiple linear regression results for AHLOS are summarized in Table 3 and shows that 40% of the variation in AHLOS has been explained. Sex, recurrent stroke and dementia mellitus were no longer statistically associated ($p<0.05$) with AHLOS in multiple regression. No variables included from the univariable analysis with $p>0.05$ became statistically significant in the multivariable analysis. Developing an inpatient complication and being institutionalized were still strongly positively related to AHLOS. After adjusting for patient

covariates and confounding factors, AHLOS was still shown to significantly differ between hospitals, with the shortest and longest AHLOS observed for hospitals 5 and 2, respectively.

There were no obvious differences between the results using complete cases only (Tables S5-6 in the online supplementary document 2) and multiple imputation.

**Table 3** Multiple regression analysis for AHLOS (n=2233; $R^2$=40%)

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 0.99 | 0.92 to 1.07 | 0.80 |
| Recurrent Stroke | 1.00 | 0.91 to 1.10 | 1.00 |
| Diabetes Mellitus | 1.08 | 0.98 to 1.19 | 0.12 |
| Dementia | 1.20 | 1.05 to 1.38 | 0.01 |
| Hypercholesterolemia | 0.94 | 0.85 to 1.04 | 0.25 |
| Myocardial Infarction or Ischaemic Heart | 1.01 | 0.93 to 1.10 | 0.83 |
| Previous Cancer | 1.17 | 1.03 to 1.33 | 0.01 |
| COPD | 0.91 | 0.77 to 1.07 | 0.23 |
| Pre-stroke Rankin Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.03 to 1.28 | 0.02 |
| 2 | 1.15 | 1.00 to 1.33 | 0.05 |
| 3 | 1.33 | 1.13 to 1.56 | <0.001 |
| 4 & 5 | 1.15 | 0.96 to 1.38 | 0.12 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 0.86 | 0.75 to 0.99 | 0.04 |
| Institution | 0.52 | 0.44 to 0.62 | <0.001 |
| Haemorrhagic Stroke | 0.84 | 0.75 to 0.95 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.34 | 1.22 to 1.48 | <0.001 |
| POCS | 1.44 | 1.26 to 1.63 | <0.001 |
| TACS | 1.49 | 1.31 to 1.70 | <0.001 |
| No Brain Lateralisation | 0.82 | 0.73 to 0.93 | <0.001 |
| Inpatient Complication | 1.72 | 1.58 to 1.87 | <0.001 |
| Discharge Destination (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.99 | 1.74 to 2.27 | <0.001 |
| Institution | 3.58 | 3.09 to 4.15 | <0.001 |
| Interim/Rehab Setting | 2.18 | 1.94 to 2.46 | <0.001 |
| Death | 0.85 | 0.74 to 0.97 | 0.02 |
| Winter Admission | 1.15 | 1.07 to 1.24 | <0.001 |
| Weekend Admission | 1.04 | 0.96 to 1.13 | 0.30 |
| Hospital (reference 1) | | | <0.001 |
| 2 | 2.76 | 1.80 to 4.22 | <0.001 |
| 3 | 1.24 | 1.09 to 1.42 | <0.001 |
| 4 | 1.36 | 1.15 to 1.61 | <0.001 |
| 5 | 0.85 | 0.75 to 0.95 | 0.01 |
| 6 | 1.06 | 0.92 to 1.22 | 0.42 |
| 7 | 1.19 | 1.03 to 1.37 | 0.02 |
| 8 | 0.99 | 0.85 to 1.14 | 0.84 |

*β estimates and 95% confidence intervals were calculated for predicted log AHLOS. Prior to reporting they were transformed back to AHLOS through exponentiation and represent geometric mean AHLOS

***Graphical exploratory analysis***

Mean baseline AHLOS of each hospital (estimated from the multiple regression model) was plotted against hospital stroke volume and clustered by hospital type in Figure 2. It appears that hospitals (of either type) that have that have higher stroke volumes have a shorter AHLOS than those with lower stroke volumes. In addition, it also appears that secondary hospitals have longer AHLOS in general than tertiary hospitals when all patient covariates are taken into account.

No discernible patterns were seen for mean baseline hospital AHLOS and staffing levels, surgery facilities, number of stroke patients treated outside the stroke unit, number of non-stroke patients treated on the stroke unit, and bed numbers (Figures S1-13 in the online supplementary document 2).

## DISCUSSION

This multi-centre cohort study has demonstrated that substantial heterogeneities exist in stroke hospital service and staff provision across three counties in the East of England. After adjusting for patient characteristics and confounding factors, we have shown that AHLOS significantly differed between hospitals. This suggests that the heterogeneities we see in stroke care between hospitals are having an effect on AHLOS of these patients. It also appears from our exploratory analysis that the volume of stroke patients admitted to hospital and the type of hospital may play a role in partially explaining these hospital-level AHLOS differences.

A number of other studies have demonstrated hospital-level variation in AHLOS due to hospital factors, such as stroke unit volume and hospital size.[12, 23] However, these studies did not account for important covariates such as inpatient complications and discharge destination. Indeed, our analysis has shown how strongly these two factors are associated with a patient's AHLOS, and so by adjusting for them in our model, our study has been able to establish that any remaining differences in this outcome between hospitals is due to hospital-level factors. We have therefore shown that, in addition to stroke-related mortality,[7-11] other important patient outcomes are determined by hospital heterogeneities. This finding is particularly relevant given its strong correlation with inpatient costs and the variation in AHLOS seen both nationally and regionally.[16, 24]

Our exploration of hospital characteristics indicates that being admitted to a hospital that has a higher stroke volume compared to one that has a lower stroke volume may be responsible for shortening AHLOS. This has also been demonstrated for high-volume stroke units in a previous study.[23] This latter study, however, did not adjust for inpatient complications and discharge destination. However, in other studies that have adequately adjusted for these

patient characteristics, higher stroke volumes have also been shown to be significantly associated with lowered risk of mortality which implies that this hospital-level characteristic has an impact on outcomes in stroke.[11, 25-26]

In addition to hospital stroke volume, hospital type is another hospital-level characteristic that appears to play a role in influencing AHLOS. We have shown that tertiary hospitals (also referred to as academic hospitals) generally have a lower AHLOS compared to secondary hospitals. This finding is in agreement with a previous multicentre study in Argentina which demonstrated that unadjusted median AHLOS was shorter for academic hospitals.[27]

It may be that the quality of care and accessibility to resources and sub-specialists is better in these higher volume or academic hospitals, and this is leading to more favourable outcomes.[28] For example, it has been shown that stroke patients admitted to high-volume stroke units have significantly greater odds of being treated and assessed earlier than those admitted to lower-volume units.[23] This apparent increase in efficiency likely results from the greater pressure on beds these higher-volume units experience which requires them to have a faster throughput of patients. Furthermore, it has been shown that admission rates to stroke units are significantly higher in academic hospitals, and pneumonia rates are lower.[27] The reason for this is not yet clear but is likely to play a role in determining AHLOS.

Hospital 8, however appears to contradict the above findings in that although it has one of the lowest AHLOS, it is a secondary hospital and it also has one of the smallest volume of stroke patients in the study. Such a discrepancy is likely to be a reflection of the small number of hospitals assessed, as there are likely to be a number of competing factors playing a role in determining hospital-level AHLOS variance. Although hospital 8 has one of the lowest stroke volumes and is a secondary hospital, it has the highest number of fte senior doctors, health care associates and nurses, and physiotherapists per five beds, and the lowest number of

hospital beds per CT scanners out of all the hospitals studied. Staffing levels are likely to be an important determinant of AHLOS, given that higher nurse: bed ratios have been shown to be important in reducing other stroke-related outcomes, such as mortality.[8-9]

The main strength of our study is its prospective design and the detailed patient-level data we obtained. This allowed us to gain a better understanding of the extent to which the variation in AHLOS exists over and above patient characteristics. A gold standard randomized controlled trial would be unethical and ineffective at exploring these hospital-level variations, thus our observational study design is the best approach to answer these important questions. The robust statistical analysis has allowed easy and quick visualization of notable patterns in the dataset and provides a candid assessment of the research objectives by considering the limits of inference due to the small number of hospitals. Multiple imputation has also reduced potential bias that may have otherwise been introduced from complete case analysis alone.

The major limitation of this study was the small number of hospitals that has restricted the conclusions we can make from our exploratory analysis of hospital characteristics. A number of competing factors may be playing a role in determining AHLOS, but due to this small sample size and large heterogeneities between the hospitals and their stroke units, we are unable to disentangle any definitive relationships. Furthermore, although National Institute for Health Stroke Scale (NIHSS) and a patient's mRS at discharge has been shown to be associated with stroke patients' AHLOS,[14, 16, 18, 29] they were excluded as covariates from the main analysis. As NIHSS scores were only calculated for those who were potentially eligible for thrombolysis at the time of our study, the incompleteness was not missing at random and would have introduced collection bias into our results. As discharge mRS and discharge destination both included a categorical factor representing inpatient death only one of these variables could be included into the analysis due to issues of multi-collinearity. However, we hypothesized that discharge destination could more readily explain a patient's AHLOS due to

waiting times associated with institutionalization. Furthermore, as this study only covers eight NHS hospitals in the East of England, the findings may not be generalisable to healthcare settings outside the UK.

Although some studies have shown a link between a number of hospital characteristics and AHLOS, no study has yet addressed the issue of clustering. A study with an adequate number of hospitals, robust statistical techniques (such as multi-level modelling) and high-quality data is therefore required in order to identify the types of services and staffing levels required for lowering AHLOS.

In summary, the heterogeneities that exist in stroke care at the regional UK level have the ability to lead to differences in stroke-patient outcomes such as, AHLOS. This provides a powerful message for patients, clinicians, service providers and policymakers – that there are modifiable hospital factors that can determine better outcomes in stroke. For example, low volume hospitals could consider reducing their stroke bed numbers as a means to increase their efficiency. Countries that are in the process of developing their healthcare systems can use these findings to inform their decision making in delivering optimal care.

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**Author Contributions:** M.T cleaned the data, undertook the statistical analysis and interpretation of results, reviewed the literature and, prepared the manuscript. D.M and P.K.M supervised the study. D.M provided statistical analysis advice and assistance. M.O.B, E.A.W, J.F.P and P.K.M conceptualized and designed the use of ASCNES and obtained funding. S.D.M was ASCNES study coordinator and managed the data. All authors reviewed the manuscript and contributed in critical revision and final manuscript preparation.

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**Patient consent:** Not required.

**Ethics approval:** Ethical approval was obtained from the NRES Committee East of England – Norfolk (REC Reference number 10/H0310/44).

**Data sharing statement:** The datasets generated and analysed during the current study are available from the ASCNES team on reasonable request.

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**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

**Figure 2** Model estimates of mean baseline AHLOS per hospital against hospital stroke volume and clustered by hospital type with 95% confidence intervals. Multiple regression model was adjusted for patient covariates.

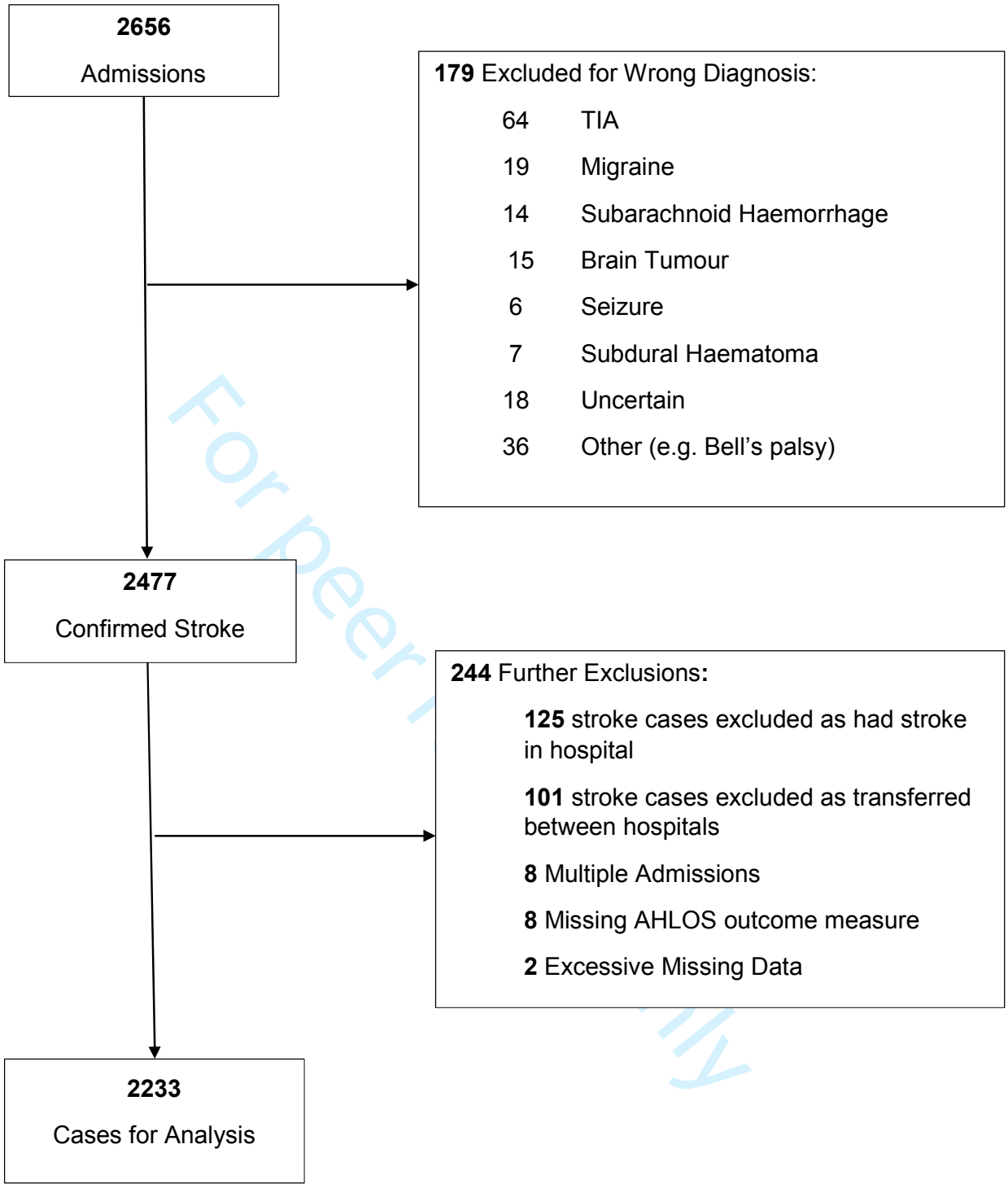


**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

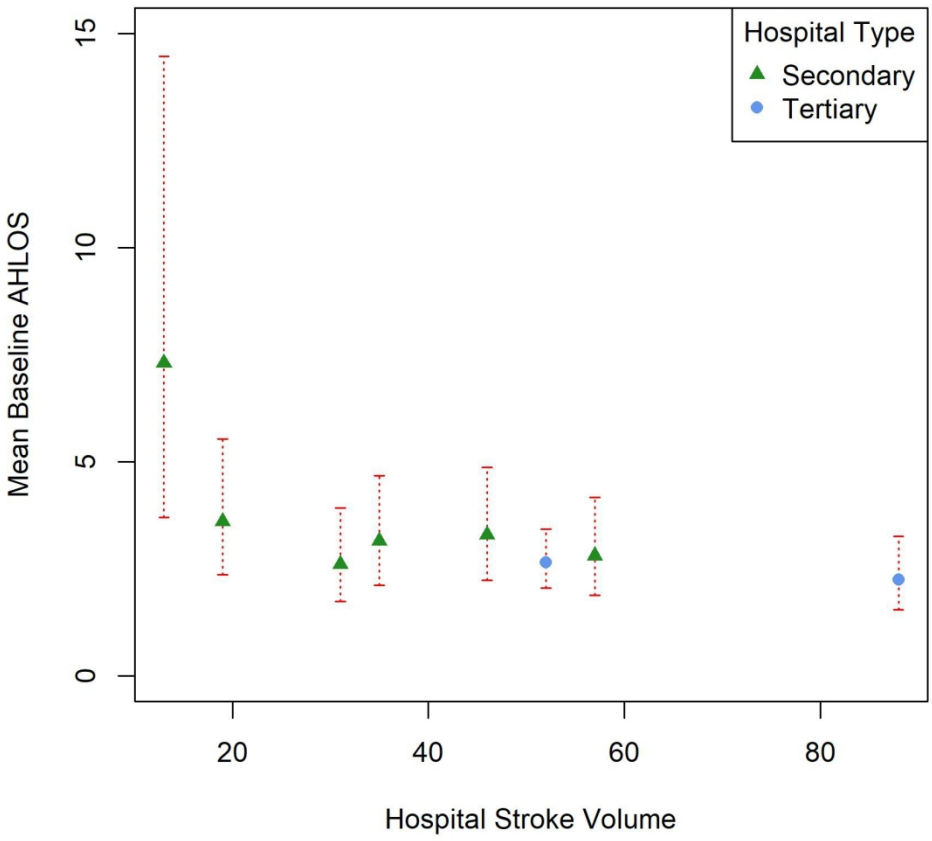


Figure 2 Model estimates of mean baseline AHLOS per hospital against hospital stroke volume and clustered by hospital type with 95% confidence intervals. Multiple regression model was adjusted for patient covariates.

152x152mm (300 x 300 DPI)

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BMC Health Services Research

STUDY PROTOCOL Open Access

# Evaluation of stroke services in Anglia stroke clinical network to examine the variation in acute services and stroke outcomes

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## Abstract

**Background:** Stroke is the third leading cause of death in developed countries and the leading cause of long-term disability worldwide. A series of national stroke audits in the UK highlighted the differences in stroke care between hospitals. The study aims to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes, after accounting for case mix differences and individual prognostic factors.

**Methods/Design:** We will conduct a cohort study in eight acute NHS trusts within East of England, with at least one year of follow-up after stroke. The study population will be a systematically selected representative sample of patients admitted with stroke during the study period, recruited within each hospital. We will collect individual patient data on prognostic characteristics, health care received, outcomes and costs of care and we will also record relevant characteristics of each provider organisation. The determinants of one year outcome including patient reported outcome will be assessed statistically with proportional hazards regression models. Self (or proxy) completed EuroQol (EQ-5D) questionnaires will measure quality of life at baseline and follow-up for cost utility analyses.

**Discussion:** This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services which will bring direct benefit to the patients.

## Background

Stroke is the third leading cause of mortality and the number one cause of long-term disability in the UK. More than 150,000 people suffer a stroke in the UK each year [1]. It costs the NHS approximately £ 7 billion per annum [2]. Stroke incidence rises sharply with age and despite better primary and secondary preventative measures, the total number of strokes is set to rise in the UK [3]. Nevertheless, stroke care in UK is far from ideal: patients having a worse outcome in terms of death and dependency than many other European countries [4-6], at least in part due to differences in care provided [7]. There is also variation in outcome between different localities within the UK [8-11], these local differences being highlighted in the most recent publication of the National Sentinel Stroke Audit in 2009 [12]. These differnces probably arise as a result of substantial variations in how the stroke services are provided across the UK. Examples of such differences are access to neurovascular/neurosurgical service, early supported

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discharge, and stroke specialist on call rota for thrombolysis. The presence or absence of variations in stroke outcomes as a result of variation in care and how much the observed variations in patients' outcomes including patient reported outcome measure (PROM) are determined by the differences in service delivery have not been examined previously.

We hypothesise that variation in patient outcomes including mortality, length of stay, institutionalisation rate, and patient reported outcomes between care providers can partly be explained by the different ways in which stroke services are delivered. The main objectives of the study are (1) to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes after accounting for case mix differences and individual prognostic factors, and (2) to obtain preliminary data to identify sample size and inform future pragmatic real world setting RCTs in the area of health service delivery in stroke.

## Methods/Design

A prospective cohort study will be conducted to identify characteristics of services that are associated with the best outcomes including patient reported outcomes, taking into account case-mix and patients' prognostic features. The study will consist of two components (1) consecutive stroke admissions in selected months (a total of 8 months) and (2) a prospective study of patient reported outcome in some of these selected months.

### Sample Population

For the first component, the sample population will be stroke patients who are admitted to any of the hospitals within the Anglia region of Stroke & Heart Clinical Network between October 2009 and September 2011. Baseline data are already recorded, prior to the study commencement, as part of routine clinical data collection by Anglia Stroke Clinical Network (as described in detail below). The study sample will be a systematically selected sample (every third month) rather than a consecutive cohort of patients admitted to eight acute NHS hospital trusts. Therefore, this is not a consecutive case study; instead it seeks to be representative of the catchment population of the hospital and has taken into account the seasonal variation in stroke incidence and outcome [13].

For the patient reported outcome component of the study the following inclusion and exclusion criteria will be used. Inclusion criteria are (1) age > = 18 years, (2) admitted to hospital with stroke (diagnosed by stroke physicians) during the study months, (3) able to provide informed consent or patient's personal consultee agrees to study participation. Exclusion criteria include (1) age <18 years, (2) patients with pre-existing diagnosis of dementia (for PROM component only).

The Anglia Stroke Network was funded through the NHS Improvement Programme, following the publication of the National Stroke Strategy in December 2007. The Network was established in April 2008 to support the development of stroke services in Norfolk, Suffolk and Cambridgeshire regions. Since its inception, the Network regularly collected data to capture clinical service activities of the eight acute hospital trusts in the Network for the purpose of monitoring of services benchmarked by National targets and guidance from National Institute of Health & Clinical Excellence (NICE) in England and Wales. Data collection commenced in January 2009 and involves the individual trusts collecting clinical data which is fed back to the network by monthly reports. The total number of strokes admitted to the 8 acute trusts within the Network is approximately 4,000 per annum in 2009. The stroke cases were identified prospectively data were collected by the clinical team who looked after the patients and anonymised raw clinical data were sent to the network on monthly basis. The network collates and analyses the data for above mentioned purposes.

### Sample size

Since this is an exploratory study designed to provide information for further analytic research, sample size will be determined partly pragmatically rather than on particular hypothesis tests. For illustration purposes, a total sample of 2264 patients would provide 80% power to detect a constant Hazard ratio (HR) of 0.76 for one-year mortality between two groups of roughly equal size, based on the log-rank test. This assumes a 20% one-year mortality rate in the reference group, no loss to follow-up before one year and 2-sided type I error of 5%. If one-year mortality is 30%, then 2264 patients would provide 76% power to detect a HR of 0.81.

### Plan of investigation

The study will have a cohort design. We will follow up a cohort of patients systematically selected from each trust. For pragmatic purposes we will sample all patients who are admitted every third month, starting from October 2009. Over one calendar month, there will be ~ 300-350 stroke cases entered into the Network Clinical Data. Between October 2009 and September 2011, the Clinical Network would have collected a total of eight 3-monthly datasets per trust (i.e. 8 study months in total: Oct 2009, Jan 2010, April 2010, July 2010, October 2010, Jan 2011, April 2011, July 2011). Therefore, the estimated total cohort size with baseline clinical data will be ~ 2,400 stroke cases

during this exercise (30% of 4000 patients admitted annually in 8 trusts = 1200 × 2 yrs).

We will collect patient data by hospital trusts and conduct a questionnaire survey of patients' outcomes. Due to the nature of the study we would need 100% follow-up in randomly selected populations. Because we will be using a partially historical cohort, to avoid selection bias for mortality outcome, informed consent from all eligible participants will not be feasible. Therefore, it is most appropriate for the clinical team to collect the outcome data to comply with current ethical guidance in the UK. Therefore, the identifiable patient data will only be held at the local NHS trusts.

Neither the network nor the investigators will have access to any identifiable patient information (e.g. name, address). For outcome data we will utilise death certificate and hospital episode data from the Patient Administrative System (PAS) as described previously [14,15]. This approach will be used in conjunction with telephone and postal follow-up for questionnaire surveys such as EQ-5 D, and Stroke Impact Scale. These data will be counter-checked using discharge coding records, which record each hospital episode.

The clinical teams will retrieve case records to collect (1) baseline measures which were not recorded in baseline Network surveys and (2) outcome measures including mortality and hospital length of stay. At study commencement (October 2010) one year follow up data can be collected immediately for October 2009 cohorts (follow up complete at end September 2010). The follow up will be completed in September 2012 as the stroke patients included in the last survey for the study conducted by the Network in July 2011 will complete one year follow-up in June 2012 and data collection of the study will be completed by July-August 2012 with the view of final cohort data arrival to research team by the end of December 2012.

Due to multi-centre nature of the study the individual sites are expected to join the study at different time points (after their respective NHS Research & Development Committees' approval). We will collect characteristics of stroke services, patient related factors, prognostic indicators, treatment options and trial/study participation. Missing prognostic data will be imputed statistically, to ensure that all eligible patients are included in the primary analysis (see also Statistical Methods).

The service characteristics of interest include:

***At hospital level***

- staffing (including junior doctors and therapists (whole time equivalent), physicians characteristics
- university or district general hospital
- distance from tertiary referral centre
- availability of vascular surgery on site, neuro-surgery and neuro ITU on site
- monitoring beds
- physician on call rota
- compliance with NICE guidelines

***At patient level***

- provision of thrombolysis and CT
- medication

### Outcome measurements

Primary outcome of the study will be one year mortality comparison between services with different characteristics. The secondary outcomes will include (1) final discharge destination (good or poor outcome) [16], (2) length of acute hospital stay, (3) length of stay in rehabilitation, (4) complications during acute and rehab-hospital stay and significant procedures (e.g. aspiration pneumonia, myocardial infarction), (5) readmissions, (6) composite cardiovascular events (recurrent TIA/Stroke/Acute Coronary Syndrome, Myocardial infarction).

### Patient Reported Outcome Measures (PROM)

PROM will consist of (1) Stroke Impact Scale, (2) health related quality of life: EQ-5 D at one year in those who completed questionnaire at the baseline, (3) modified RANKIN, (4) Barthel score and (5) health service use.

### Statistical analysis

Quantitative data will be analysed by multivariate Cox-proportional hazards to examine the relationships between different aspects of health services and time to death, adjusting for prognostic characteristics. Multiple logistic or linear regression models will be constructed as appropriate for dichotomised and continuous outcome variables respectively. T tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data will be used to compare continuous outcomes. Volume-outcome relationships will be investigated. Missing prognostic and EQ-5 D data will be imputed, based on each patient's other prognostic characteristics. Clustering of data by hospital trust will be investigated and, if necessary, taken into account, and intra-class correlation coefficients calculated to inform future research.

### Economic evaluation

Health care resources are scarce and it is therefore important to ensure that evaluations are undertaken in order to ensure that services provided by the NHS constitute value for money. Within this study we will thereby seek to estimate the cost-effectiveness of different stroke service deliveries.

Costs will first be calculated from the perspective of the NHS and personal social services (PSS). Thus, levels

of resources use will be recorded during the follow-up period, including the length of original hospital stay, input by the multi-disciplinary team, other investigations (e.g. x-ray) and any complications (including details of any further hospital admissions). Unit costs will subsequently be assigned to each of these resource items, enabling both the total mean cost in participants and the incremental cost between two different service deliveries (chosen to compare the cost effectiveness, e.g. traditional on call rota vs. telemedicine) to be calculated after adjusting for other factors. The main measure of effectiveness to be used in the economic analysis will the EQ-5 D [17], where responses will be sought at baseline, and at 12 month as mentioned above. This will enable the overall effect of each mode of service delivery, and the incremental effect of services to be estimated.

***Outcome***

As the National Institute of Health and Clinical Excellence [18] recommends use of the EQ-5 D [17] within cost-effectiveness analysis this will be our primary measure within the economic analyses. EQ-5 D data will be collected at two University Hospitals and two district general hospitals within the clinical network. We will use "mapping" strategy to estimate the cost-effectiveness analyses across the region. The use of mapping, where scores from a condition-specific (non preference-based) measure are 'converted' into a utility (preference-based) score using a pre-defined formulae, has been advocated (in certain instances) by the UK National Institute of Health and Clinical Excellence (NICE) [18], and has been used to estimate the utility scores, and in turn cost-effectiveness, of a number of health care interventions [19]. Mapping presents the possibility of not asking all participants to complete the EQ-5 D. In this study we propose to take advantage of this by developing a mapping algorithm based on the response from participants participating in this component to predict the EQ-5 D for participants in retrospective cohorts and those who did not participate in PROM component.

Because the quality of life measure (EQ-5D) which can be used to estimate health utility and calculate QALYs (Quality Adjusted Life Years) for economic evaluation is outside the remit of routine data collection and cannot be done retrospectively, we will collect EQ-5 D data in only the second year of the study (October 2010 and January, April and July 2011 cohorts and one year follow up data to be collected September and December 2011, and March and June 2012) in those who provide informed consent to the study (we estimate that the sample will be approximately 15-20% of the whole sample after excluding the one year pre-study period (between October 2009-September 2010) and after taking into account of refusal rate (estimated ~ 30%) in trusts with Stroke or Comprehensive Local Research Network Research Nurses.

**Economic Analysis**

In the Economic analysis if one option is shown to be less costly and more effective than another option (for example, telemedicine vs. on call system) then that option will 'dominate' the other and be deemed cost-effective. Alternatively, the incremental cost-effectiveness ratio (ICER) associated with a particular option will be estimated and assessed in relation to a range of cost-effectiveness thresholds. The associated level of uncertainty will also be characterised by e.g. estimating the cost-effectiveness acceptability curve (CEAC) for each intervention and conducting value of information analysis [20]. Sensitivity analysis will also be undertaken to assess the robustness of conclusions to key assumptions. We will also seek to identify what resource items should be monitored in a future study (i.e. what are the big cost drivers which are likely to be affected by the intervention) and how these items should be identified.

The study is funded by the NIHR Research for Patient Benefit Programme (PB-PG-1208-18240) and obtained ethical approval from the Norfolk Research Ethics Committee.

## Discussion

In this study we specifically aim to identify services that are associated with the best clinical outcomes including mortality and hospital length of stay including patient reported outcome adjusting for patient prognostic factors and potential confounders. Our study will be able to provide useful information in stroke service provision in UK and beyond. Furthermore, inclusion of patient reported outcome is novel and exciting component of our study.

Studies which have examined the delivery of specific services such as rapid imaging, have shown improvement in patients' outcome in stroke [21]. A recent report from Germany suggested that a telestroke network may be a useful strategy to implement in their non-urban stroke services [22]. Lees et al (2008) [23] highlighted that there is room for improvement in terms of acute services for stroke. Interestingly, one of the observations was that centres with higher workload performed better. There is also existing evidence in Cancer literature that centres with higher surgical caseload have better outcomes [24]. There has also been a recent evaluation of the impact on stroke outcome by evidence-based practice in an Australian setting [25]. Examples of service delivery that are associated with better outcomes include organised stroke unit care [26], thrombolysis treatment and appropriate secondary prevention [27], and early supported discharge

in selected patients [28,29]. However, the cost-effectiveness of such services has yet to be fully examined.

Rodgers et al [30] highlighted the need for improvement in hospital-based stroke services e.g. stroke unit staffing levels were lower than was available in RCTs. The accumulating body of evidence has been a major driving force behind the UK Government's strategy to improve stroke care (National Stroke Strategy, 2007) [31]. A key strand of the strategy was to set up stroke networks to deliver stroke service development across geographically defined areas. The stroke networks have worked to agree minimum standards for stroke care and they have worked with commissioners to assist the commissioning process for stroke services. The acute stroke services are currently delivered by different NHS trusts and there is therefore a wide range of inequality in service availability and provision with differeing structure and local support systems.

This research aims to utilise NHS data in the most meaningful and innovative way and we aim to maximize the benefit with minimum investment to produce best research output for patient care by collaborating with clinical teams and the network in providing excellent value for money. This observational study seeks to identify areas of clinical practice which merit future randomised controlled trials (RCTs) to identify best practice in improving stroke care which will be of maximum benefit to patients. We also aim to obtain preliminary data to estimate sample sizes and conduct value of information analyses to design future pragmatic RCTs of innovative ways of delivering stroke care.

As we include eight diverse NHS trusts, the findings are likely to be generalisable in the UK setting and beyond. This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will also inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services and bring direct benefit to patients.

The study will describe the variation in outcomes between different stroke services, and identify the characteristics of services associated with better outcomes after accounting for case-mix. We will also estimate the relative costs of and health gain estimated as Quality Adjusted Life Year (QALY) gain that may be demonstrated by different services. The commissioners of services will be informed as to which service delivery structures are likely to provide value for money to make purchasing decisions. They will also be better informed about the types of service associated with better patient reported outcome. Hospital trusts will be able to evaluate their services systematically and plan their care appropriately to meet local and regional needs and demands based on our study findings. Professionals will be able to reflect on the impact of services they are delivering to help improve their performance and the way services are organised by adopting the most effective and cost effective approaches. As an observational study, the study limitations include inability to control for unknown confounders and residual confounding effect of known confounders which are adjusted for. The causal relationship cannot be implied but as we stated the findings will provide knowledge about areas that requires further evaluation in clinical trial setting.

There is very little work which assesses service provision robustly against patients' own reported outcomes. This exciting study may lead to a clearer drive for patients to define what makes a good service. We hope that the best clinical practices are adopted to suit the local populations' needs and demand. As we included eight diverse NHS trusts, the findings will be generalisable in the UK setting and likely to be applicable in international setting. All these will become drivers of improvement in stroke services for the benefit of stroke sufferers.

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**Manuscripts that are under submission based on this protocol**
None.

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**Authors' contributions**
PKM, DJD, MOB designed the outline of the study. PKM, JFP, MOB, EAW, GMP, GAB and AKM obtained the funding for the study. SDM & RH contributed in protocol preparation. All authors contributed in writing of the paper. All authors read and approved the final manuscript. PKM is the guarantor.

**Competing interests**
The authors declare that they have no competing interests.

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Supplementary document to:

**Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study**

Michelle Tørnes, David McLernon, Max O Bachmann, Stanley D Musgrave, Elizabeth A Warburton, John F Potter, Phyo Kyaw Myint: On behalf of the Anglia Stroke Clinical Network Evaluation Study (ASCNES) Group

**CONTENT**

**Figure S7** Model estimates of mean baseline AHLOS per hospital and number of fte physiotherapists per five beds with 95% confidence intervals

**Figure S8** Model estimates of mean baseline AHLOS per hospital and number of fte speech and language therapists per five beds with 95% confidence intervals

**Figure S9** Model estimates of mean baseline AHLOS per hospital and number of total beds present on stroke unit with 95% confidence intervals

**Figure S10** Model estimates of mean baseline AHLOS per hospital and number of hospital beds per CT scanner with 95% confidence intervals

**Figure S11** Model estimates of mean baseline AHLOS per hospital and provision of onsite rehabilitation service with 95% confidence intervals

**Figure S12** Model estimates of mean baseline AHLOS per hospital and presence of early supported discharge scheme with 95% confidence intervals

**Figure S13** Model estimates of mean baseline AHLOS per hospital and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals

**Figure S14** Model estimates of mean baseline AHLOS per hospital and number of stroke patients treated outside the stroke unit per day per five stroke unit beds with 95% confidence intervals

**Table S1** Variables used to inform multiple imputation of missing data

| Variable | Measure |
|---|---|
| I. Independent Variables | |
| Trust | 0=Trust 1 1 =Trust 2 2 =Trust 3 3=Trust 4 4=Trust 5 4=Trust 6 5=Trust 7 6=Trust 8 |
| Sex | 0=Male 1=Female |
| Age | Continuous, years |
| Recurrent Stroke | 0=No 1=Yes |
| Diabetes Mellitus | 0=No 1=Yes |
| Dementia | 0=No 1=Yes |
| Hypercholesterolemia | 0=No 1=Yes |
| Myocardial Infarction or Ischaemic Heart Disease | 0=No 1=Yes |
| Transient Ischaemic Attack | 0=No 1=Yes |
| Previous Cancer | 0=No 1=Yes |
| Active Cancer | 0=No 1=Yes |
| Depression | 0=No 1=Yes |
| Rheumatoid Arthritis | 0=No 1=Yes |
| Chronic Obstructive Pulmonary Disease | 0=No 1=Yes |
| Pre-Stroke Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 & 5 |
| Pre-Stroke Residence | 0=Independent living without formal care<br>1=Independent living with formal care<br>2=Institutional care |
| Stroke Type | 0=Ischaemic 1=Haemorrhagic |
| Oxfordshire Community Stroke Classification | 0=LACS 1=PACS 2=POCS 3=TACS |
| Brain Lateralisation | 0=Yes 1=No |
| Inpatient Complication | 0=No 1=Yes |
| Discharge Destination | 0=Independent living without formal care<br>1=Independent living with formal care<br>2=Institutional care<br>3=Interim or rehabilitation setting<br>4=Death |
| Season of Admission | 0=Summer 1=Winter |
| Day of Admission | 0=Weekday 1=Weekend |
| II. Dependent Variable | |
| Logarithmic acute hospital LOS | Continuous, days |
| III. Auxiliary Variables | |
| Discharge Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 5=5 6=6 |
| Atrial Fibrillation | 0=No 1=Yes |
| Baseline Systolic Blood Pressure | Continuous, mmHg |
| Baseline Diastolic Blood Pressure | Continuous, mmHg |
| Glucose Concentration on Admission | Continuous, mmol/L |
| Weight | Continuous, kg |
| Heart Rate | Continuous, beats per minute |
| Temperature | Continuous, ˚C |
| Oxygen Saturation | Continuous, % |
| ITU or HDU admission | 0. No 1. Yes |
| Systolic Blood Pressure at Discharge | Continuous, mmHg |
| Diastolic Blood Pressure at Discharge | Continuous, mm Hg |

**Table S2** Sample characteristics of the 2333 patients included in analysis per individual hospital (n (%) unless otherwise stated)

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Age, y, median (IQR) | 78<br>(68 to 85) | 87<br>(81 to 92) | 79<br>(72 to 86) | 79<br>(70 to 86) | 79<br>(71 to 85) | 78<br>(71 to 85) | 80<br>(68 to 85) | 80<br>(71 to 87) |
| Sex, female | 180 (52) | 9 (56) | 197 (56) | 76 (53) | 309 (50) | 155 (55) | 116 (46) | 123 (55) |
| Recurrent Stroke | 50 (14) | 5 (31) | 61 (17) | 19 (17) | 143 (23) | 62 (22) | 66 (26) | 42 (19) |
| Diabetes Mellitus | 48 (14) | 1 (6) | 59 (17) | 17 (15) | 92 (15) | 66 (23) | 44 (17) | 43 (19) |
| Dementia | 26 (7) | 1 (6) | 35 (10) | 10 (9) | 58 (9) | 29 (10) | 23 (9) | 25 (11) |
| Hypercholesterolemia | 48 (14) | 3 (19) | 24 (7) | 7 (6) | 61 (10) | 80 (28) | 38 (15) | 94 (42) |
| Hypertensive | 225 (64) | 8 (50) | 202 (58) | 56 (50) | 446 (72) | 200 (71) | 187 (74) | 159 (71) |
| Myocardial Infarction or Ischaemic Heart Disease | 45 (13) | 3 (19) | 87 (25) | 30 (27) | 142 (23) | 80 (28) | 49 (19) | 81 (36) |
| Transient Ischaemic Attack | 32 (9) | 3 (19) | 58 (17) | 17 (15) | 113 (18) | 40 (14) | 47 (19) | 30 (13) |
| Previous Cancer | 33 (9) | 1 (6) | 38 (11) | 12 (11) | 41 (7) | 18 (6) | 21 (8) | 31 (14) |
| Active Cancer | 24 (7) | 2 (12) | 8 (2) | 10 (9) | 49 (8) | 9 (3) | 20 (8) | 15 (7) |
| Depression | 13 (4) | 0 (0) | 17 (5) | 8 (7) | 33 (5) | 11 (4) | 18 (7) | 17 (8) |
| Rheumatoid Arthritis | 11 (3) | 1 (6) | 43 (12) | 3 (3) | 83 (13) | 2 (1) | 7 (3) | 4 (2) |
| COPD | 15 (4) | 1 (6) | 20 (6) | 6 (5) | 26 (4) | 20 (7) | 11 (4) | 17 (8) |
| Pre-stroke Rankin Score | | | | | | | | |
| 0 | 84 (43) | 3 (19) | 117 (36) | - | 330 (56) | 126 (64) | 136 (56) | 118 (53) |
| 1 | 60(31) | 3 (19) | 75 (23) | - | 87 (15) | 16 (8) | 61 (25) | 33 (15) |
| 2 | 24 (12) | 3 (19) | 51 (16) | - | 56 (9) | 17 (9) | 16 (7) | 24 (11) |
| 3 | 21 (11) | 2 (12) | 38 (12) | - | 60 (10) | 20 (10) | 15 (6) | 28 (13) |
| 4 & 5 | 7 (4) | 5 (31) | 44 (14) | - | 57 (10) | 18 (9) | 16 (7) | 20 (9) |
| Pre-Stroke Residence | | | | | | | | |
| Independent living with formal care | 21 (6) | 4 (25) | 23 (7) | 15 (14) | 62 (10) | 30 (11) | 34 (13) | 21 (10) |
| Independent living w/o formal care | 292 (86) | 9 (56) | 285 (82) | 86 (77) | 493 (80) | 215 (77) | 193 (77) | 179 (82) |
| Institution | 28 (8) | 3 (19) | 40 (11) | 10 (9) | 63 (10) | 35 (12) | 23 (9) | 18 (8) |

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Stroke Type | | | | | | | | |
| Ischaemic | 293 (85) | 14 (100) | 286 (87) | 90 (91) | 541 (88) | 233 (85) | 213 (87) | 194 (88) |
| Haemorrhagic | 50 (15) | 0 (0) | 43 (13) | 9 (9) | 73 (12) | 40 (15) | 32 (13) | 26(12) |
| Oxford Community Stroke Project Classification | | | | | | | | |
| LACS | 64 (24) | 1 (7) | 95 (29) | 20 (28) | 149 (25) | 51 (18) | 39 (19) | 84 (39) |
| PACS | 117 (43) | 11 (79) | 109 (33) | 38 (54) | 216 (37) | 147 (53) | 80 (39) | 66 (30) |
| POCS | 51 (19) | - | 29 (9) | 3 (4) | 117 (20) | 21 (8) | 33 (16) | 25 (12) |
| TACS | 38 (14) | 2 (14) | 99 (30) | 10 (14) | 107 (18) | 57 (21) | 52 (25) | 42 (19) |
| No Brain Lateralisation | 50 (15) | 2 (13) | 14 (4) | 9 (9) | 129 (21) | 1 (0.4) | 30 (12) | 9 (4) |
| Inpatient Complication | 108 (31) | 4 (25) | 34 (10) | 36 (25) | 229 (37) | 109 (39) | 83 (33) | 52 (23) |
| Discharge Destination | | | | | | | | |
| Death | 53 (17) | 5 (31) | 77 (22) | 29 (21) | 110 (18) | 58 (21) | 47 (19) | 35 (16) |
| Independent living with formal care | 54 (17) | 2 (12) | 24 (7) | 3 (2) | 34 (6) | 42 (15) | 44 (18) | 21 (10) |
| Independent living w/o formal care | 147 (48) | 7 (44) | 141 (40) | 78 (55) | 272 (44) | 112 (40) | 119 (47) | 130 (59) |
| Institution | 29 (9) | 2 (12) | 57 (16) | 13 (9) | 50 (8) | 33 (12) | 34 (14) | 34 (15) |
| Interim/rehab Setting | 26 (8) | 0 (0) | 51 (15) | 18 (13) | 152 (25) | 32 (12) | 7 (3) | 1 (0) |
| Winter Admission | 172 (49) | 16 (100) | 181 (52) | 73 (51) | 332 (54) | 140 (50) | 131 (52) | 114 (51) |
| Weekend Admission | 113 (32) | 3 (19) | 98 (28) | 43 (30) | 177 (29) | 74 (26) | 55 (22) | 51 (23) |

**Table S3** Sample characteristics of complete cases and those with at least one variable missing

| Patient Characteristic | Complete Cases (n=1486) | Cases with at least one missing variable (n=747) |
|---|---|---|
| | Median (IQR) or No. (%) | |
| Age, y | 79 (71 to 86) | 79 (69 to 86) |
| Sex, female | 777 (52) | 388 (52) |
| Recurrent Stroke | 327 (22) | 121 (17) |
| Diabetes Mellitus | 257 (17) | 113 (16) |
| Dementia | 138 (9) | 69 (10) |
| Hypercholesterolemia | 262 (18) | 93 (13) |
| Hypertensive | 1047 (70) | 436 (61) |
| Myocardial Infarction or Ischaemic Heart Disease | 361 (24) | 156 (22) |
| TIA | 248 (17) | 92 (13) |
| Previous Cancer | 140 (9) | 55 (8) |
| Active Cancer | 91 (6) | 46 (6) |
| Depression | 78 (5) | 39 (5) |
| Rheumatoid Arthritis | 129 (9) | 25 (3) |
| COPD | 76 (5) | 40 (6) |
| Pre-stroke Rankin Score | | |
| 0 | 758 (51) | 156 (51) |
| 1 | 281 (19) | 54 (18) |
| 2 | 167 (11) | 24 (8) |
| 3 | 149 (10) | 35 (11) |
| 4 & 5 | 131 (9) | 36 (12) |
| Pre-stroke Residence | | |
| Independent living with formal care | 145 (10) | 65 (9) |
| Independent living without formal care | 1205 (81) | 547 (79) |
| Institution | 136 (9) | 84 (12) |
| Haemorrhagic Stroke | 138 (9) | 135 (21) |
| Oxford Community Stroke Project Classification | | |
| LACS | 405 (27) | 98 (20) |
| PACS | 569 (38) | 215 (44) |
| POCS | 211 (14) | 68 (14) |
| TACS | 301 (20) | 106 (22) |
| No Brain Lateralisation | 173 (12) | 71 (12) |
| Inpatient Complication | 419 (28) | 236 (32) |
| Discharge Destination | | |
| Death | 233 (16) | 181 (26) |
| Independent living with formal care | 145 (10) | 79 (11) |
| Independent living without formal care | 708 (48) | 298 (43) |
| Institution | 181 (12) | 71 (10) |
| Interim/Rehab Setting | 219 (15) | 68 (10) |
| Winter Admission | 766 (52) | 393 (53) |
| Weekend Admission | 401 (27) | 213 (29) |

**Table S4** Univariable regression analysis for multiply imputed dataset for AHLOS (n=2233).

| Patient Characteristic | β | 95% CI | *P* | $R^2$ |
|---|---|---|---|---|
| Age, y | 1.02 | 1.02 to 1.02 | <0.001 | 4.8 |
| Sex, female | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 1.17 | 1.05 to 1.31 | 0.01 | 0.4 |
| Diabetes Mellitus | 1.16 | 1.03 to 1.31 | 0.02 | 0.3 |
| Dementia | 1.46 | 1.25 to 1.70 | <0.001 | 1.1 |
| Hypercholesterolemia | 0.84 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1.02 | 0.93 to 1.12 | 0.66 | 0 |
| Myocardial Infarction/ Ischaemic Heart Disease* | 1.07 | 0.96 to 1.19 | 0.23 | 0.1 |
| TIA | 1.07 | 0.94 to 1.21 | 0.30 | 0.1 |
| Previous Cancer | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 0.97 | 0.80 to 1.16 | 0.72 | 0 |
| Depression | 1.06 | 0.86 to 1.29 | 0.59 | 0 |
| Rheumatoid Arthritis | 1.10 | 0.92 to 1.31 | 0.31 | 0.1 |
| COPD | 0.86 | 0.71 to 1.06 | 0.15 | 0.1 |
| Pre-stroke Rankin Score (reference 0) | | | <0.001 | 5.5 |
| 1 | 1.57 | 1.38 to 1.79 | <0.001 | |
| 2 | 1.63 | 1.39 to 1.91 | <0.001 | |
| 3 | 1.94 | 1.65 to 2.28 | <0.001 | |
| 4 & 5 | 1.32 | 1.13 to 1.55 | <0.001 | |
| Pre-stroke Residence (reference Independent living w/o formal care) | | | <0.001 | 1.4 |
| Independent living with formal care | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 1.13 | 0.97 to 1.31 | 0.11 | |
| Haemorrhagic Stroke | 0.83 | 0.73 to 0.96 | 0.01 | 0.3 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 | 4.0 |
| PACS | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 1.22 | 1.05 to 1.42 | 0.01 | |
| TACS | 1.66 | 1.45 to 1.90 | <0.001 | |
| Brain Lateralisation | 0.69 | 0.60 to 0.80 | <0.001 | 1.2 |
| Inpatient Complication | 2.13 | 1.94 to 2.34 | <0.001 | 10.3 |
| Discharge Destination (reference Independent living w/o formal care) | | | <0.001 | 25.7 |
| Independent living with formal care | 2.56 | 2.24 to 2.93 | <0.001 | |
| Institution | 4.44 | 3.91 to 5.05 | <0.001 | |
| Interim/Rehab Setting | 2.61 | 2.31 to 2.94 | <0.001 | |
| Death | 1.15 | 1.03 to 1.28 | 0.01 | |
| Summer Admission | 1.20 | 1.09 to 1.31 | <0.001 | 0.7 |
| Weekday Admission | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | <0.001 | 2.4 |
| 2 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 1.18 | 1.00 to 1.41 | 0.05 | |
| 8 | 0.86 | 0.72 to 1.03 | 0.11 | |

**Table S5** Univariable linear regression complete case analysis for AHLOS

| Patient Characteristic | N | β | 95% CI | *P* | % $R^2$ |
|---|---|---|---|---|---|
| Age, y | 2231 | 1.02 | 1.02 to 1.02 | <0.001 | 4.7 |
| Sex, female | 1165 v. 1066 | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 448 v. 1755 | 1.17 | 1.05 to 1.31 | 0.005 | 0.3 |
| Diabetes Mellitus | 370 v. 1833 | 1.16 | 1.03 to 1.31 | 0.02 | 0.2 |
| Dementia | 207 v. 1996 | 1.46 | 1.25 to 1.70 | <0.001 | 1.0 |
| Hypercholesterolemia | 355 v. 1848 | 0.85 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1483 v. 720 | 1.03 | 0.93 to 1.13 | 0.57 | 0 |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 v. 1686 | 1.07 | 0.96 to 1.19 | 0.23 | 0 |
| TIA | 340 v. 1863 | 1.06 | 0.94 to 1.20 | 0.32 | 0 |
| Previous Cancer | 195 v. 2008 | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 137 v. 2066 | 0.96 | 0.80 to 1.15 | 0.65 | 0 |
| Depression | 117 v. 2086 | 1.05 | 0.86 to 1.28 | 0.65 | 0 |
| Rheumatoid Arthritis | 154 v. 2049 | 1.10 | 0.92 to 1.31 | 0.31 | 0 |
| COPD | 116 v. 2087 | 0.86 | 0.70 to 1.05 | 0.14 | 0.1 |
| Pre-stroke Rankin Score (reference 0) | | | | <0.001 | 5.8 |
| 1 | 335 v. 914 | 1.58 | 1.39 to 1.80 | <0.001 | |
| 2 | 191 v. 914 | 1.62 | 1.38 to 1.90 | <0.001 | |
| 3 | 184 v. 914 | 1.97 | 1.67 to 2.31 | <0.001 | |
| 4 & 5 | 167 v. 914 | 1.45 | 1.22 to 1.71 | <0.001 | |
| Pre-stroke Residence (reference Independent living without formal care) | | | | <0.001 | 1.3 |
| Independent living with formal care | 210 v. 1752 | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 220 v. 1752 | 1.14 | 0.98 to 1.32 | 0.09 | |
| Haemorrhagic Stroke | 273 v. 1864 | 0.85 | 0.74 to 0.97 | 0.02 | 0.2 |
| Oxford Community Stroke Project Classification (reference LACS) | | | | <0.001 | 4.3 |
| PACS | 784 v. 503 | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 279 v. 503 | 1.24 | 1.06 to 1.44 | 0.01 | |
| TACS | 407 v. 503 | 1.75 | 1.53 to 2.01 | <0.001 | |
| No Brain Lateralisation | 244 v. 1822 | 0.68 | 0.59 to 0.79 | <0.001 | 1.3 |
| Inpatient Complication | 655 v. 1578 | 2.13 | 1.94 to 2.34 | <0.001 | 10 |
| Discharge Destination (reference Independent living without formal care) | | | | <0.001 | 25 |
| Independent living with formal care | 414 v. 1006 | 2.56 | 2.24 to 2.92 | <0.001 | |
| Institution | 224 v. 1006 | 4.38 | 3.86 to 4.97 | <0.001 | |
| Interim/Rehab Setting | 252 v. 1006 | 2.61 | 2.31 to 2.94 | <0.001 | |
| Death | 287 v. 1006 | 1.13 | 1.02 to 1.26 | 0.02 | |
| Winter Admission | 1159 v. 1074 | 1.20 | 1.09 to 1.31 | <0.001 | 0.6 |
| Weekend Admission | 614 v. 1619 | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | | <0.001 | 2.1 |
| 2 | 16 v. 350 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 350 v. 350 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 143 v. 350 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 618 v. 350 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 281 v. 350 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 252 v. 350 | 1.18 | 1.00 to 1.41 | 0.05 | |
| 8 | 223 v. 350 | 0.86 | 0.72 to 1.03 | 0.11 | |

**Table S6** Multiple Linear Regression Complete Case Analysis for AHLOS (n=1554, $R^2$=43%).

| Patient Characteristic | N | β | 95% CI | *P* |
|---|---|---|---|---|
| Age, y | 1554 | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 816 v. 738 | 0.96 | 0.88 to 1.04 | 0.32 |
| Recurrent Stroke | 335 v. 1219 | 1.00 | 0.91 to 1.11 | 0.98 |
| Diabetes Mellitus | 265 v. 1289 | 1.00 | 0.90 to 1.12 | 0.94 |
| Dementia | 142 v. 1412 | 1.26 | 1.08 to 1.46 | 0.003 |
| Hypercholesterolemia | 271 v. 1283 | 0.93 | 0.84 to 1.04 | 0.22 |
| Myocardial Infarction or Ischaemic Heart | 377 v. 1177 | 1.00 | 0.91 to 1.10 | 0.98 |
| Previous Cancer | 146 v. 1408 | 1.19 | 1.04 to 1.37 | 0.01 |
| COPD | 83 v. 1471 | 0.91 | 0.77 to 1.09 | 0.32 |
| Pre-stroke Rankin Score (reference 0) | | | | <0.001 |
| 1 | 294 v. 799 | 1.11 | 1.00 to 1.24 | 0.06 |
| 2 | 173 v. 799 | 1.16 | 1.01 to 1.33 | 0.04 |
| 3 | 155 v. 799 | 1.34 | 1.14 to 1.58 | <0.001 |
| 4 & 5 | 133 v. 799 | 1.27 | 1.05 to 1.53 | 0.01 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | | <0.001 |
| Independent living with formal care | 154 v. 1262 | 0.86 | 0.74 to 1.00 | 0.05 |
| Institution | 138 v. 1262 | 0.49 | 0.40 to 0.59 | <0.001 |
| Haemorrhagic Stroke | 141 v. 1413 | 0.90 | 0.78 to 1.04 | 0.15 |
| Oxford Community Stroke Project Classification | | | | <0.001 |
| PACS | 602 v. 425 | 1.28 | 1.16 to 1.42 | <0.001 |
| POCS | 220 v. 425 | 1.39 | 1.22 to 1.59 | <0.001 |
| TACS | 307 v. 425 | 1.56 | 1.37 to 1.79 | <0.001 |
| No Brain Lateralisation | 178 v. 1376 | 0.90 | 0.79 to 1.03 | 0.11 |
| Inpatient Complication | 442 v. 1112 | 1.65 | 1.50 to 1.82 | <0.001 |
| Discharge Destination (reference Independent living without formal care) | | | | <0.001 |
| Independent living with formal care | 156 v. 743 | 1.97 | 1.70 to 2.29 | <0.001 |
| Institution | 187 v. 743 | 3.73 | 3.17 to 4.39 | <0.001 |
| Interim/Rehab Setting | 235 v. 743 | 2.17 | 1.91 to 2.46 | <0.001 |
| Death | 233 v. 743 | 0.98 | 0.84 to 1.15 | 0.82 |
| Winter Admission | 798 v. 756 | 1.14 | 1.05 to 1.23 | 0.001 |
| Weekend Admission | 425 v. 1129 | 1.04 | 0.95 to 1.13 | 0.39 |
| Hospital (reference1) | | | | <0.001 |
| 2 | 14 v. 134 | 2.80 | 1.81 to 4.34 | <0.001 |
| 3 | 384 v. 134 | 1.39 | 1.18 to 1.65 | <0.001 |
| 4 | - | - | - | - |
| 5 | 568 v. 134 | 0.90 | 0.77 to 1.04 | 0.16 |
| 6 | 159 v. 134 | 1.23 | 1.02 to 1.49 | 0.03 |
| 7 | 194 v. 134 | 1.37 | 1.14 to 1.63 | <0.001 |
| 8 | 201 v. 134 | 1.11 | 0.93 to 1.33 | 0.23 |

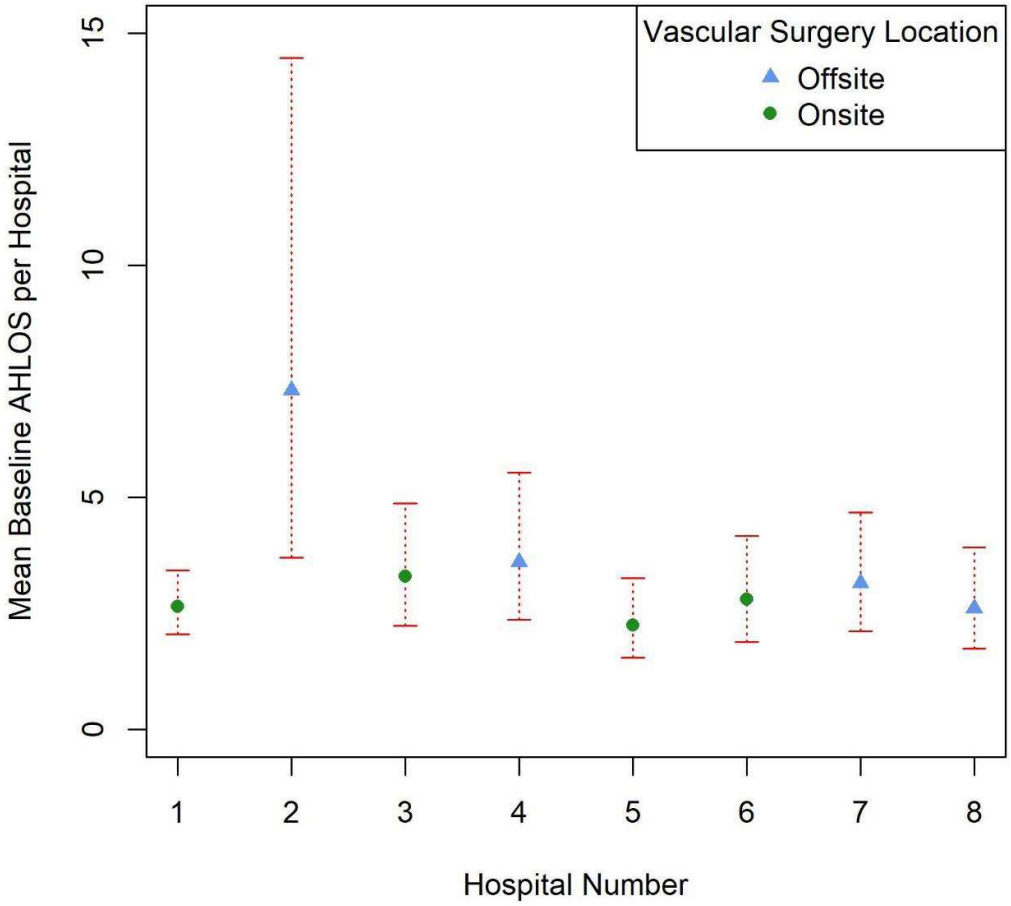


**Figure S1** Model estimates of mean baseline AHLOS per hospital and presence of vascular surgery onsite with 95% confidence intervals

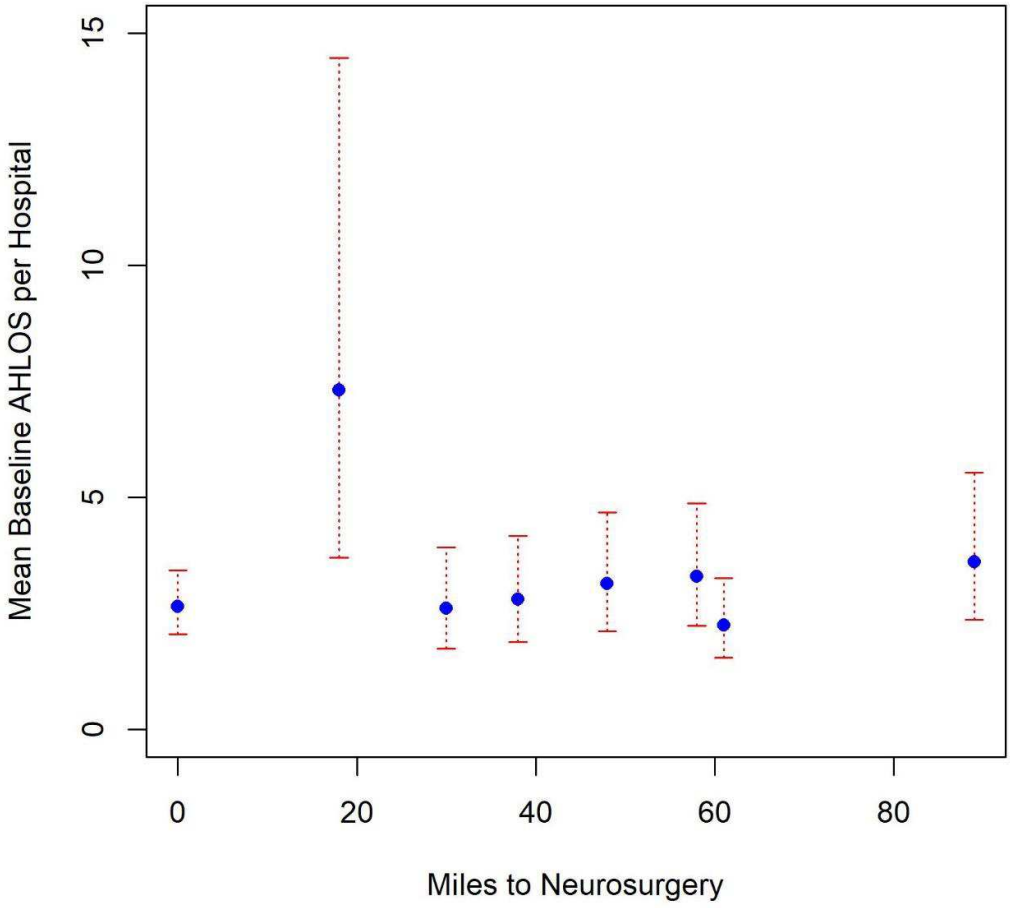


**Figure S2** Model estimates of mean baseline AHLOS per hospital and distance to neurosurgical facility with 95% confidence intervals

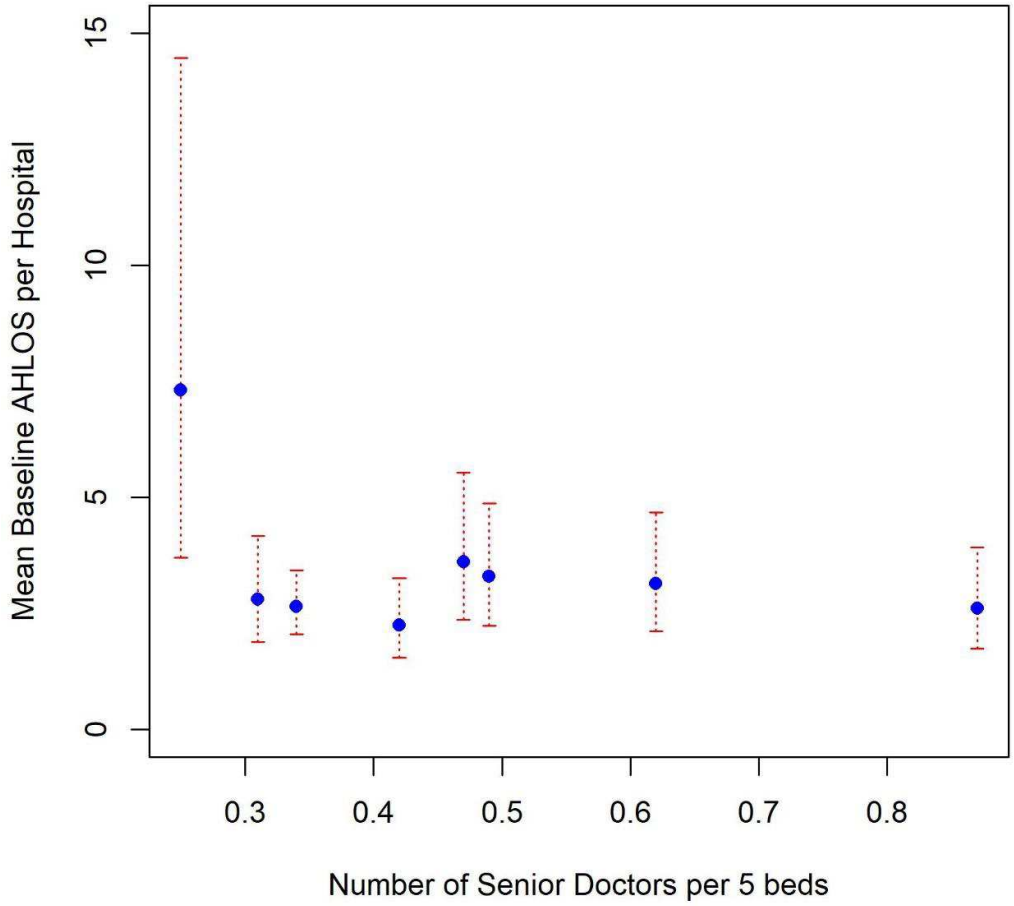


**Figure S3** Model estimates of mean baseline AHLOS per hospital and number of fte senior doctors per five beds available during weekdays with 95% confidence intervals

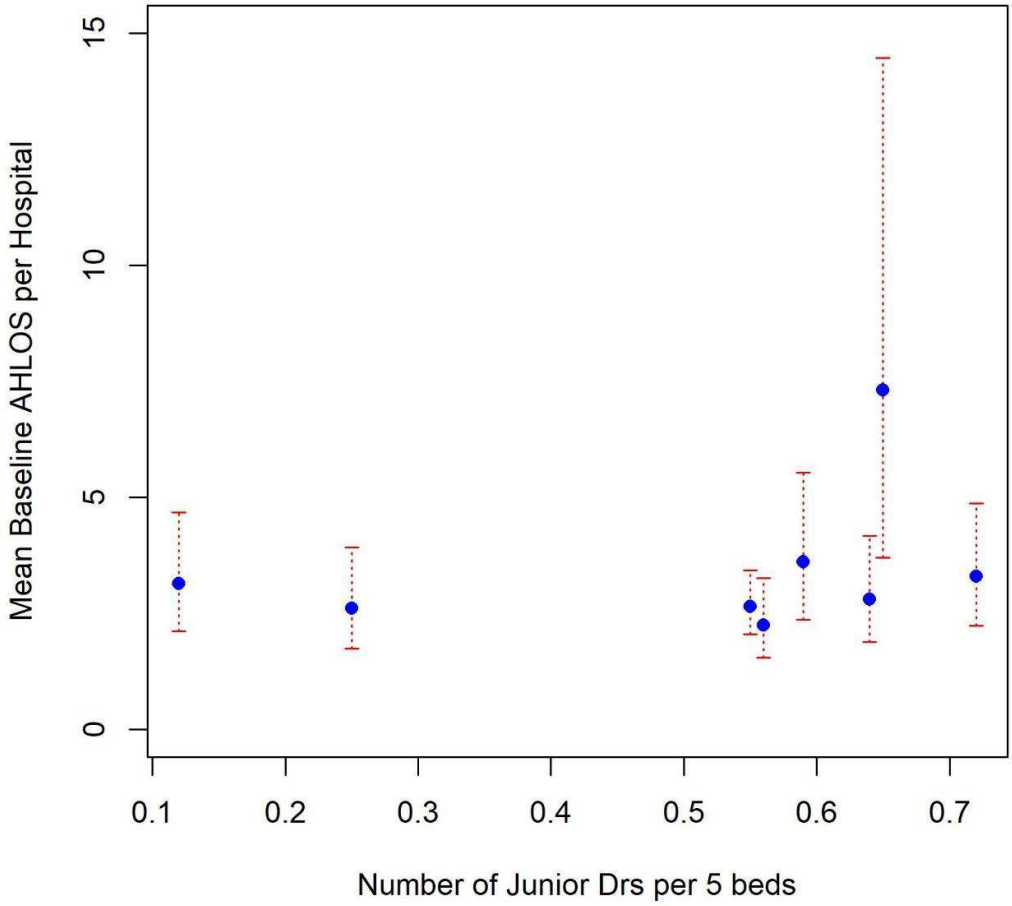


**Figure S4** Model estimates of mean baseline AHLOS per hospital and number of fte junior doctors per five beds available during weekdays with 95% confidence intervals

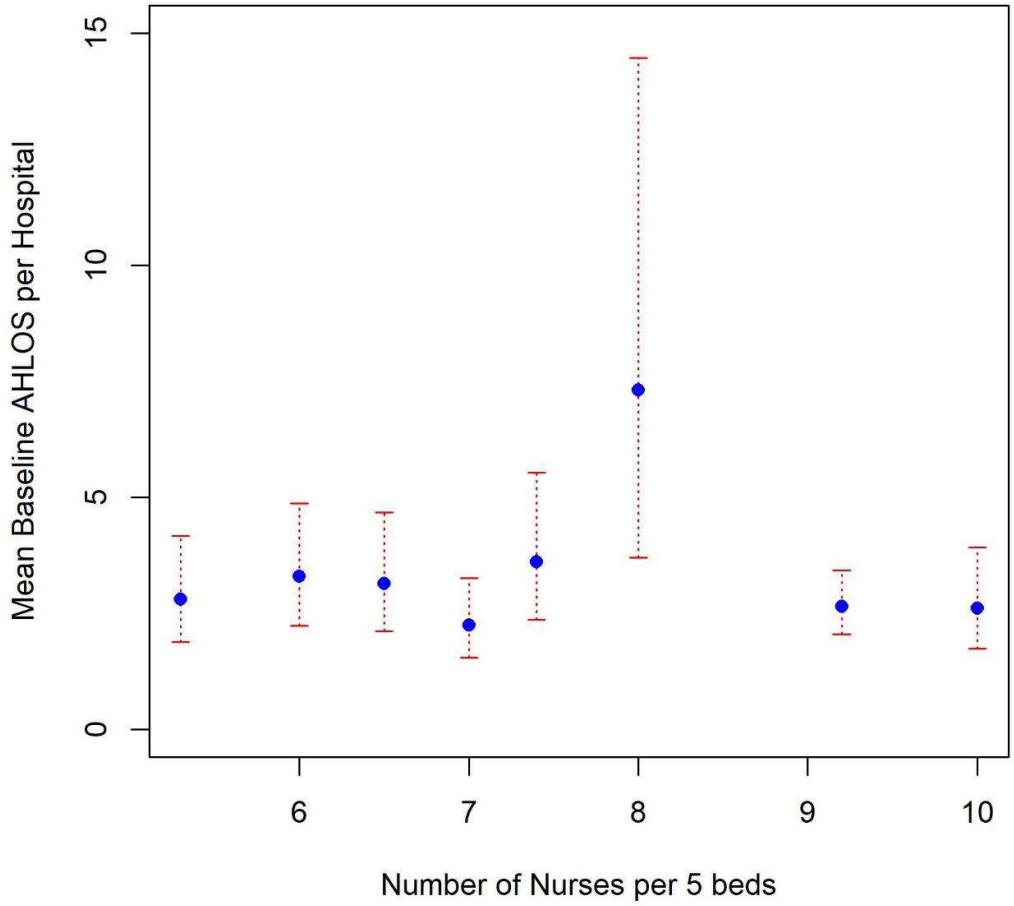


**Figure S5** Model estimates of mean baseline AHLOS per hospital and number of fte health care associates and nurses per five beds with 95% confidence intervals

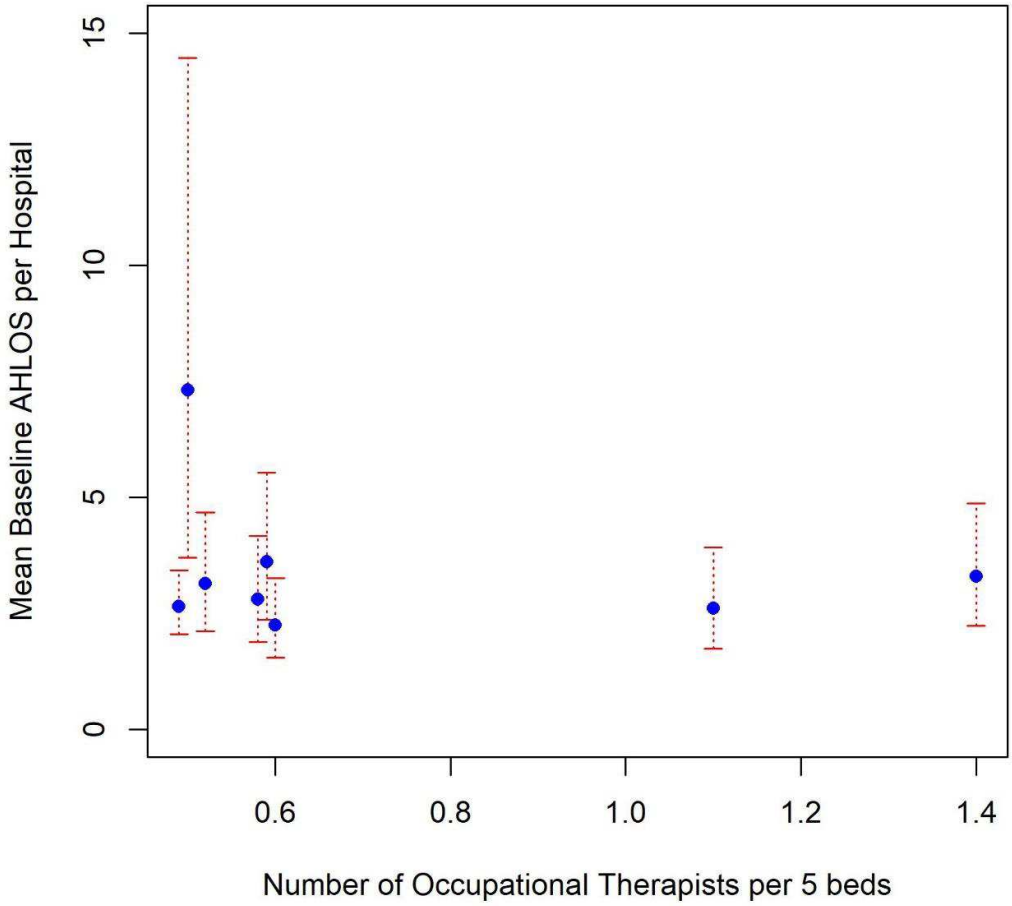


**Figure S6** Model estimates of mean baseline AHLOS per hospital and number of fte occupational therapists per five beds with 95% confidence intervals

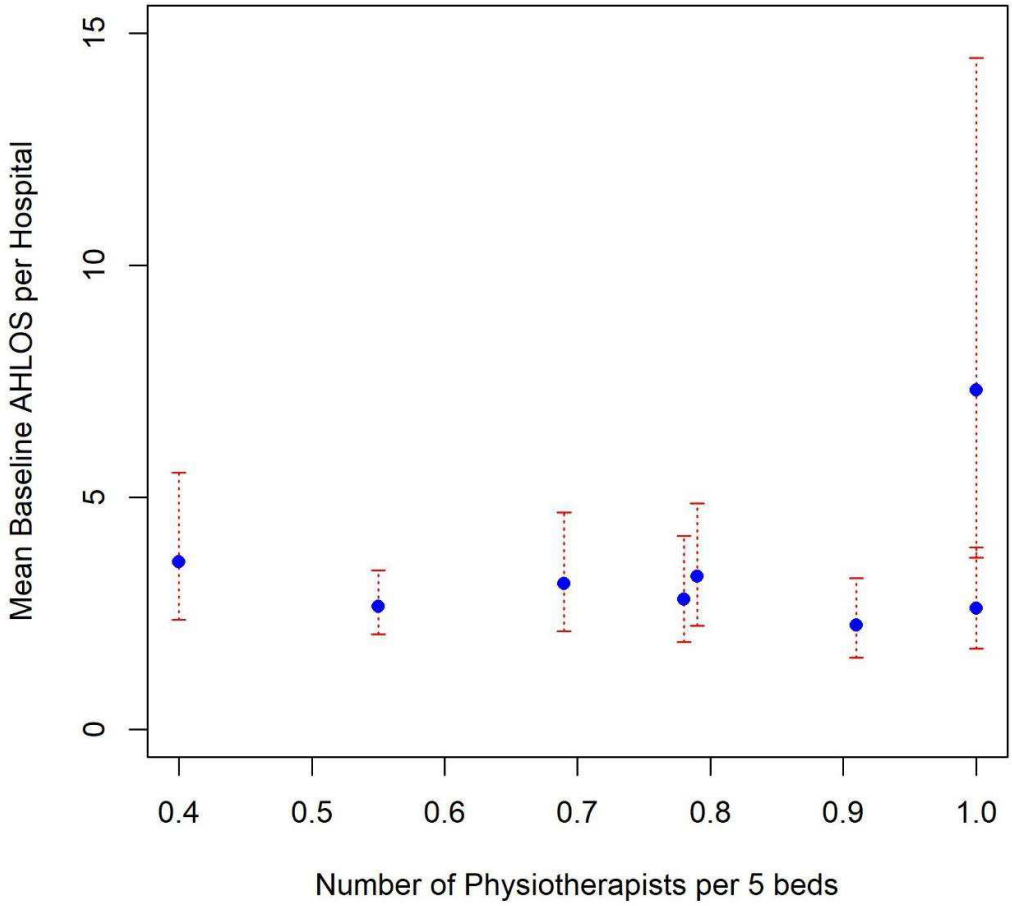


**Figure S7** Model estimates of mean baseline AHLOS per hospital and number of fte physiotherapists per five beds with 95% confidence intervals

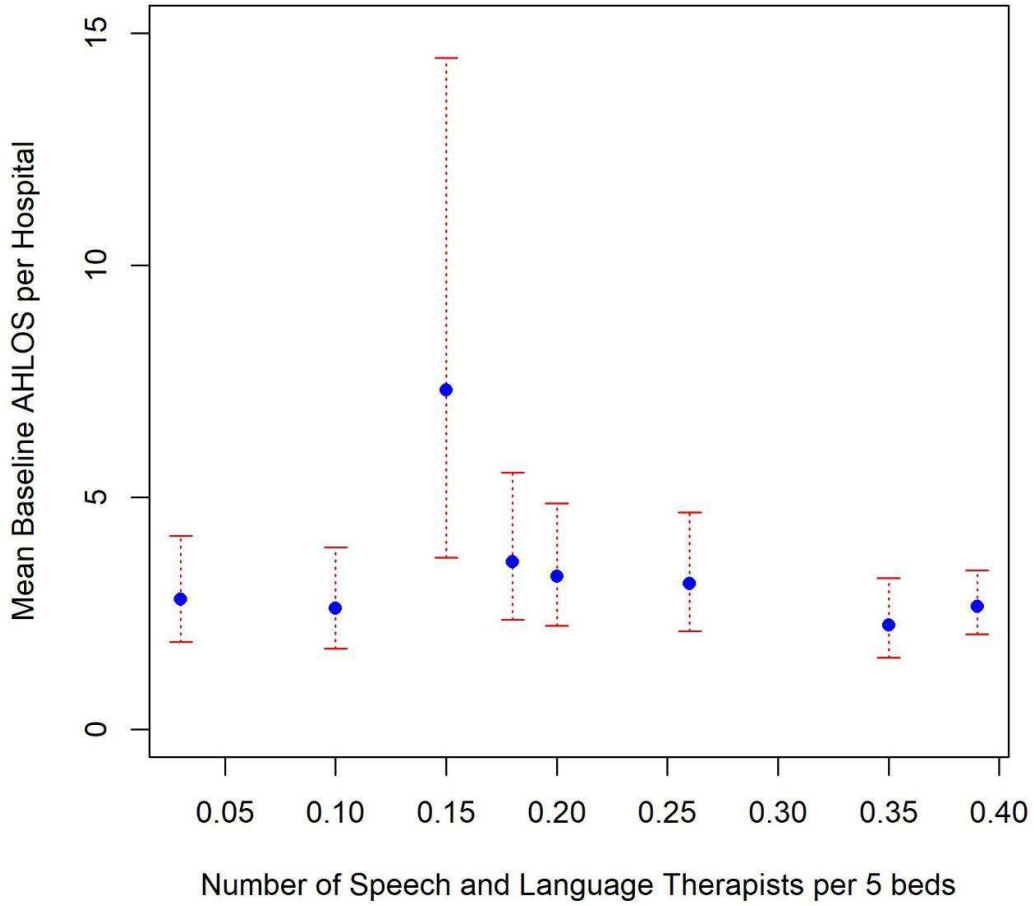


**Figure S8** Model estimates of mean baseline AHLOS per hospital and number of fte speech and language therapists per five beds with 95% confidence intervals

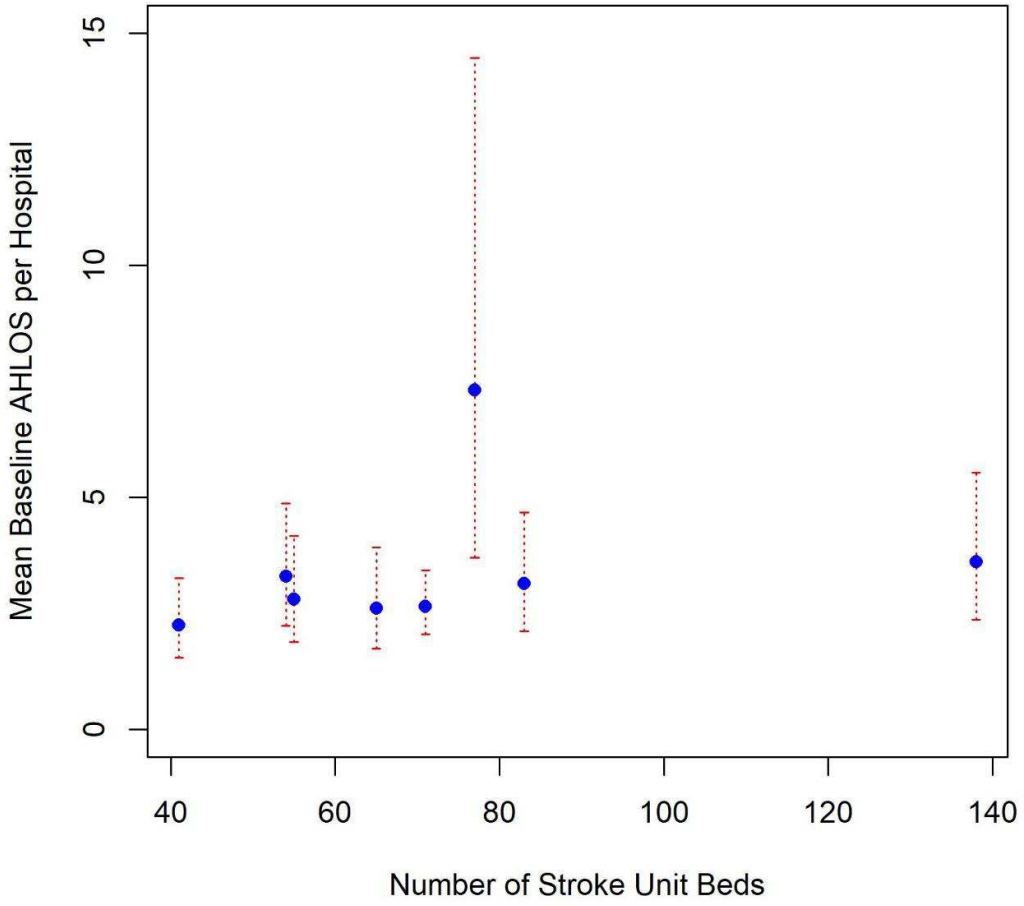


**Figure S9** Model estimates of mean baseline AHLOS per hospital and number of total beds present on stroke unit with 95% confidence intervals

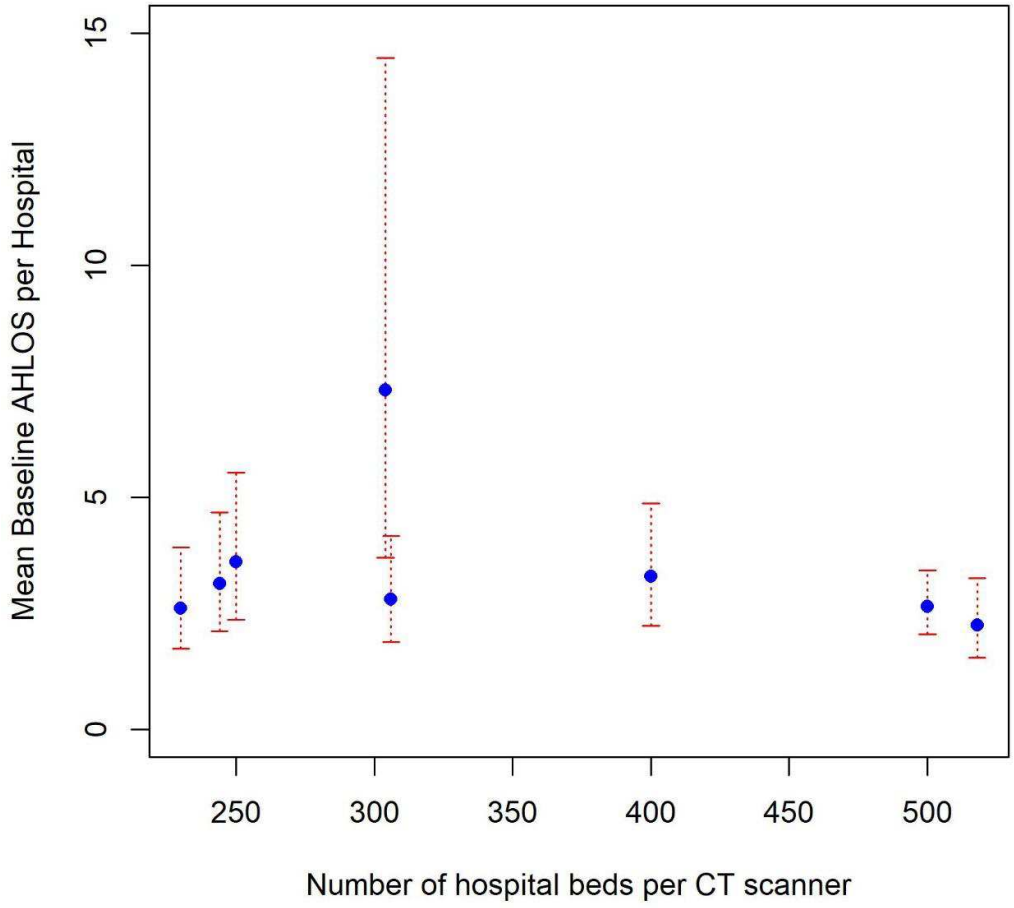


**Figure S10** Model estimates of mean baseline AHLOS per hospital and number of hospital beds per CT scanner with 95% confidence intervals

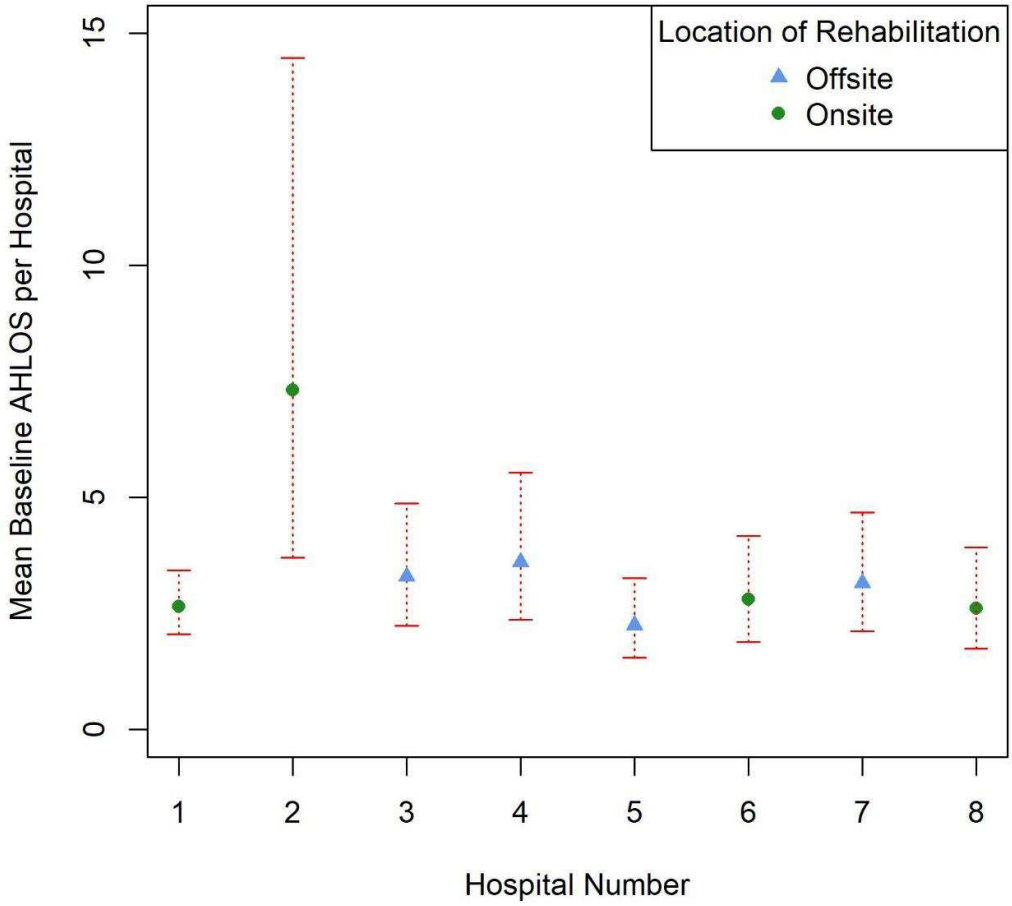


**Figure S11** Model estimates of mean baseline AHLOS per hospital and provision of onsite rehabilitation service with 95% confidence intervals

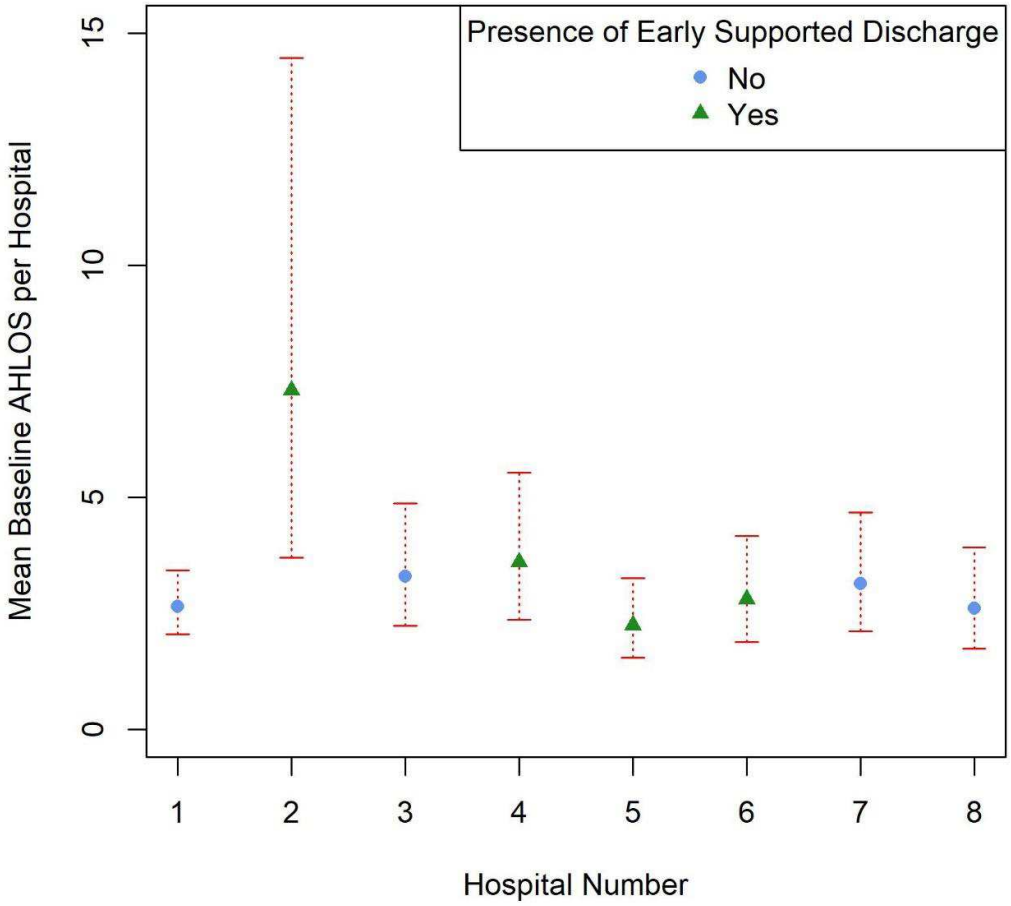


**Figure S12** Model estimates of mean baseline AHLOS per hospital and presence of early supported discharge scheme with 95% confidence intervals

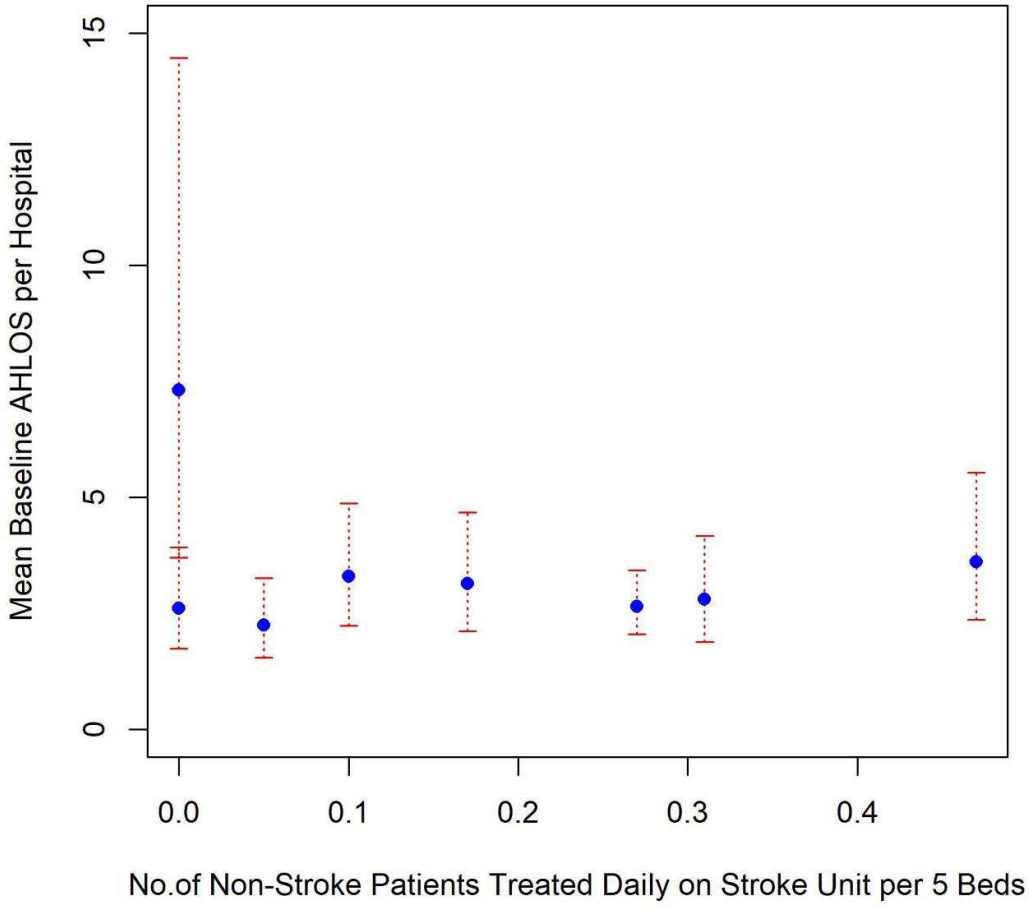


**Figure S13** Model estimates of mean baseline AHLOS per hospital and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals

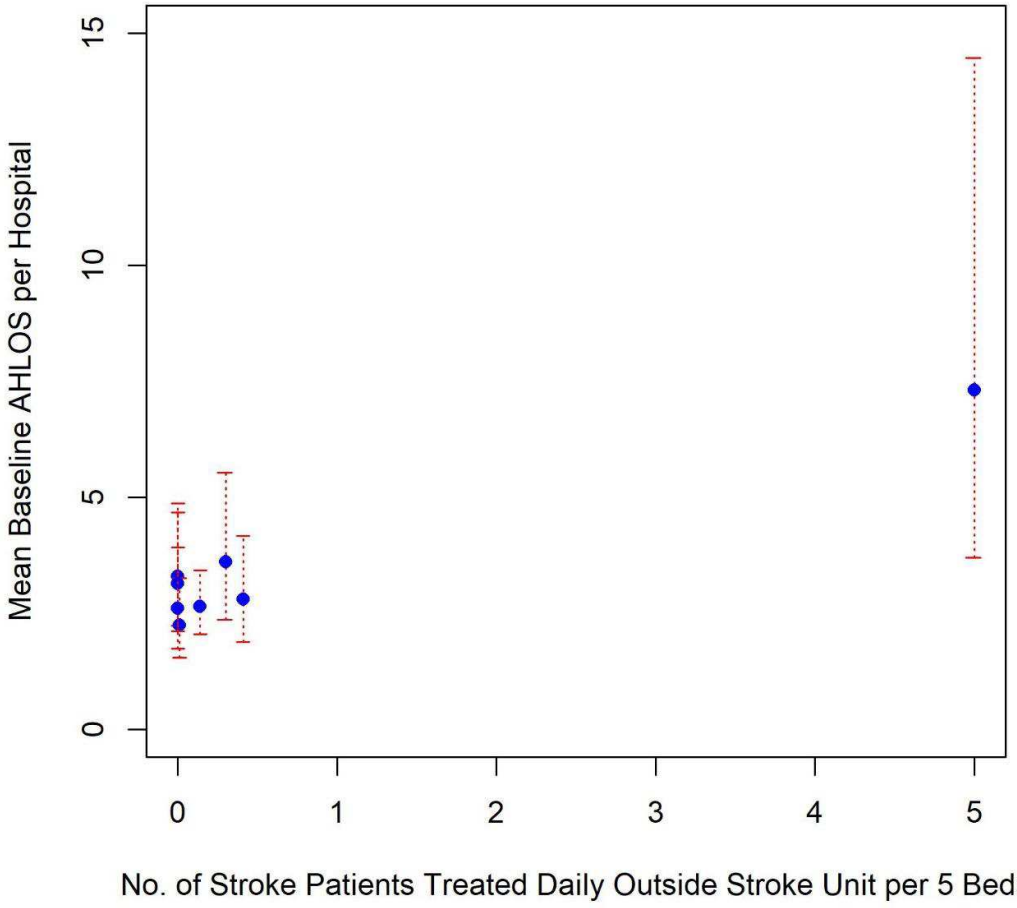


**Figure S14** Model estimates of mean baseline AHLOS per hospital and number of stroke patients treated outside the stroke unit per day per five stroke unit beds with 95% confidence intervals

**STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies***

| Section/Topic | Item # | Recommendation | Reported on page # |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 & 2 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 4 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 4 & 5 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 6 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 6 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 7 & 8 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 8 |
| Study size | 10 | Explain how the study size was arrived at | 6 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 7 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 8 & 9 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | NA |
| | | (*c*) Explain how missing data were addressed | 8 & 9 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | NA |
| | | (*e*) Describe any sensitivity analyses | NA |
| **Results** | | | |

| | | | |
|---|---|---|---|
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 10 |
| | | (b) Give reasons for non-participation at each stage | 10 |
| | | (c) Consider use of a flow diagram | |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 10 & 11 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 10 & 11 |
| | | (c) Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | 12 & 13 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 14 - 16 |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 15 & 17 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 18 |
| **Limitations** | | | |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 18 - 21 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 21 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 22 |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

# Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study

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| Primary Subject Heading: | Epidemiology |
| Secondary Subject Heading: | Health services research, Neurology, Geriatric medicine |
| Keywords: | Acute hospital, Health Services Research, Length of Stay, Outcome, Stroke < NEUROLOGY |
| | |

# Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study

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Word count: 4821

**Keywords:** Acute hospital, Health Services Research, Length of Stay, Outcome, Stroke

## ABSTRACT

**Objectives:** To determine whether stroke patients' acute hospital length of stay (AHLOS) varies between hospitals, over and above cases mix differences, and to investigate the hospital-level explanatory factors.

**Design:** A multicentre prospective cohort study.

**Setting:** Eight National Health Service acute hospital trusts within the Anglia Stroke & Heart Clinical Network in the East of England, UK.

**Participants:** The study sample was systematically selected to include all consecutive patients admitted within a month to any of the eight hospitals, diagnosed with stroke by an accredited stroke physician every third month between October 2009 and September 2011.

**Primary and secondary outcome measures:** AHLOS was defined as the number of days between date of hospital admission and discharge or death, whichever came first. We used a multiple linear regression model to investigate the association between hospital (as a fixed-effect) and AHLOS, adjusting for a number of important patient covariates, such as age, sex, stroke type, residence prior to stroke, Modified Rankin Scale score, comorbidities, and inpatient complications. Exploratory data analysis was utilized to gain insight into the hospital-level characteristics which may contribute to the hospital-level variance. These included hospital type, stroke monthly case volume, service provisions (i.e. onsite rehabilitation), and staffing levels.

**Results:** A total of 2233 stroke admissions (52% female, median age (interquartile range (IQR)) 79 (70 to 86) years, 83% ischaemic stroke) were included. The overall median AHLOS (IQR) was 9 (4 to 21) days. After adjusting for patient covariates, AHLOS still differed significantly between hospitals ($p<0.001$). Furthermore, hospitals with the longest adjusted AHLOS's had predominantly lower stroke volumes.

**Conclusions:** We have clearly demonstrated that AHLOS varies between different hospitals. We highlight the potential importance of stroke volume in influencing these differences but cannot discount the potential effect of unmeasured confounders.

## ARTICLE SUMMARY

### Strengths and limitations of this study

- This is a comprehensive study that has used multi-centre data to determine whether acute hospital length of stay of stroke patients varies across hospitals in the UK, after adjustment for patient-level covariates, such as age, sex, pre-stroke and discharge Modified Rankin Scale score, stroke type, residence prior to stroke, comorbidities, and inpatient complications.
- With a wealth of detailed patient data, we were able to adjust for the important covariates, inpatient complications and discharge Modified Rankin Scale score, which previous studies have not addressed when investigating hospital-level factors.
- Although hospital-level effects estimates were not calculated due to the limited hospital sample size of eight, we explored these factors descriptively and adjusted for clustering by including hospital as a fixed-effect.
- Although National Institute for Health Stroke Scale (NIHSS) stroke patients' scores are known to be associated with acute hospital length of stay, we were unable to adjust for this as this was only calculated for patients who were potentially eligible for thrombolysis and would have introduced information bias.

## INTRODUCTION

Stroke is the second leading cause of mortality and the third leading cause of disability in the world, with a global incidence of 16.9 million in 2010.[1-2] While acute hospitalization for stroke in the US has been estimated at a cost of $31,667 per patient, total direct stroke-related annual medical costs are expected to triple, from $71.6 billion in 2012 to $184.1 billion by 2030.[3-4]

Considerable differences in stroke-related outcomes exist worldwide, with the highest age-standardized stroke-related mortality and disability adjusted life-years rates observed in Russia and Eastern European countries.[1] Stark regional disparities within countries are also apparent. In the UK, for example, there exists a clear north-south divide where the lowest stroke-related mortality rates are observed almost exclusively in the South of England.[5] Such differences in outcomes likely reflect underlying stroke incidence rates and variations in exposure to relevant risk factors.[5-6] However, we and others have demonstrated that some of the differences in post-stroke survival have also been explained by disparities in available resources and medical care.[7-11] Studies assessing the effect of stroke care heterogeneities have largely focused on mortality as the primary outcome.

However, it is possible that heterogeneities in stroke care also impact other important stroke-related outcomes, such as a patient's acute hospital length of stay (AHLOS). To date, researchers have mainly identified patient-related determinants of AHLOS,[12-15] with little exploration into hospital-level influences. Of the few studies that have investigated hospital-level variance, factors such as hospital type, size, teaching status and location have been implicated in partially driving differences in AHLOS.[12,16-19] Although, none of these have been conducted in a UK National Health Service (NHS) setting.

During acute hospitalization, AHLOS is the main driver of acute care costs.[20] Determining the hospital-level factors influencing AHLOS therefore provides invaluable information to

service providers and policymakers who can develop optimal management strategies and enhance patient care by minimizing service deficiencies, costs and bed shortages.

The aim of this study was to investigate whether there are variations in stroke patients' AHLOS which can be partly explained by heterogeneities in characteristics of stroke care between hospitals in a UK NHS setting. We also aimed to explore which hospital-level factors drive such hospital variations in AHLOS.

## METHODS

### Study design

A multi-centre prospective cohort study was conducted at eight acute NHS Trusts within the Anglia Stroke & Heart Clinical Network (ASHCN) which covers the three counties of Suffolk, Norfolk and Cambridgeshire, in the East of England with a catchment population of approximately 2.5 million. The detailed study protocol has previously been published (see supplementary document 1).[21] Ethical approval was obtained from the NRES Committee East of England – Norfolk (REC Reference number 10/H0310/44).

### Participants

The study population included all patients, aged 18 years or older, admitted to any of the eight hospitals within the ASHCN diagnosed with stroke by an accredited stroke physician between October 2009 and September 2011. Stroke was defined as a focal neurological impairment of sudden onset and lasting more than 24 hours (or leading to death) as a consequence of an intracerebral ischaemic or haemorrhagic event. This definition excludes diagnoses of transient-ischaemic attacks (TIAs), subdural haematomas and subarachnoid haemorrhages. Stroke diagnosis was confirmed in all stroke patients through cerebral imagining (either using computed tomography (CT) or magnetic resonance imaging (MRI)). Diagnoses by the stroke physician were coded using ICD-10. The study sample was systematically selected to include all consecutive stroke patients admitted every third month of this 2-year period, resulting in a total of eight study months and sample size of 2656. The robustness of this sampling technique has been confirmed.[22]

### Participant Hospitals

The participating hospitals, although part of the same network, do not coordinate the care of patients or work together to provide regional care. They are independent NHS Trusts that

serve their local communities and therefore are individually responsible for managing stroke patients. Admission, transfer and discharge policies should be similar across these hospitals. There are also no known differences in access to rehabilitation, home care or nursing homes. Stroke services available at each site should be proportionate to the hospital's catchment population. However, as stroke volumes differ, some hospitals may experience greater pressure on their resources and facilities than others. Access to available resources also varies between the hospitals, with some providing onsite rehabilitation, neurosurgery and vascular surgery. Palliative care management may also differ between the sites.

**Data collection**

Clinical teams responsible for the care of stroke patients in each of the hospitals prospectively recorded individual patient data. Patient data routinely collected by each participating site for the ASHCN surveys was used in this study. Additional baseline patient and outcome data were also retrieved from case records, discharge summaries and Patient Administrative Systems by the clinical teams. Data were anonymized and sent to the ASHCN coordinating centre where it was collated and sent to the research team. Any identifiable patient information was held only at the local NHS Trusts - the network and investigators did not have access to these details.

Data on health service characteristics were collected from clinical leads or service managers at each stroke unit and updated every six months over the 2-year study period by research staff.[21]

**Definition of variables**

Our outcome measure, AHLOS, was treated as a continuous variable and defined as the number of days from, and including, the patients' date of hospital admission to their date of discharge or death, whichever came first.

Patient level covariates adjusted for were: age (treated as a continuous variable), sex, pre-stroke Modified Rankin Scale (mRS) as an indicator of pre-stroke frailty, pre-stroke residence status, stroke type, Oxfordshire Community Stroke Project (OCSP) (a stroke classification system), presence or absence of lateralisation signs, acute inpatient complications (such as another stroke, pneumonia, urinary tract infection (UTI), seizures, myocardial infarction, acute coronary syndrome), established comorbidities (including previous stroke/TIA, previous myocardial infarction or ischaemic heart disease, previous cancer), presence of other relevant comorbidities (including diabetes mellitus, dementia, hypercholesterolemia, hypertension, cancer, depression, rheumatoid arthritis and chronic obstructive pulmonary disease), day and season of admission, and discharge mRS (including in-hospital death). An inpatient complication was defined as any disease, disorder or condition that developed after the index stroke i.e. during the acute admission, whereas comorbidities were defined as those that were known to have occurred prior to stroke.

Independent hospital-level variables of interest were: hospital type (secondary or tertiary), hospital stroke volume (mean number of stroke patients admitted and treated in hospital per month), presence of vascular surgery onsite, distance to neurosurgical facility, onsite rehabilitation service provision, presence of an early supported discharge scheme, number of full-time equivalent (fte) staff per five beds (senior doctors and junior doctors available during weekdays, healthcare associates and nurses, occupational therapists, physiotherapists and, speech and language therapists), number of total beds present on the stroke unit per 100 stroke admissions, total number of hospital beds per CT scanner, number of non-stroke patients treated daily on the stroke unit per five beds, number of stroke patients treated daily on wards outside the stroke unit per day per five beds, and the mean index of multiple deprivation (IMD) of the county in which each hospital serves.

In NHS England, hospitals are either termed secondary or tertiary, dependent on the level of specialist service provided. Tertiary hospitals provide more specialised care in larger, regional or national centres, compared to their secondary counterparts e.g. neurosurgery unit where smaller units are not viable nor practical. These more centralised hospitals are usually dedicated in providing super-speciality care beyond sub-specialty (e.g. neuro-endocrine surgery is a super speciality of neurosurgery which is a sub-specialty of the specialty of Surgery), and therefore have access to more advanced equipment and expertise specific to the conditions in which it subspecialises in. This doesn't apply to stroke directly, but it is relevant for those who have stroke and require neurosurgical intervention.

Five bed days was used as the denominator as this is how the 2016 national clinical guidelines for stroke reports the recommended staffing levels for UK stroke units, and therefore provides for a comparison.[23]

The IMD score was used as an aggregate measure of socioeconomic status in this study. This measure is based on several domains, including income, employment, education, health, crime, barriers to housing and services and the living environment, that are believed to provide an indication of deprivation. To assign an IMD score, England is sub-divided into 32, 844 smaller areas, with a score of 1 representing the area in England that is considered to be the most deprived and a score of 32, 844 the least deprived.[24] In our study we have taken the mean 2010 IMD scores of the areas that make up the counties of Suffolk, Norfolk and Cambridgeshire and assigned these to each of the hospitals to which they are located.[25]

Processes of care measures were not accounted for in our study as we believe they are intermediate variables that lie on the casual pathway between hospital-level factors and stroke patient outcomes,[10] and therefore should not be adjusted for. Including them in our regression model could otherwise lead to over-adjustment bias.[26,27]

## Statistical analyses

Data were available from only eight hospitals which is below the suggested critical number required to reliably estimate hospital effects through multi-level modelling.[28] Therefore, a single-level multiple linear regression model using ordinary least squares was conducted with hospital as a fixed-effect and AHLOS as the outcome. To qualify for inclusion in the multivariable model, patient-level variables had to have a p-value<0.3 in univariable analysis. The standardized residuals of the model were positively skewed. However, a logarithmic transformation of AHLOS subsequently removed the skewness. Before reporting, we transformed the predicted logarithmic AHLOS values back to AHLOS, with exponentiated regression coefficients representing geometric means of AHLOS.

To explore hospital-level factors, we plotted the hospital intercept estimates of AHLOS from the regression model (mean baseline AHLOS of each hospital), against the hospital-level characteristics of interest. This is the recommended method to use on clustered data to explore hospital effects when the number of higher level units is small and hence are not interpretable in likelihood estimation.[28,29]

## Sensitivity analyses

Due to limited resources, Hospital 2 failed to collect data for the full study period. Patient-level data was only collected in this hospital for October 2009 and January 2010, culminating in a low number of stroke cases for analysis (n=16). To investigate whether this small cluster may affect our results we performed a sensitivity analysis excluding Hospital 2. Furthermore, although we collected patient data on discharge destination, we did not include this as a covariate in our multiple regression model due to issues of multi-collinearity with discharge mRS (both had categories for inpatient death). We hypothesised that discharge mRS could more readily explain a patient's AHLOS indirectly through discharge destination

(i.e. more severe disability increases the risk of institutionalisation which prolongs AHLOS due to associated waiting lists), and directly through patient recovery (i.e. a patient with more severe disability will likely take longer to recover than a patient with no disability, meaning it will take longer for a safe patient discharge). If we were to include discharge destination instead, AHLOS variance due to differences in disability and recovery time amongst patients with the same discharge placement would not be accounted for. To check the impact of excluding discharge destination on our findings we have performed a further sensitivity analysis replacing discharge mRS with discharge destination in our multiple regression model.

**Multiple imputation**

To increase power and reduce potential bias of complete case analysis, we performed multiple imputation by chained equations using the MICE package in R.[30] All the independent variables of interest, AHLOS and a number of auxiliary variables (i.e. variables in our dataset that were not used in our model) (Table S1 in the online supplementary document 2) informed the imputation. Sixty-four datasets were imputed as the inclusion of auxiliary variables increased the case wise missingness to 64%. Each dataset was pooled together using Rubin's rules.[31] The distribution of sample characteristics between individuals with complete and incomplete data were compared using the appropriate hypothesis testing. Complete case analysis was also conducted so that any differences in results from the multiple imputation analysis could be reported.

All analyses were performed using R version 3.3.1 for Windows.[32]

**Patient and public involvement**

The project was managed by project leader (PKM) who worked in close partnership with the project group of the study and the project steering group. The project steering group included

public and patient representatives, recruited through Patient and Public Involvement in Research (PPIRes). PPIRes members were invited to attend research steering group meetings over the study duration to oversee the project.

## RESULTS

### Description of sample characteristics

Of the 2656 patients admitted consecutively to the eight NHS hospitals during the inclusion period with an initial diagnosis of stroke, 278 were excluded for the following reasons: eventually diagnosed with a condition other than stroke (n=179), transferred between hospitals (both among the eight study hospitals and from or to outside the region) (n=101), had missing data for admission and discharge dates (n=8). This left a total of 2233 patients for the study analysis (Figure 1).

The median age (interquartile range (IQR)) of our cohort was 79 (70 to 86) years, 52% were female, and 83% had an ischaemic stroke (Table 1). The distributions of patient characteristics appear to vary between hospitals (Table S2 in the online supplementary document 2). Although there were low proportions of missing data for each independent variable (Table 1), this compounded to 33% of patients having at least one variable missing. Hospital 4 did not collect data on pre-stroke mRS and 30 cases from Hospital 3 had missing data on all comorbidities. Patients with complete data were less likely to have a haemorrhagic stroke, be institutionalised prior to stroke and have an inpatient death, and more likely to have had a previous stroke or TIA, have hypercholesterolemia, hypertension, rheumatoid arthritis, have a lacunar stroke and have a discharge mRS of 6, than patients who had a least one missing variable. However, there were no significant differences in other patient characteristics such as age, sex, pre-stroke mRS score, brain lateralisation, inpatient complication and admission timing between the two (Table S3 in the online supplementary document 2).

**Table 1** Sample characteristics of patients included in analysis (n=2233) and missing data

| Patient Characteristic | Median (IQR) or No. (%) | Missing Data (%) |
|---|---|---|
| Age, y | 79 (70 to 86) | 2 (0.1) |
| Sex, female | 1165 (52) | 2 (0.1) |
| Recurrent Stroke* | 448 (20) | 30 (1) |
| Diabetes Mellitus* | 370 (17) | 30 (1) |
| Dementia* | 207 (9) | 30 (1) |
| Hypercholesterolemia* | 355 (16) | 30 (1) |
| Hypertensive* | 1483 (66) | 30 (1) |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 (23) | 30 (1) |
| TIA* | 340 (15) | 30 (1) |
| Previous Cancer* | 195 (9) | 30 (1) |
| Active Cancer* | 137 (6) | 30 (1) |
| Depression* | 137 (6) | 30 (1) |
| Rheumatoid Arthritis* | 154 (7) | 30 (1) |
| COPD* | 116 (5) | 30 (1) |
| Pre-stroke mRS Score | | 442 (20) |
| 0 | 914 (41) | |
| 1 | 335 (15) | |
| 2 | 191 (9) | |
| 3 | 184 (8) | |
| 4 & 5 | 167 (7) | |
| Pre-Stroke Residence | | 51 (2) |
| Independent living with formal care | 210 (9) | |
| Independent living without formal care | 1752 (78) | |
| Institution | 220 (10) | |
| Ischaemic Stroke | 1864 (83) | 96 (4) |
| Oxford Community Stroke Project Classification | | 260 (12) |
| LACS | 503 (23) | |
| PACS | 784 (35) | |
| POCS | 279 (12) | |
| TACS | 407 (18) | |
| No Brain Lateralisation | 244 (12) | 167 (8) |
| Inpatient Complication* | 655 (29) | 0 (0) |
| Discharge mRS Score | | 50 (2) |
| 0 | 260 (12) | 329 (15) |
| 1 | 352 (16) | |
| 2 | 212 (9) | |
| 3 | 291 (13) | |
| 4 | 238 (11) | |
| 5 | 137 (6) | |
| 6 | 414 (19) | |
| Winter Admission | 1159 (52) | 0 (0) |
| Weekend Admission | 614 (27) | 0 (0) |

IQR, Interquartile Range; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disorder; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

*No information was assumed to indicate absence of condition or complication

**Hospital service characteristics**

Service characteristics of each hospital are outlined in Table 2, with median AHLOS. After standardization, by taking account of stroke admission volume, number of stroke unit beds, and size of hospital, there was still extensive heterogeneity in bed capacity, staffing levels, and the number of CT scanners provided at each hospital, respectively. Variations between hospitals also existed in terms of service and facility provision. For example, a number of hospitals provided rehabilitation care, neurosurgery or vascular surgery onsite, whilst others did not. The overall median AHLOS (IQR) was 9 (4 to 21) days and there appeared to be crude variations in this outcome between hospitals.

**Table 2** Hospital characteristics per individual hospital self-reported by clinical leads or service managers at each hospital

| Hospital Characteristics | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| General Characteristics | | | | | | | | |
| Catchment Population | 400,000 | 160,000 | 350,000 | 230,000 | 680,000 | 300,000 | 240,000 | 275,000 |
| Hospital Type | Tertiary | Secondary | Secondary | Secondary | Tertiary | Secondary | Secondary | Secondary |
| Hospital Stroke Volume (No. of ASCNES admissions per month) | 52 | 13 | 46 | 19 | 88 | 57 | 35 | 31 |
| Facilities and Services | | | | | | | | |
| No. of hospital beds | 1000 | 304 | 800 | 500 | 123 | 611 | 488 | 460 |
| No. of stroke unit beds (per 100 admissions) | 71 | 77 | 54 | 138 | 41 | 55 | 83 | 65 |
| No. of hospital beds per CT scanners | 500 | 304 | 400 | 250 | 51 | 306 | 244 | 230 |
| Distance to Vascular Surgery (miles) | 0 | 18 | 0 | 25 | 0 | 0 | 43 | 30 |
| Distance to Neurosurgery (miles) | 0 | 18 | 58 | 89 | 61 | 38 | 48 | 30 |
| Rehabilitation Provision | Onsite | Onsite | Offsite | Offsite | Offsite | Onsite | Offsite | Onsite |
| Early Supported Discharge Provision | No | Yes | No | Yes | Yes | Yes | No | No |
| Stroke Unit Staffing Levels* | | | | | | | | |
| Senior doctors† | 0.34 | 0.25 | 0.49 | 0.47 | 0.4 | 0.31 | 0.62 | 0.87 |
| Junior doctors † | 0.55 | 0.65 | 0.72 | 0.59 | 0.5 | 0.64 | 0.12 | 0.25 |
| Health care associates and nurses (band 5-7) | 9.2 | 8 | 6 | 7.4 | 7 | 5.3 | 6.5 | 10 |
| Physiotherapists (band 2-8) | 0.55 | 1 | 0.79 | 0.4 | 0.9 | 0.78 | 0.69 | 1 |
| Occupational Therapists (band 3-8) | 0.49 | 0.5 | 1.4 | 0.59 | 0.6 | 0.58 | 0.52 | 1.1 |
| Speech and Language Therapists | 0.39 | 0.15 | 0.2 | 0.18 | 0.3 | 0.03 | 0.26 | 0.1 |
| No. of non-stroke patients treated daily on stroke unit (per five stroke unit beds) | 0.27 | 0 | 0.10 | 0.47 | 0.0 | 0.31 | 0.17 | 0 |
| No. of stroke patients treated daily outside stroke unit (per five stroke unit beds) | 0.14 | 5 | 0 | 0.30 | 0.01 | 0.41 | 0 | 0 |
| Median AHLOS (IQR) | 8 (4 to 20) | 29 (24 to 42) | 11 (5 to 27) | 14 (4 to 30) | 8 (4 to 14) | 10 (5 to 22) | 11 (6 to 23) | 7 (3 to 20) |

ASCNES, Anglia Stroke Clinical Network Evaluation Study; CT, Computerised Tomography; AHLOS, Acute Hospital Length of Stay; IQR, Interquartile Range.

*Number of fte staff per five stroke unit beds (weighted average for the four study periods taken). NHS banding refers to the pay scale system of healthcare staff in the UK and relates to their level of experience. Higher bands reflect higher pay and experience.

† Weekday numbers only

**Univariable linear regression**

In univariable linear regression (Table S4 in the online supplementary document 2), patients who were older, female, had previous cancer, a previous stroke, had diabetes mellitus, had dementia , had a pre-stroke or discharge mRS score greater than 0, had a OCSP other than a lacunar infarct, had an inpatient complication, were living independently at home without formal care (compared to those who had formal care) prior to stroke, or were a winter admission had a significantly longer AHLOS ($p<0.05$). Patients who had a haemorrhagic stroke, hypercholesterolemia, or showed no signs of brain lateralisation were all shown to be significantly associated with a shorter AHLOS ($p<0.01$).

The strongest associations with AHLOS were seen for inpatients who developed a complication, who had a pre-stroke mRS score of 3, who were admitted to Hospital 2 or who had a discharge mRS score of ≥2. Inpatient complications were associated with twice as long an AHLOS compared to those without a complication. Similarly, patients with a pre-stroke mRS score of 3 were 94% more likely to have a longer AHLOS than those with an mRS of 0. Patients admitted to Hospital 2 had 2.69 times the AHLOS of those admitted to Hospital 1. Compared to patients with a discharge mRS score, those with a score of 2, 3, 4 or 5 had over a 2, 3, 4, and 5-fold increase in AHLOS, respectively. Not unsurprisingly, discharge mRS score appeared to explain the majority of AHLOS variance ($R^2=31.1\%$).

Being hypertensive, having a history of a myocardial infarction or ischaemic heart disease, having previously had a TIA, having active cancer, depression, rheumatoid arthritis or chronic obstructive pulmonary disease were not shown to be significantly associated with AHLOS. Furthermore, admissions to Hospitals 6 and 8 were also not shown to be significantly associated with a difference in AHLOS compared to Hospital 1 admissions.

**Multiple linear regression**

Multiple linear regression results for AHLOS are summarized in Table 3 and shows that 42.7% of the variation in AHLOS has been explained. Sex, recurrent stroke, diabetes mellitus, hypercholesterolemia, previous cancer, a pre-stroke mRS score of 1 to 3 (with reference to a score of 0) and living at home independently without formal care prior to stroke were no longer statistically associated with AHLOS in multiple regression ($p>0.05$). Furthermore, being admitted to Hospital 3 or 4 as opposed to Hospital 1 were no longer associated with a significant difference in AHLOS. No variables included from the univariable analysis with $p>0.05$ became statistically significant in the multivariable analysis, except for living in an institution prior to stroke which was associated with a 19% reduced AHLOS compared to those living independently without formal care. Developing an inpatient complication and having a discharge mRS score between 2 and 5 were still strongly positively related to AHLOS. After adjusting for patient covariates, AHLOS was still shown to significantly differ between hospitals, with the shortest and longest AHLOS observed for Hospitals 5 and 2, respectively.

There were no obvious differences between the results using complete cases only (Tables S5-6 in the online supplementary document 2) and multiple imputation.

**Table 3** Multiple regression analysis for AHLOS (n=2233; $R^2$=42.7%)

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 1.01 | 0.94 to 1.09 | 0.79 |
| Recurrent Stroke | 1.03 | 0.94 to 1.12 | 0.57 |
| Diabetes Mellitus | 1.06 | 0.97 to 1.17 | 0.21 |
| Dementia | 1.28 | 1.12 to 1.46 | <0.001 |
| Hypercholesterolemia | 0.94 | 0.85 to 1.05 | 0.27 |
| Myocardial Infarction or Ischaemic Heart | 1.00 | 0.92 to 1.09 | 0.98 |
| Previous Cancer | 1.12 | 0.99 to 1.27 | 0.08 |
| COPD | 0.90 | 0.77 to 1.06 | 0.21 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.06 | 0.95 to 1.19 | 0.28 |
| 2 | 0.90 | 0.77 to 1.04 | 0.15 |
| 3 | 0.94 | 0.80 to 1.11 | 0.47 |
| 4 & 5 | 0.71 | 0.59 to 0.86 | <0.001 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.07 | 0.94 to 1.23 | 0.92 |
| Institution | 0.81 | 0.69 to 0.95 | 0.01 |
| Haemorrhagic Stroke | 0.80 | 0.71 to 0.90 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.30 | 1.18 to 1.42 | <0.001 |
| POCS | 1.34 | 1.18 to 1.53 | <0.001 |
| TACS | 1.29 | 1.13 to 1.48 | <0.001 |
| No Brain Lateralisation | 0.85 | 0.75 to 0.96 | 0.01 |
| Inpatient Complication | 1.70 | 1.56 to 1.85 | <0.001 |
| Discharge mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.01 to 1.31 | 0.04 |
| 2 | 1.74 | 1.50 to 2.04 | <0.001 |
| 3 | 2.70 | 2.32 to 3.13 | <0.001 |
| 4 | 3.51 | 2.98 to 4.14 | <0.001 |
| 5 | 5.07 | 4.19 to 6.14 | <0.001 |
| 6 | 1.24 | 1.05 to 1.48 | 0.01 |
| Winter Admission | 1.15 | 1.08 to 1.24 | <0.001 |
| Weekend Admission | 1.03 | 0.95 to 1.11 | 0.50 |
| Hospital (reference 1) | | | <0.001 |
| 2 | 2.09 | 1.38 to 3.17 | 0.001 |
| 3 | 1.07 | 0.94 to 1.22 | 0.29 |
| 4 | 1.08 | 0.90 to 1.31 | 0.40 |
| 5 | 0.78 | 0.69 to 0.87 | <0.001 |
| 6 | 0.93 | 0.81 to 1.07 | 0.33 |
| 7 | 1.15 | 1.00 to 1.32 | 0.05 |
| 8 | 0.82 | 0.70 to 0.94 | 0.01 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Intervals; COPD, Chronic Obstructive Pulmonary Disorder; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

*β estimates and 95% confidence intervals were calculated for predicted log AHLOS. Prior to reporting they were transformed back to AHLOS through exponentiation and represent geometric mean AHLOS

**Graphical exploratory analysis**

Mean baseline AHLOS of each hospital (estimated from the multiple regression model) was plotted against hospital stroke volume and clustered by hospital type in Figure 2. It appears that hospitals (of either type) that have higher stroke volumes have a shorter AHLOS than those with lower stroke volumes when patient covariates are taken into account. To note also, Hospital 2 deviates largely from all the other hospitals with respect to the number of stroke patients treated daily outside the stroke unit (see Figure S1 in the online supplementary document 2).

No discernible patterns were seen for mean baseline hospital AHLOS and staffing levels, surgery facilities, number of non-stroke patients treated on the stroke unit, bed numbers, and IMD score (Figures S2-15 in the online supplementary document 2).

**Sensitivity analyses results**

Excluding Hospital 2 in our first sensitivity analysis did not alter our results (Table S7 in the online supplementary document 2). For our second sensitivity analysis, although the results were similar, the amount of variance explained reduced from an $R^2$ value of 42.7% to 40%. Furthermore, significant differences in AHLOS were shown between our reference hospital and Hospitals 3 and 4, which was not shown in our main analysis (Table S8 in the online supplementary document 2).

## DISCUSSION

This multi-centre cohort study has demonstrated that substantial heterogeneities exist in stroke hospital service and staff provision across three counties in the East of England. After adjusting for patient characteristics and confounding factors, we have shown that AHLOS significantly differed between hospitals. This suggests that the heterogeneities we see in stroke care between hospitals have an effect on AHLOS of these patients. It also appears from our exploratory analysis that the volume of stroke patients admitted to hospital may play a role in partially explaining these hospital-level AHLOS differences. Furthermore, the large deviation in AHLOS of Hospital 2 seems to be related to the number of stroke patients that were not being treated on a stroke unit.

In agreement with our findings, two previous studies in Japan and Denmark have shown that hospitals with higher stroke volumes are those in which AHLOS is shorter.[16,19] The reason higher volume hospitals lead to more favourable outcomes may simply be down to the fact that "practice makes perfect" i.e. the stroke physicians in these hospitals treat a greater number of patients and are hence, more experienced and able to deliver higher quality care.[16,33-34] Svendsen *et al*., 2012 also demonstrated that stroke patients admitted to high-volume stroke units have significantly greater odds of being treated and assessed earlier than those admitted to lower-volume units, which could also explain their better outcomes.[19]

To translate these findings into practice may mean the centralisation of stroke services. Although this has been successfully implemented in urban centres such as Manchester and London,[35-36] this may not be feasible in more rural areas where travel times would compromise timely thrombolysis treatment.[10,37] Alternatively, a hub and spoke model of stroke care could be introduced whereby patients are first treated in their local hospital, and when stable for transfer are re-directed to larger hub centres where they can gain access to

more specialised care.[38] Specifically, patients with severe stroke or with complex health needs could be redirected to these better performing high-volume centres.

Any recommendations that would lead to changes in stroke volume for the benefit of a reduced AHLOS should not compromise the quality of care. However, it has previously been reported that higher stroke volumes are independently associated with a lower risk of mortality.[10-11,39-40] Therefore modifying this hospital factor may not only lead to a potential modest decrease in inpatient costs and more available bed days but could also be beneficial to the health outcomes of patients.

The large variation in AHLOS between Hospital 2 and the other hospitals in our study is also interesting to note. This coincides with a stark contrast in the number of stroke patients that were not treated in a stroke unit in Hospital 2 compared to the others. It could therefore be surmised that the large deviation in AHLOS of this hospital is driven by a lack of access to stroke unit care. This would be unsurprising given that stroke unit care has been consistently found to improve outcomes, including AHLOS, possibly due to a higher intensity of physiological monitoring, therapy and early mobilisation implemented in these discrete units.[41-44]

Other hospital-level factors that have been shown to influence a stroke patient's AHLOS include hospital size and teaching status.[12,16-18] However, these relationships were not apparent in our exploratory analysis. To investigate these and other hospital characteristics further, we require a larger sample of hospitals. This issue with sample size is also apparent when we study Hospital 8 which, although has one of the lowest AHLOS, also has one of the smallest volume of stroke patients in the study, and therefore contradicts our previous finding. Such a discrepancy is likely a reflection of the small number of hospitals assessed, as there are likely to be several competing factors playing a role in determining hospital-level

AHLOS variance. For example, although Hospital 8 has one of the lowest stroke volumes it has the highest number of fte senior doctors, health care associates and nurses, and physiotherapists per five beds, and the lowest number of hospital beds per CT scanners out of all the hospitals studied. Staffing levels may be what is responsible for this supposed contradiction as they are likely to be an important determinant of AHLOS, given that higher nurse: bed ratios have been shown to be important in reducing other stroke-related outcomes, such as mortality.[7,10]

Although not the focus of our study, we have also demonstrated several important patient variables that influence AHLOS, specifically discharge mRS, having dementia or having an inpatient complication. Other researchers have confirmed the strength of these relationships. For example, Fujinio *et al*., 2013 showed that mRS before discharge was associated with a difference in 5.77 days in AHLOS,[16] whilst another study showed that dementia increased AHLOS by 6.5 days.[14] Complications such as congestive heart failure, falls, UTI and pneumonia have also been shown to prolong a patient's AHLOS.[15,45-46] It is therefore important for any future studies exploring hospital-level factors to properly adjust for these patient variables, in addition to NIHSS which is another important covariate. This is especially pertinent given that the studies examining hospital-level factors and AHLOS in stroke to date have failed to adjust for these specifically. Finally, our findings in relation to other patient factors such as age, sex, stroke type and pre-stroke residence are in general agreement with other literature.[12-14,47-48]

The main strength of our study is its prospective design and the detailed patient-level data we obtained. This allowed us to gain a better understanding of the extent to which the variation in AHLOS exists over and above patient characteristics. We have optimised the use of available NHS data as the starting block for informing future pragmatic real-world setting RCTs by first identifying potential health service factors that could lead to important

interventions. Furthermore, the findings of this study can presently be used to inform clinicians, healthcare service providers, commissioners and policy makers as to where improvements can be achieved in stroke care. The robust statistical analysis has allowed easy and quick visualization of notable patterns in the dataset and provides a candid assessment of the research objectives by considering the limits of inference due to the small number of hospitals. Multiple imputation has also reduced potential bias that may have otherwise been introduced from complete case analysis alone.

The major limitation of this study was the small number of hospitals that has restricted the conclusions we can make from our exploratory analysis of hospital characteristics. Furthermore, although NIHSS and a patient's discharge destination has been shown to be associated with stroke patients' AHLOS,[14,20] they were excluded as covariates from the main analysis. As NIHSS scores were only calculated for those who were potentially eligible for thrombolysis at the time of our study, the incompleteness was not missing at random and would have introduced information bias into our results. As discharge mRS and discharge destination both included a categorical factor representing inpatient death only one of these variables could be included into the analysis due to issues of multi-collinearity. However, we hypothesized that discharge mRS score could more readily explain a patient's AHLOS whilst also serving as a proxy for discharge destination. In addition, socioeconomic status which has also been shown to relate to AHLOS in stroke patients,[18] and differences in palliative care policies were not known. This means that any remaining difference in AHLOS between hospitals may not only be due to hospital-level factors but may also be due to other unmeasured confounders. We also did not collect data on patient ethnicity, although this has previously been associated with AHLOS.[49-51] Whilst we cannot provide exact ethnic mix, the region where the study was conducted serves mainly a white British Caucasian population, with other races making up a very small minority.[52]

Furthermore, as this study covers eight NHS hospitals in the East of England that span both urban and rural regions, and as NHS policies are fairly standard, we believe these sites are generally representative of others across the UK. However, as we lacked an adequate number of hospitals to run a multi-level model with hospital as a random effect, our findings cannot be generalised to other healthcare settings outside the UK with differing national policies.

In summary, the heterogeneities that exist in stroke care at the regional UK level have the ability to lead to differences in stroke-patient outcomes such as, AHLOS. This provides a powerful message for patients, clinicians, service providers and policymakers – that there are modifiable hospital factors that may determine better outcomes in stroke. For example, a hub and spoke model of care could be advocated to increase efficiencies whilst also providing for more beneficial stroke health outcomes. Countries that are in the process of developing their healthcare systems can use these findings to inform their decision making in delivering optimal care.

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**Author Contributions:** M.T cleaned the data, undertook the statistical analysis and interpretation of results, reviewed the literature and, prepared the manuscript. D.M and P.K.M supervised the study. D.M provided statistical analysis advice and assistance. M.O.B, E.A.W, J.F.P and P.K.M conceptualized and designed the use of ASCNES and obtained funding. S.D.M was ASCNES study coordinator and managed the data. All authors reviewed the manuscript and contributed in critical revision and final manuscript preparation.

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**Data sharing statement:** The datasets generated and analysed during the current study are available from the ASCNES team on reasonable request.

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**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

**Figure 2** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) against hospital stroke volume and clustered by hospital type with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

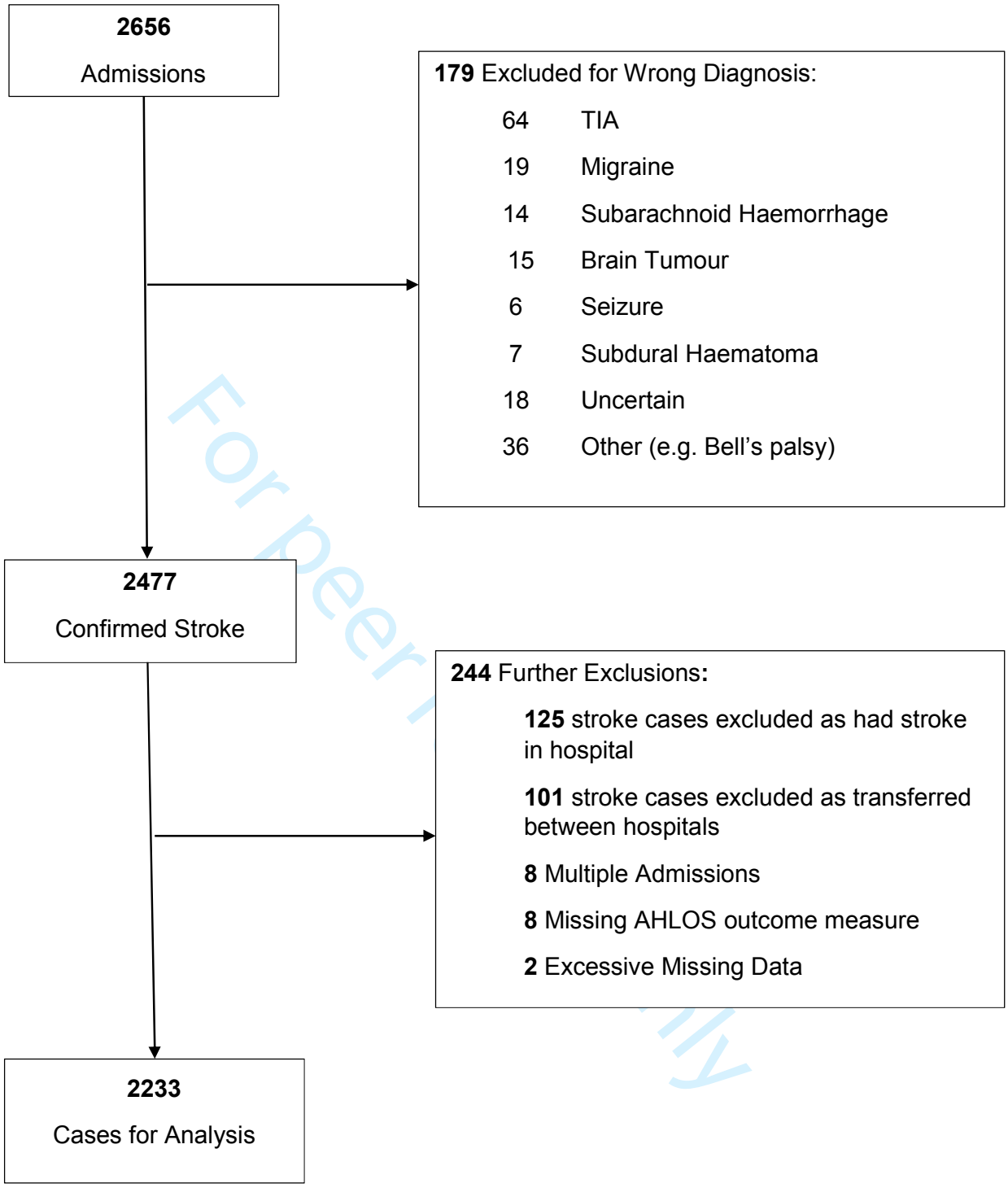
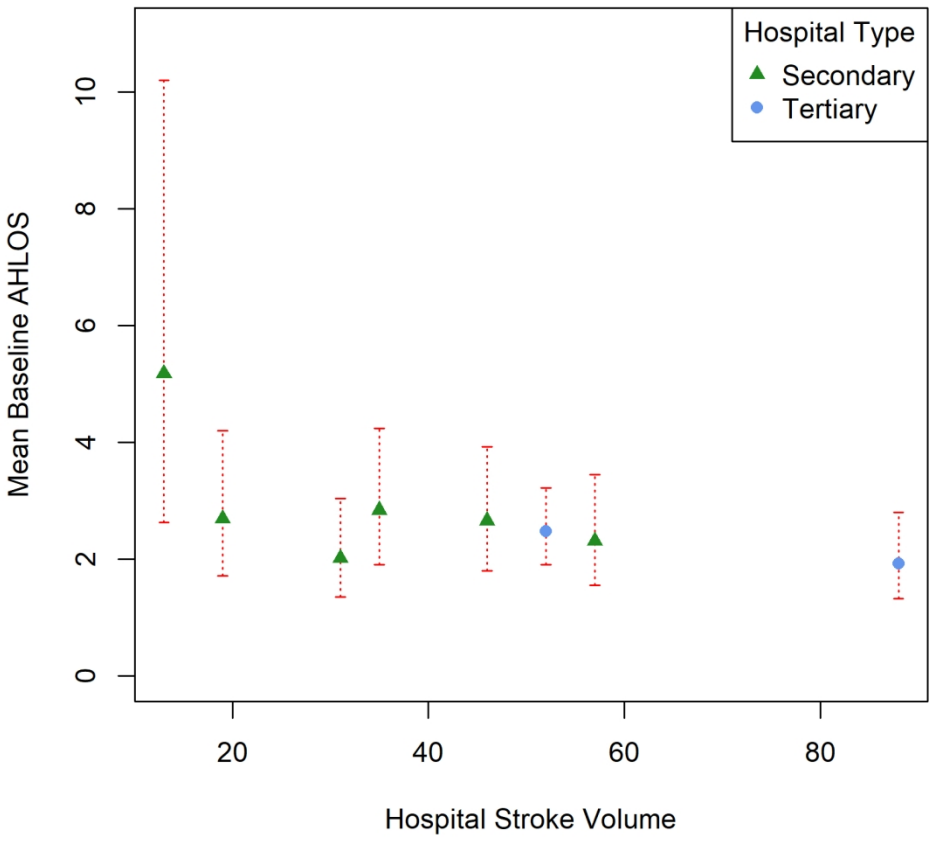



**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

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BMC Health Services Research

STUDY PROTOCOL Open Access

# Evaluation of stroke services in Anglia stroke clinical network to examine the variation in acute services and stroke outcomes

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## Abstract

**Background:** Stroke is the third leading cause of death in developed countries and the leading cause of long-term disability worldwide. A series of national stroke audits in the UK highlighted the differences in stroke care between hospitals. The study aims to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes, after accounting for case mix differences and individual prognostic factors.

**Methods/Design:** We will conduct a cohort study in eight acute NHS trusts within East of England, with at least one year of follow-up after stroke. The study population will be a systematically selected representative sample of patients admitted with stroke during the study period, recruited within each hospital. We will collect individual patient data on prognostic characteristics, health care received, outcomes and costs of care and we will also record relevant characteristics of each provider organisation. The determinants of one year outcome including patient reported outcome will be assessed statistically with proportional hazards regression models. Self (or proxy) completed EuroQol (EQ-5D) questionnaires will measure quality of life at baseline and follow-up for cost utility analyses.

**Discussion:** This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services which will bring direct benefit to the patients.

## Background

Stroke is the third leading cause of mortality and the number one cause of long-term disability in the UK. More than 150,000 people suffer a stroke in the UK each year [1]. It costs the NHS approximately £ 7 billion per annum [2]. Stroke incidence rises sharply with age and despite better primary and secondary preventative measures, the total number of strokes is set to rise in the UK [3]. Nevertheless, stroke care in UK is far from ideal: patients having a worse outcome in terms of death and dependency than many other European countries [4-6], at least in part due to differences in care provided [7]. There is also variation in outcome between different localities within the UK [8-11], these local differences being highlighted in the most recent publication of the National Sentinel Stroke Audit in 2009 [12]. These differnces probably arise as a result of substantial variations in how the stroke services are provided across the UK. Examples of such differences are access to neurovascular/neurosurgical service, early supported

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discharge, and stroke specialist on call rota for thrombolysis. The presence or absence of variations in stroke outcomes as a result of variation in care and how much the observed variations in patients' outcomes including patient reported outcome measure (PROM) are determined by the differences in service delivery have not been examined previously.

We hypothesise that variation in patient outcomes including mortality, length of stay, institutionalisation rate, and patient reported outcomes between care providers can partly be explained by the different ways in which stroke services are delivered. The main objectives of the study are (1) to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes after accounting for case mix differences and individual prognostic factors, and (2) to obtain preliminary data to identify sample size and inform future pragmatic real world setting RCTs in the area of health service delivery in stroke.

## Methods/Design

A prospective cohort study will be conducted to identify characteristics of services that are associated with the best outcomes including patient reported outcomes, taking into account case-mix and patients' prognostic features. The study will consist of two components (1) consecutive stroke admissions in selected months (a total of 8 months) and (2) a prospective study of patient reported outcome in some of these selected months.

### Sample Population

For the first component, the sample population will be stroke patients who are admitted to any of the hospitals within the Anglia region of Stroke & Heart Clinical Network between October 2009 and September 2011. Baseline data are already recorded, prior to the study commencement, as part of routine clinical data collection by Anglia Stroke Clinical Network (as described in detail below). The study sample will be a systematically selected sample (every third month) rather than a consecutive cohort of patients admitted to eight acute NHS hospital trusts. Therefore, this is not a consecutive case study; instead it seeks to be representative of the catchment population of the hospital and has taken into account the seasonal variation in stroke incidence and outcome [13].

For the patient reported outcome component of the study the following inclusion and exclusion criteria will be used. Inclusion criteria are (1) age > = 18 years, (2) admitted to hospital with stroke (diagnosed by stroke physicians) during the study months, (3) able to provide informed consent or patient's personal consultee agrees to study participation. Exclusion criteria include (1) age <18 years, (2) patients with pre-existing diagnosis of dementia (for PROM component only).

The Anglia Stroke Network was funded through the NHS Improvement Programme, following the publication of the National Stroke Strategy in December 2007. The Network was established in April 2008 to support the development of stroke services in Norfolk, Suffolk and Cambridgeshire regions. Since its inception, the Network regularly collected data to capture clinical service activities of the eight acute hospital trusts in the Network for the purpose of monitoring of services benchmarked by National targets and guidance from National Institute of Health & Clinical Excellence (NICE) in England and Wales. Data collection commenced in January 2009 and involves the individual trusts collecting clinical data which is fed back to the network by monthly reports. The total number of strokes admitted to the 8 acute trusts within the Network is approximately 4,000 per annum in 2009. The stroke cases were identified prospectively data were collected by the clinical team who looked after the patients and anonymised raw clinical data were sent to the network on monthly basis. The network collates and analyses the data for above mentioned purposes.

### Sample size

Since this is an exploratory study designed to provide information for further analytic research, sample size will be determined partly pragmatically rather than on particular hypothesis tests. For illustration purposes, a total sample of 2264 patients would provide 80% power to detect a constant Hazard ratio (HR) of 0.76 for one-year mortality between two groups of roughly equal size, based on the log-rank test. This assumes a 20% one-year mortality rate in the reference group, no loss to follow-up before one year and 2-sided type I error of 5%. If one-year mortality is 30%, then 2264 patients would provide 76% power to detect a HR of 0.81.

### Plan of investigation

The study will have a cohort design. We will follow up a cohort of patients systematically selected from each trust. For pragmatic purposes we will sample all patients who are admitted every third month, starting from October 2009. Over one calendar month, there will be ~ 300-350 stroke cases entered into the Network Clinical Data. Between October 2009 and September 2011, the Clinical Network would have collected a total of eight 3-monthly datasets per trust (i.e. 8 study months in total: Oct 2009, Jan 2010, April 2010, July 2010, October 2010, Jan 2011, April 2011, July 2011). Therefore, the estimated total cohort size with baseline clinical data will be ~ 2,400 stroke cases

during this exercise (30% of 4000 patients admitted annually in 8 trusts = 1200 × 2 yrs).

We will collect patient data by hospital trusts and conduct a questionnaire survey of patients' outcomes. Due to the nature of the study we would need 100% follow-up in randomly selected populations. Because we will be using a partially historical cohort, to avoid selection bias for mortality outcome, informed consent from all eligible participants will not be feasible. Therefore, it is most appropriate for the clinical team to collect the outcome data to comply with current ethical guidance in the UK. Therefore, the identifiable patient data will only be held at the local NHS trusts.

Neither the network nor the investigators will have access to any identifiable patient information (e.g. name, address). For outcome data we will utilise death certificate and hospital episode data from the Patient Administrative System (PAS) as described previously [14,15]. This approach will be used in conjunction with telephone and postal follow-up for questionnaire surveys such as EQ-5 D, and Stroke Impact Scale. These data will be counter-checked using discharge coding records, which record each hospital episode.

The clinical teams will retrieve case records to collect (1) baseline measures which were not recorded in baseline Network surveys and (2) outcome measures including mortality and hospital length of stay. At study commencement (October 2010) one year follow up data can be collected immediately for October 2009 cohorts (follow up complete at end September 2010). The follow up will be completed in September 2012 as the stroke patients included in the last survey for the study conducted by the Network in July 2011 will complete one year follow-up in June 2012 and data collection of the study will be completed by July-August 2012 with the view of final cohort data arrival to research team by the end of December 2012.

Due to multi-centre nature of the study the individual sites are expected to join the study at different time points (after their respective NHS Research & Development Committees' approval). We will collect characteristics of stroke services, patient related factors, prognostic indicators, treatment options and trial/study participation. Missing prognostic data will be imputed statistically, to ensure that all eligible patients are included in the primary analysis (see also Statistical Methods).

The service characteristics of interest include:

***At hospital level***

- staffing (including junior doctors and therapists (whole time equivalent), physicians characteristics
- university or district general hospital
- distance from tertiary referral centre
- availability of vascular surgery on site, neuro-surgery and neuro ITU on site
- monitoring beds
- physician on call rota
- compliance with NICE guidelines

***At patient level***

- provision of thrombolysis and CT
- medication

### Outcome measurements

Primary outcome of the study will be one year mortality comparison between services with different characteristics. The secondary outcomes will include (1) final discharge destination (good or poor outcome) [16], (2) length of acute hospital stay, (3) length of stay in rehabilitation, (4) complications during acute and rehab-hospital stay and significant procedures (e.g. aspiration pneumonia, myocardial infarction), (5) readmissions, (6) composite cardiovascular events (recurrent TIA/Stroke/Acute Coronary Syndrome, Myocardial infarction).

### Patient Reported Outcome Measures (PROM)

PROM will consist of (1) Stroke Impact Scale, (2) health related quality of life: EQ-5 D at one year in those who completed questionnaire at the baseline, (3) modified RANKIN, (4) Barthel score and (5) health service use.

### Statistical analysis

Quantitative data will be analysed by multivariate Cox-proportional hazards to examine the relationships between different aspects of health services and time to death, adjusting for prognostic characteristics. Multiple logistic or linear regression models will be constructed as appropriate for dichotomised and continuous outcome variables respectively. T tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data will be used to compare continuous outcomes. Volume-outcome relationships will be investigated. Missing prognostic and EQ-5 D data will be imputed, based on each patient's other prognostic characteristics. Clustering of data by hospital trust will be investigated and, if necessary, taken into account, and intra-class correlation coefficients calculated to inform future research.

### Economic evaluation

Health care resources are scarce and it is therefore important to ensure that evaluations are undertaken in order to ensure that services provided by the NHS constitute value for money. Within this study we will thereby seek to estimate the cost-effectiveness of different stroke service deliveries.

Costs will first be calculated from the perspective of the NHS and personal social services (PSS). Thus, levels

of resources use will be recorded during the follow-up period, including the length of original hospital stay, input by the multi-disciplinary team, other investigations (e.g. x-ray) and any complications (including details of any further hospital admissions). Unit costs will subsequently be assigned to each of these resource items, enabling both the total mean cost in participants and the incremental cost between two different service deliveries (chosen to compare the cost effectiveness, e.g. traditional on call rota vs. telemedicine) to be calculated after adjusting for other factors. The main measure of effectiveness to be used in the economic analysis will the EQ-5 D [17], where responses will be sought at baseline, and at 12 month as mentioned above. This will enable the overall effect of each mode of service delivery, and the incremental effect of services to be estimated.

***Outcome***

As the National Institute of Health and Clinical Excellence [18] recommends use of the EQ-5 D [17] within cost-effectiveness analysis this will be our primary measure within the economic analyses. EQ-5 D data will be collected at two University Hospitals and two district general hospitals within the clinical network. We will use "mapping" strategy to estimate the cost-effectiveness analyses across the region. The use of mapping, where scores from a condition-specific (non preference-based) measure are 'converted' into a utility (preference-based) score using a pre-defined formulae, has been advocated (in certain instances) by the UK National Institute of Health and Clinical Excellence (NICE) [18], and has been used to estimate the utility scores, and in turn cost-effectiveness, of a number of health care interventions [19]. Mapping presents the possibility of not asking all participants to complete the EQ-5 D. In this study we propose to take advantage of this by developing a mapping algorithm based on the response from participants participating in this component to predict the EQ-5 D for participants in retrospective cohorts and those who did not participate in PROM component.

Because the quality of life measure (EQ-5D) which can be used to estimate health utility and calculate QALYs (Quality Adjusted Life Years) for economic evaluation is outside the remit of routine data collection and cannot be done retrospectively, we will collect EQ-5 D data in only the second year of the study (October 2010 and January, April and July 2011 cohorts and one year follow up data to be collected September and December 2011, and March and June 2012) in those who provide informed consent to the study (we estimate that the sample will be approximately 15-20% of the whole sample after excluding the one year pre-study period (between October 2009-September 2010) and after taking into account of refusal rate (estimated ~ 30%) in trusts with Stroke or Comprehensive Local Research Network Research Nurses.

**Economic Analysis**

In the Economic analysis if one option is shown to be less costly and more effective than another option (for example, telemedicine vs. on call system) then that option will 'dominate' the other and be deemed cost-effective. Alternatively, the incremental cost-effectiveness ratio (ICER) associated with a particular option will be estimated and assessed in relation to a range of cost-effectiveness thresholds. The associated level of uncertainty will also be characterised by e.g. estimating the cost-effectiveness acceptability curve (CEAC) for each intervention and conducting value of information analysis [20]. Sensitivity analysis will also be undertaken to assess the robustness of conclusions to key assumptions. We will also seek to identify what resource items should be monitored in a future study (i.e. what are the big cost drivers which are likely to be affected by the intervention) and how these items should be identified.

The study is funded by the NIHR Research for Patient Benefit Programme (PB-PG-1208-18240) and obtained ethical approval from the Norfolk Research Ethics Committee.

## Discussion

In this study we specifically aim to identify services that are associated with the best clinical outcomes including mortality and hospital length of stay including patient reported outcome adjusting for patient prognostic factors and potential confounders. Our study will be able to provide useful information in stroke service provision in UK and beyond. Furthermore, inclusion of patient reported outcome is novel and exciting component of our study.

Studies which have examined the delivery of specific services such as rapid imaging, have shown improvement in patients' outcome in stroke [21]. A recent report from Germany suggested that a telestroke network may be a useful strategy to implement in their non-urban stroke services [22]. Lees et al (2008) [23] highlighted that there is room for improvement in terms of acute services for stroke. Interestingly, one of the observations was that centres with higher workload performed better. There is also existing evidence in Cancer literature that centres with higher surgical caseload have better outcomes [24]. There has also been a recent evaluation of the impact on stroke outcome by evidence-based practice in an Australian setting [25]. Examples of service delivery that are associated with better outcomes include organised stroke unit care [26], thrombolysis treatment and appropriate secondary prevention [27], and early supported discharge

in selected patients [28,29]. However, the cost-effectiveness of such services has yet to be fully examined.

Rodgers et al [30] highlighted the need for improvement in hospital-based stroke services e.g. stroke unit staffing levels were lower than was available in RCTs. The accumulating body of evidence has been a major driving force behind the UK Government's strategy to improve stroke care (National Stroke Strategy, 2007) [31]. A key strand of the strategy was to set up stroke networks to deliver stroke service development across geographically defined areas. The stroke networks have worked to agree minimum standards for stroke care and they have worked with commissioners to assist the commissioning process for stroke services. The acute stroke services are currently delivered by different NHS trusts and there is therefore a wide range of inequality in service availability and provision with differeing structure and local support systems.

This research aims to utilise NHS data in the most meaningful and innovative way and we aim to maximize the benefit with minimum investment to produce best research output for patient care by collaborating with clinical teams and the network in providing excellent value for money. This observational study seeks to identify areas of clinical practice which merit future randomised controlled trials (RCTs) to identify best practice in improving stroke care which will be of maximum benefit to patients. We also aim to obtain preliminary data to estimate sample sizes and conduct value of information analyses to design future pragmatic RCTs of innovative ways of delivering stroke care.

As we include eight diverse NHS trusts, the findings are likely to be generalisable in the UK setting and beyond. This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will also inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services and bring direct benefit to patients.

The study will describe the variation in outcomes between different stroke services, and identify the characteristics of services associated with better outcomes after accounting for case-mix. We will also estimate the relative costs of and health gain estimated as Quality Adjusted Life Year (QALY) gain that may be demonstrated by different services. The commissioners of services will be informed as to which service delivery structures are likely to provide value for money to make purchasing decisions. They will also be better informed about the types of service associated with better patient reported outcome. Hospital trusts will be able to evaluate their services systematically and plan their care appropriately to meet local and regional needs and demands based on our study findings. Professionals will be able to reflect on the impact of services they are delivering to help improve their performance and the way services are organised by adopting the most effective and cost effective approaches. As an observational study, the study limitations include inability to control for unknown confounders and residual confounding effect of known confounders which are adjusted for. The causal relationship cannot be implied but as we stated the findings will provide knowledge about areas that requires further evaluation in clinical trial setting.

There is very little work which assesses service provision robustly against patients' own reported outcomes. This exciting study may lead to a clearer drive for patients to define what makes a good service. We hope that the best clinical practices are adopted to suit the local populations' needs and demand. As we included eight diverse NHS trusts, the findings will be generalisable in the UK setting and likely to be applicable in international setting. All these will become drivers of improvement in stroke services for the benefit of stroke sufferers.

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**Manuscripts that are under submission based on this protocol**
None.

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**Authors' contributions**
PKM, DJD, MOB designed the outline of the study. PKM, JFP, MOB, EAW, GMP, GAB and AKM obtained the funding for the study. SDM & RH contributed in protocol preparation. All authors contributed in writing of the paper. All authors read and approved the final manuscript. PKM is the guarantor.

**Competing interests**
The authors declare that they have no competing interests.

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Supplementary document to:

**Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study**

Michelle Tørnes, David McLernon, Max O Bachmann, Stanley D Musgrave, Elizabeth A Warburton, John F Potter, Phyo Kyaw Myint: On behalf of the Anglia Stroke Clinical Network Evaluation Study (ASCNES) Group

**CONTENT**

**Figure S3** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and distance to neurosurgical facility with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S4** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte senior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S5** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte junior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S6** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte health care associates and nurses per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S7** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte occupational therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S8** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte physiotherapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S9** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte speech and language therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S10** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of total beds present on stroke unit per 100 admissions with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S11** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of hospital beds per computed tomography (CT) scanner with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S12** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and provision of onsite rehabilitation service with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S13** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of early supported discharge scheme with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S14** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S15** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and mean Index of Multiple Deprivation (IMD) score of the counties in which the hospital serves with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Table S1** Variables used to inform multiple imputation of missing data

| Variable | Measure |
|---|---|
| I. Independent Variables | |
| Trust | 0=Trust 1 1 =Trust 2 2 =Trust 3 3=Trust 4 4=Trust 5 4=Trust 6 5=Trust 7 6=Trust 8 |
| Sex | 0=Male 1=Female |
| Age | Continuous, years |
| Recurrent Stroke | 0=No 1=Yes |
| Diabetes Mellitus | 0=No 1=Yes |
| Dementia | 0=No 1=Yes |
| Hypercholesterolemia | 0=No 1=Yes |
| Myocardial Infarction or Ischaemic Heart Disease | 0=No 1=Yes |
| Transient Ischaemic Attack | 0=No 1=Yes |
| Previous Cancer | 0=No 1=Yes |
| Active Cancer | 0=No 1=Yes |
| Depression | 0=No 1=Yes |
| Rheumatoid Arthritis | 0=No 1=Yes |
| Chronic Obstructive Pulmonary Disease | 0=No 1=Yes |
| Pre-Stroke modified Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 & 5 |
| Pre-Stroke Residence | 0=Independent living without formal care 1=Independent living with formal care 2=Institutional care |
| Stroke Type | 0=Ischaemic 1=Haemorrhagic |
| Oxfordshire Community Stroke Classification | 0=LACS 1=PACS 2=POCS 3=TACS |
| Brain Lateralisation | 0=Yes 1=No |
| Inpatient Complication | 0=No 1=Yes |
| Discharge modified Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 5=5 6=6 |
| Season of Admission | 0=Summer 1=Winter |
| Day of Admission | 0=Weekday 1=Weekend |
| II. Dependent Variable | |
| Logarithmic acute hospital LOS | Continuous, days |
| III. Auxiliary Variables | |
| Discharge Destination | 0=Independent living without formal care 1=Independent living with formal care 2=Institutional care 3=Interim or rehabilitation setting 4=Death |
| Atrial Fibrillation | 0=No 1=Yes |
| Baseline Systolic Blood Pressure | Continuous, mmHg |
| Baseline Diastolic Blood Pressure | Continuous, mmHg |
| Glucose Concentration on Admission | Continuous, mmol/L |
| Weight | Continuous, kg |
| Heart Rate | Continuous, beats per minute |
| Temperature | Continuous, ˚C |
| Oxygen Saturation | Continuous, % |
| ITU or HDU admission | 0. No 1. Yes |
| Systolic Blood Pressure at Discharge | Continuous, mmHg |
| Diastolic Blood Pressure at Discharge | Continuous, mm Hg |

LOS, Length of Stay; ITU, Intensive Care Unit; HDU, High Dependency Unit.

**Table S2** Sample characteristics of the 2333 patients included in analysis per individual hospital (n (%) unless otherwise stated)

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Age, y, median (IQR) | 78<br>(68 to 85) | 87<br>(81 to 92) | 79<br>(72 to 86) | 79<br>(70 to 86) | 79<br>(71 to 85) | 78<br>(71 to 85) | 80<br>(68 to 85) | 80<br>(71 to 87) |
| Sex, female | 180 (52) | 9 (56) | 197 (56) | 76 (53) | 309 (50) | 155 (55) | 116 (46) | 123 (55) |
| Recurrent Stroke | 50 (14) | 5 (31) | 61 (17) | 19 (17) | 143 (23) | 62 (22) | 66 (26) | 42 (19) |
| Diabetes Mellitus | 48 (14) | 1 (6) | 59 (17) | 17 (15) | 92 (15) | 66 (23) | 44 (17) | 43 (19) |
| Dementia | 26 (7) | 1 (6) | 35 (10) | 10 (9) | 58 (9) | 29 (10) | 23 (9) | 25 (11) |
| Hypercholesterolemia | 48 (14) | 3 (19) | 24 (7) | 7 (6) | 61 (10) | 80 (28) | 38 (15) | 94 (42) |
| Hypertensive | 225 (64) | 8 (50) | 202 (58) | 56 (50) | 446 (72) | 200 (71) | 187 (74) | 159 (71) |
| Myocardial Infarction or Ischaemic Heart Disease | 45 (13) | 3 (19) | 87 (25) | 30 (27) | 142 (23) | 80 (28) | 49 (19) | 81 (36) |
| Transient Ischaemic Attack | 32 (9) | 3 (19) | 58 (17) | 17 (15) | 113 (18) | 40 (14) | 47 (19) | 30 (13) |
| Previous Cancer | 33 (9) | 1 (6) | 38 (11) | 12 (11) | 41 (7) | 18 (6) | 21 (8) | 31 (14) |
| Active Cancer | 24 (7) | 2 (12) | 8 (2) | 10 (9) | 49 (8) | 9 (3) | 20 (8) | 15 (7) |
| Depression | 13 (4) | 0 (0) | 17 (5) | 8 (7) | 33 (5) | 11 (4) | 18 (7) | 17 (8) |
| Rheumatoid Arthritis | 11 (3) | 1 (6) | 43 (12) | 3 (3) | 83 (13) | 2 (1) | 7 (3) | 4 (2) |
| COPD | 15 (4) | 1 (6) | 20 (6) | 6 (5) | 26 (4) | 20 (7) | 11 (4) | 17 (8) |
| Pre-stroke mRS Score | | | | | | | | |
| 0 | 84 (43) | 3 (19) | 117 (36) | - | 330 (56) | 126 (64) | 136 (56) | 118 (53) |
| 1 | 60(31) | 3 (19) | 75 (23) | - | 87 (15) | 16 (8) | 61 (25) | 33 (15) |
| 2 | 24 (12) | 3 (19) | 51 (16) | - | 56 (9) | 17 (9) | 16 (7) | 24 (11) |
| 3 | 21 (11) | 2 (12) | 38 (12) | - | 60 (10) | 20 (10) | 15 (6) | 28 (13) |
| 4 & 5 | 7 (4) | 5 (31) | 44 (14) | - | 57 (10) | 18 (9) | 16 (7) | 20 (9) |
| Pre-Stroke Residence | | | | | | | | |
| Independent living with formal care | 21 (6) | 4 (25) | 23 (7) | 15 (14) | 62 (10) | 30 (11) | 34 (13) | 21 (10) |
| Independent living w/o formal care | 292 (86) | 9 (56) | 285 (82) | 86 (77) | 493 (80) | 215 (77) | 193 (77) | 179 (82) |
| Institution | 28 (8) | 3 (19) | 40 (11) | 10 (9) | 63 (10) | 35 (12) | 23 (9) | 18 (8) |

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Stroke Type | | | | | | | | |
| Ischaemic | 293 (85) | 14 (100) | 286 (87) | 90 (91) | 541 (88) | 233 (85) | 213 (87) | 194 (88) |
| Haemorrhagic | 50 (15) | 0 (0) | 43 (13) | 9 (9) | 73 (12) | 40 (15) | 32 (13) | 26(12) |
| Oxford Community Stroke Project Classification | | | | | | | | |
| LACS | 64 (24) | 1 (7) | 95 (29) | 20 (28) | 149 (25) | 51 (18) | 39 (19) | 84 (39) |
| PACS | 117 (43) | 11 (79) | 109 (33) | 38 (54) | 216 (37) | 147 (53) | 80 (39) | 66 (30) |
| POCS | 51 (19) | - | 29 (9) | 3 (4) | 117 (20) | 21 (8) | 33 (16) | 25 (12) |
| TACS | 38 (14) | 2 (14) | 99 (30) | 10 (14) | 107 (18) | 57 (21) | 52 (25) | 42 (19) |
| No Brain Lateralisation | 50 (15) | 2 (13) | 14 (4) | 9 (9) | 129 (21) | 1 (0.4) | 30 (12) | 9 (4) |
| Inpatient Complication | 108 (31) | 4 (25) | 34 (10) | 36 (25) | 229 (37) | 109 (39) | 83 (33) | 52 (23) |
| Discharge mRS Score | | | | | | | | |
| 0 | 37 (15) | 0 (0) | 11 (3) | 0 (0) | 114 (19) | 44 (16) | 42 (17) | 22 (10) |
| 1 | 65 (25) | 2 (12) | 55 (17) | 0 (0) | 97 (16) | 25 (12) | 55 (23) | 53 (24) |
| 2 | 36 (14) | 1 (6) | 46 (14) | 0 (0) | 57 (10) | 20 (9) | 33 (14) | 19 (9) |
| 3 | 41 (16) | 4 (25) | 40 (12) | 0 (0) | 87 (15) | 36 (17) | 34 (14) | 49 (22) |
| 4 | 19 (7) | 3 (19) | 57 (17) | 0 (0) | 89 (15) | 25 (12) | 16 (7) | 29 (13) |
| 5 | 4 (2) | 1 (6) | 47 (14) | 0 (0) | 40 (7) | 14 (7) | 16 (7) | 15 (7) |
| 6 | 53 (21) | 5 (31) | 77 (23) | 29 (100) | 110 (19) | 58 (27) | 47 (19) | 35 (16) |
| Winter Admission | 172 (49) | 16 (100) | 181 (52) | 73 (51) | 332 (54) | 140 (50) | 131 (52) | 114 (51) |
| Weekend Admission | 113 (32) | 3 (19) | 98 (28) | 43 (30) | 177 (29) | 74 (26) | 55 (22) | 51 (23) |

IQR, Interquartile Range; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S3** Sample characteristics of complete cases and those with at least one variable missing

| Patient Characteristic | Complete Cases (n=1496) | Cases with at least one missing variable | *P* |
|---|---|---|---|
| | Median (IQR) or No. (%) | | |
| Age, y* | 79 (71 to 86) | 79 (70 to 86) | 0.34 |
| Sex, female† | 781 (52) | 384 (52) | 1 |
| Comorbidities† | | | |
| Recurrent Stroke | 328 (22) | 120 (17) | 0.01 |
| Diabetes Mellitus | 259 (17) | 111 (16) | 0.38 |
| Dementia | 138 (9) | 69 (10) | 0.75 |
| Hypercholesterolemia | 264 (18) | 91 (13) | 0.01 |
| Hypertensive | 1054 (70) | 429 (61) | <0.001 |
| Myocardial Infarction or Ischaemic Heart Disease | 362(24) | 155 (22) | 0.26 |
| TIA | 248 (17) | 92 (13) | 0.04 |
| Previous Cancer | 140 (9) | 55 (8) | 0.25 |
| Active Cancer | 93 (6) | 44 (6) | 1 |
| Depression | 79 (5) | 38 (5) | 1 |
| Rheumatoid Arthritis | 129 (9) | 25 (3) | <0.001 |
| COPD | 76 (5) | 40 (6) | 0.64 |
| Pre-stroke mRS Score‡ | | | 0.62 |
| 0 | 765 (51) | 149 (51) | |
| 1 | 284 (19) | 51 (17) | |
| 2 | 167 (11) | 24 (8) | |
| 3 | 149 (10) | 35 (12) | |
| 4 & 5 | 131 (9) | 36 (12) | |
| Pre-stroke Residence† | | | <0.001 |
| Independent living with formal care | 145 (10) | 65 (9) | |
| Independent living without formal | 1215 (81) | 537 (78) | |
| Institution | 136 (9) | 84 (12) | |
| Haemorrhagic Stroke† | 138 (9) | 135 (21) | <0.001 |
| Oxford Community Stroke Project‡ | | | 0.05 |
| LACS | 411 (27) | 92 (19) | |
| PACS | 570 (38) | 214 (45) | |
| POCS | 214 (14) | 65 (14) | |
| TACS | 301 (20) | 106 (22) | |
| No Brain Lateralisation† | 174 (12) | 70 (12) | 0.74 |
| Inpatient Complication† | 421 (28) | 234 (32) | 0.09 |
| Discharge mRS Score‡ | | | 0.02 |
| 0 | 218 (15) | 42 (10) | |
| 1 | 295 (20) | 57 (14) | |
| 2 | 177 (12) | 35 (9) | |
| 3 | 243 (16) | 48 (12) | |
| 4 | 209 (14) | 29 (7) | |
| 5 | 121 (8) | 16 (4) | |
| 6 | 233 (16) | 181 (44) | |

| | | | |
|---|---|---|---|
| Winter Admission† | 770 (51) | 389 (53) | 0.59 |
| Weekend Admission† | 401 (27) | 213 (29) | 0.32 |

IQR, Interquartile Range; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Two sample t-test*

*† $\mathcal{X}^2$ test*

*ǂ $\mathcal{X}^2$ test for trend*

**Table S4** Univariable regression analysis for multiple imputed dataset for AHLOS (n=2233)

| Patient Characteristic | β | 95% CI | *P* | $R^2$ |
|---|---|---|---|---|
| Age, y | 1.02 | 1.02 to 1.02 | <0.001 | 4.8 |
| Sex, female | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 1.17 | 1.05 to 1.31 | 0.01 | 0.4 |
| Diabetes Mellitus | 1.16 | 1.03 to 1.31 | 0.02 | 0.3 |
| Dementia | 1.46 | 1.25 to 1.70 | <0.001 | 1.1 |
| Hypercholesterolemia | 0.84 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1.02 | 0.93 to 1.12 | 0.66 | 0 |
| Myocardial Infarction/ Ischaemic Heart Disease* | 1.07 | 0.96 to 1.19 | 0.23 | 0.1 |
| TIA | 1.07 | 0.94 to 1.21 | 0.30 | 0.1 |
| Previous Cancer | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 0.97 | 0.80 to 1.16 | 0.72 | 0 |
| Depression | 1.06 | 0.86 to 1.29 | 0.59 | 0 |
| Rheumatoid Arthritis | 1.10 | 0.92 to 1.31 | 0.31 | 0.1 |
| COPD | 0.86 | 0.71 to 1.06 | 0.15 | 0.1 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 | 5.5 |
| 1 | 1.57 | 1.38 to 1.79 | <0.001 | |
| 2 | 1.63 | 1.39 to 1.91 | <0.001 | |
| 3 | 1.94 | 1.65 to 2.28 | <0.001 | |
| 4 & 5 | 1.32 | 1.13 to 1.55 | <0.001 | |
| Pre-stroke Residence (reference Independent living w/o formal care) | | | <0.001 | 1.4 |
| Independent living with formal care | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 1.13 | 0.97 to 1.31 | 0.11 | |
| Haemorrhagic Stroke | 0.83 | 0.73 to 0.96 | 0.01 | 0.3 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 | 4.0 |
| PACS | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 1.22 | 1.05 to 1.42 | 0.01 | |
| TACS | 1.66 | 1.45 to 1.90 | <0.001 | |
| Brain Lateralisation | 0.69 | 0.60 to 0.80 | <0.001 | 1.2 |
| Inpatient Complication | 2.13 | 1.94 to 2.34 | <0.001 | 10.3 |
| Discharge mRS Score (reference 0) | | | <0.001 | 31.1 |
| 1 | 1.24 | 1.07 to 1.42 | 0.003 | |
| 2 | 2.04 | 1.75 to 2.39 | <0.001 | |
| 3 | 3.35 | 2.90 to 3.87 | <0.001 | |
| 4 | 4.20 | 3.60 to 4.90 | <0.001 | |
| 5 | 6.67 | 5.62 to 7.91 | <0.001 | |
| 6 | 1.57 | 1.37 to 1.80 | <0.001 | |
| Winter Admission | 1.20 | 1.09 to 1.31 | <0.001 | 0.7 |
| Weekend Admission | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | <0.001 | 2.4 |
| 2 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 1.18 | 1.00 to 1.41 | 0.05 | |

| Patient Characteristic | β | 95% CI | *P* | $R^2$ |
|---|---|---|---|---|
| 8 | 0.86 | 0.72 to 1.03 | 0.11 | |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S5** Univariable linear regression complete case analysis for AHLOS

| Patient Characteristic | N | β | 95% CI | *P* | % $R^2$ |
|---|---|---|---|---|---|
| Age, y | 2231 | 1.02 | 1.02 to 1.02 | <0.001 | 4.7 |
| Sex, female | 1165 v. 1066 | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 448 v. 1755 | 1.17 | 1.05 to 1.31 | 0.005 | 0.3 |
| Diabetes Mellitus | 370 v. 1833 | 1.16 | 1.03 to 1.31 | 0.02 | 0.2 |
| Dementia | 207 v. 1996 | 1.46 | 1.25 to 1.70 | <0.001 | 1.0 |
| Hypercholesterolemia | 355 v. 1848 | 0.85 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1483 v. 720 | 1.03 | 0.93 to 1.13 | 0.57 | 0 |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 v. 1686 | 1.07 | 0.96 to 1.19 | 0.23 | 0 |
| TIA | 340 v. 1863 | 1.06 | 0.94 to 1.20 | 0.32 | 0 |
| Previous Cancer | 195 v. 2008 | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 137 v. 2066 | 0.96 | 0.80 to 1.15 | 0.65 | 0 |
| Depression | 117 v. 2086 | 1.05 | 0.86 to 1.28 | 0.65 | 0 |
| Rheumatoid Arthritis | 154 v. 2049 | 1.10 | 0.92 to 1.31 | 0.31 | 0 |
| COPD | 116 v. 2087 | 0.86 | 0.70 to 1.05 | 0.14 | 0.1 |
| Pre-stroke mRS Score (reference 0) | | | | <0.001 | 5.8 |
| 1 | 335 v. 914 | 1.58 | 1.39 to 1.80 | <0.001 | |
| 2 | 191 v. 914 | 1.62 | 1.38 to 1.90 | <0.001 | |
| 3 | 184 v. 914 | 1.97 | 1.67 to 2.31 | <0.001 | |
| 4 & 5 | 167 v. 914 | 1.45 | 1.22 to 1.71 | <0.001 | |
| Pre-stroke Residence (reference Independent living without formal care) | | | | <0.001 | 1.3 |
| Independent living with formal care | 210 v. 1752 | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 220 v. 1752 | 1.14 | 0.98 to 1.32 | 0.09 | |
| Haemorrhagic Stroke | 273 v. 1864 | 0.85 | 0.74 to 0.97 | 0.02 | 0.2 |
| Oxford Community Stroke Project Classification (reference LACS) | | | | <0.001 | 4.3 |
| PACS | 784 v. 503 | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 279 v. 503 | 1.24 | 1.06 to 1.44 | 0.01 | |
| TACS | 407 v. 503 | 1.75 | 1.53 to 2.01 | <0.001 | |
| No Brain Lateralisation | 244 v. 1822 | 0.68 | 0.59 to 0.79 | <0.001 | 1.3 |
| Inpatient Complication | 655 v. 1578 | 2.13 | 1.94 to 2.34 | <0.001 | 10 |
| Discharge mRS Score (reference 0) | | | | <0.001 | 30.1 |
| 1 | 352 v. 260 | 1.25 | 1.08 to 1.44 | 0.002 | |
| 2 | 212 v. 260 | 2.01 | 1.72 to 2.36 | <0.001 | |
| 3 | 291 v. 260 | 3.30 | 2.84 to 3.82 | <0.001 | |
| 4 | 238 v. 260 | 4.17 | 3.57 to 4.87 | <0.001 | |
| 5 | 137 v. 260 | 6.97 | 5.81 to 8.37 | <0.001 | |
| 6 | 414 v. 260 | 1.58 | 1.38 to 1.81 | <0.001 | |
| Winter Admission | 1159 v. 1074 | 1.20 | 1.09 to 1.31 | <0.001 | 0.6 |
| Weekend Admission | 614 v. 1619 | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | | <0.001 | 2.1 |
| 2 | 16 v. 350 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 350 v. 350 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 143 v. 350 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 618 v. 350 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 281 v. 350 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 252 v. 350 | 1.18 | 1.00 to 1.41 | 0.05 | |

| Patient Characteristic | N | β | 95% CI | *P* | % $R^2$ |
|---|---|---|---|---|---|
| 8 | 223 v. 350 | 0.86 | 0.72 to 1.03 | 0.11 | |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S6** Multiple *l*inear *r*egression *c*omplete *c*ase *a*nalysis for AHLOS (n=1496, $R^2$=44.7%).

| Patient Characteristic | N | β | 95% CI | *P* |
|---|---|---|---|---|
| Age, y | 1496 | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 781 v. 715 | 0.98 | 0.90 to 1.07 | 0.66 |
| Recurrent Stroke | 328 v. 1168 | 1.06 | 0.96 to 1.17 | 0.27 |
| Diabetes Mellitus | 259 v. 1237 | 0.99 | 0.89 to 1.11 | 0.91 |
| Dementia | 138 v. 1358 | 1.32 | 1.13 to 1.53 | <0.001 |
| Hypercholesterolemia | 264 v. 1232 | 0.92 | 0.82 to 1.02 | 0.13 |
| Myocardial Infarction or Ischaemic Heart Disease* | 362 v. 1134 | 1.00 | 0.91 to 1.10 | 0.97 |
| Previous Cancer | 140 v. 1356 | 1.16 | 1.01 to 1.33 | 0.03 |
| COPD | 76 v. 1420 | 0.91 | 0.76 to 1.09 | 0.31 |
| Pre-stroke mRS Score (reference 0) | | | | <0.001 |
| 1 | 284 v. 765 | 1.08 | 0.96 to 1.20 | 0.21 |
| 2 | 167 v. 765 | 0.93 | 0.80 to 1.08 | 0.33 |
| 3 | 149 v. 765 | 1.00 | 0.84 to 1.19 | 0.99 |
| 4 & 5 | 131 v. 765 | 0.77 | 0.63 to 0.93 | 0.01 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | | <0.001 |
| Independent living with formal care | 145 v. 1215 | 1.02 | 0.88 to 1.19 | 0.78 |
| Institution | 136 v. 1215 | 0.83 | 0.69 to 0.98 | 0.03 |
| Haemorrhagic Stroke | 138 v. 1358 | 0.83 | 0.72 to 0.96 | 0.01 |
| Oxford Community Stroke Project Classification | | | | <0.001 |
| PACS | 570 v. 411 | 1.27 | 1.15 to 1.40 | <0.001 |
| POCS | 214 v. 411 | 1.29 | 1.13 to 1.47 | <0.001 |
| TACS | 301 v. 411 | 1.36 | 1.19 to 1.57 | <0.001 |
| No Brain Lateralisation | 174 v. 1322 | 0.93 | 0.81 to 1.05 | 0.24 |
| Inpatient Complication | 421 v. 1075 | 1.67 | 1.51 to 1.84 | <0.001 |
| Discharge mRS Score (reference 0) | | | | <0.001 |
| 1 | 295 v. 218 | 1.15 | 1.00 to 1.32 | 0.05 |
| 2 | 177 v. 218 | 1.60 | 1.36 to 1.88 | <0.001 |
| 3 | 243 v. 218 | 2.45 | 2.10 to 2.87 | <0.001 |
| 4 | 209 v. 218 | 3.39 | 2.86 to 4.02 | <0.001 |
| 5 | 121 v. 218 | 4.78 | 3.89 to 5.88 | <0.001 |
| 6 | 233 v. 218 | 1.34 | 1.11 to 1.61 | 0.002 |
| Winter Admission | 770 v. 726 | 1.16 | 1.07 to 1.25 | <0.001 |
| Weekend Admission | 401 v. 1095 | 1.06 | 0.97 to 1.15 | 0.23 |
| Hospital (reference1) | | | | <0.001 |
| 2 | 14 v. 111 | 2.08 | 1.35 to 3.21 | 0.001 |
| 3 | 278 v. 111 | 1.20 | 1.01 to 1.44 | 0.04 |
| 4 | - | - | - | - |
| 5 | 558 v. 111 | 0.84 | 0.71 to 0.98 | 0.03 |
| 6 | 142 v. 111 | 1.03 | 0.85 to 1.26 | 0.75 |
| 7 | 191 v. 111 | 1.35 | 1.13 to 1.62 | 0.001 |
| 8 | 202 v. 111 | 0.94 | 0.78 to 1.13 | 0.49 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S7** Multiple linear regression sensitivity analysis for AHLOS, excluding Hospital 2 using multiple imputed dataset (n=2217, $R^2$=44.7%).

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 1.01 | 0.94 to 1.08 | 0.86 |
| Recurrent Stroke | 1.02 | 0.93 to 1.12 | 0.68 |
| Diabetes Mellitus | 1.07 | 0.97 to 1.17 | 0.19 |
| Dementia | 1.30 | 1.13 to 1.48 | <0.001 |
| Hypercholesterolemia | 0.95 | 0.86 to 1.05 | 0.33 |
| Myocardial Infarction or Ischaemic Heart Disease* | 1.00 | 0.91 to 1.08 | 0.92 |
| Previous Cancer | 1.13 | 0.99 to 1.27 | 0.06 |
| COPD | 0.90 | 0.77 to 1.06 | 0.21 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.08 | 0.96 to 1.21 | 0.19 |
| 2 | 0.90 | 0.78 to 1.04 | 0.16 |
| 3 | 0.94 | 0.79 to 1.10 | 0.47 |
| 4 & 5 | 0.69 | 0.58 to 0.83 | <0.001 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.01 | 0.88 to 1.16 | 0.91 |
| Institution | 0.81 | 0.69 to 0.95 | 0.01 |
| Haemorrhagic Stroke | 0.80 | 0.71 to 0.90 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.30 | 1.18 to 1.43 | <0.001 |
| POCS | 1.34 | 1.18 to 1.53 | <0.001 |
| TACS | 1.29 | 1.13 to 1.47 | <0.001 |
| No Brain Lateralisation | 0.85 | 0.75 to 0.95 | 0.01 |
| Inpatient Complication | 1.70 | 1.57 to 1.85 | <0.001 |
| Discharge mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.00 to 1.32 | 0.04 |
| 2 | 1.74 | 1.48 to 2.04 | <0.001 |
| 3 | 2.72 | 2.34 to 3.16 | <0.001 |
| 4 | 3.56 | 3.02 to 4.20 | <0.001 |
| 5 | 5.12 | 4.22 to 6.22 | <0.001 |
| 6 | 1.25 | 1.05 to 1.48 | 0.01 |
| Winter Admission | 1.15 | 1.08 to 1.24 | <0.001 |
| Weekend Admission | 1.03 | 0.95 to 1.11 | 0.48 |
| Hospital (reference 1) | | | <0.001 |
| 3 | 1.08 | 0.94 to 1.22 | 0.29 |
| 4 | 1.07 | 0.89 to 1.29 | 0.40 |
| 5 | 0.78 | 0.70 to 0.87 | <0.001 |
| 6 | 0.93 | 0.81 to 1.07 | 0.33 |
| 7 | 1.15 | 1.00 to 1.32 | 0.05 |
| 8 | 0.82 | 0.70 to 0.95 | 0.01 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S8** Multiple linear regression sensitivity analysis for AHLOS, including discharge destination using multiple imputed dataset (n=2233, $R^2$=40%).

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 0.99 | 0.92 to 1.07 | 0.80 |
| Recurrent Stroke | 1.00 | 0.91 to 1.10 | 1.00 |
| Diabetes Mellitus | 1.08 | 0.98 to 1.19 | 0.12 |
| Dementia | 1.20 | 1.05 to 1.38 | 0.01 |
| Hypercholesterolemia | 0.94 | 0.85 to 1.04 | 0.25 |
| Myocardial Infarction or Ischaemic Heart | 1.01 | 0.93 to 1.10 | 0.83 |
| Previous Cancer | 1.17 | 1.03 to 1.33 | 0.01 |
| COPD | 0.91 | 0.77 to 1.07 | 0.23 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.03 to 1.28 | 0.02 |
| 2 | 1.15 | 1.00 to 1.33 | 0.05 |
| 3 | 1.33 | 1.13 to 1.56 | <0.001 |
| 4 & 5 | 1.15 | 0.96 to 1.38 | 0.12 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 0.86 | 0.75 to 0.99 | 0.04 |
| Institution | 0.52 | 0.44 to 0.62 | <0.001 |
| Haemorrhagic Stroke | 0.84 | 0.75 to 0.95 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.34 | 1.22 to 1.48 | <0.001 |
| POCS | 1.44 | 1.26 to 1.63 | <0.001 |
| TACS | 1.49 | 1.31 to 1.70 | <0.001 |
| No Brain Lateralisation | 0.82 | 0.73 to 0.93 | <0.001 |
| Inpatient Complication | 1.72 | 1.58 to 1.87 | <0.001 |
| Discharge Destination (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.99 | 1.74 to 2.27 | <0.001 |
| Institution | 3.58 | 3.09 to 4.15 | <0.001 |
| Interim/Rehab Setting | 2.18 | 1.94 to 2.46 | <0.001 |
| Death | 0.85 | 0.74 to 0.97 | 0.02 |
| Winter Admission | 1.15 | 1.07 to 1.24 | <0.001 |
| Weekend Admission | 1.04 | 0.96 to 1.13 | 0.30 |
| Hospital (reference 1) | | | <0.001 |
| 2 | 2.76 | 1.80 to 4.22 | <0.001 |
| 3 | 1.24 | 1.09 to 1.42 | <0.001 |
| 4 | 1.36 | 1.15 to 1.61 | <0.001 |
| 5 | 0.85 | 0.75 to 0.95 | 0.01 |
| 6 | 1.06 | 0.92 to 1.22 | 0.42 |
| 7 | 1.19 | 1.03 to 1.37 | 0.02 |
| 8 | 0.99 | 0.85 to 1.14 | 0.84 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

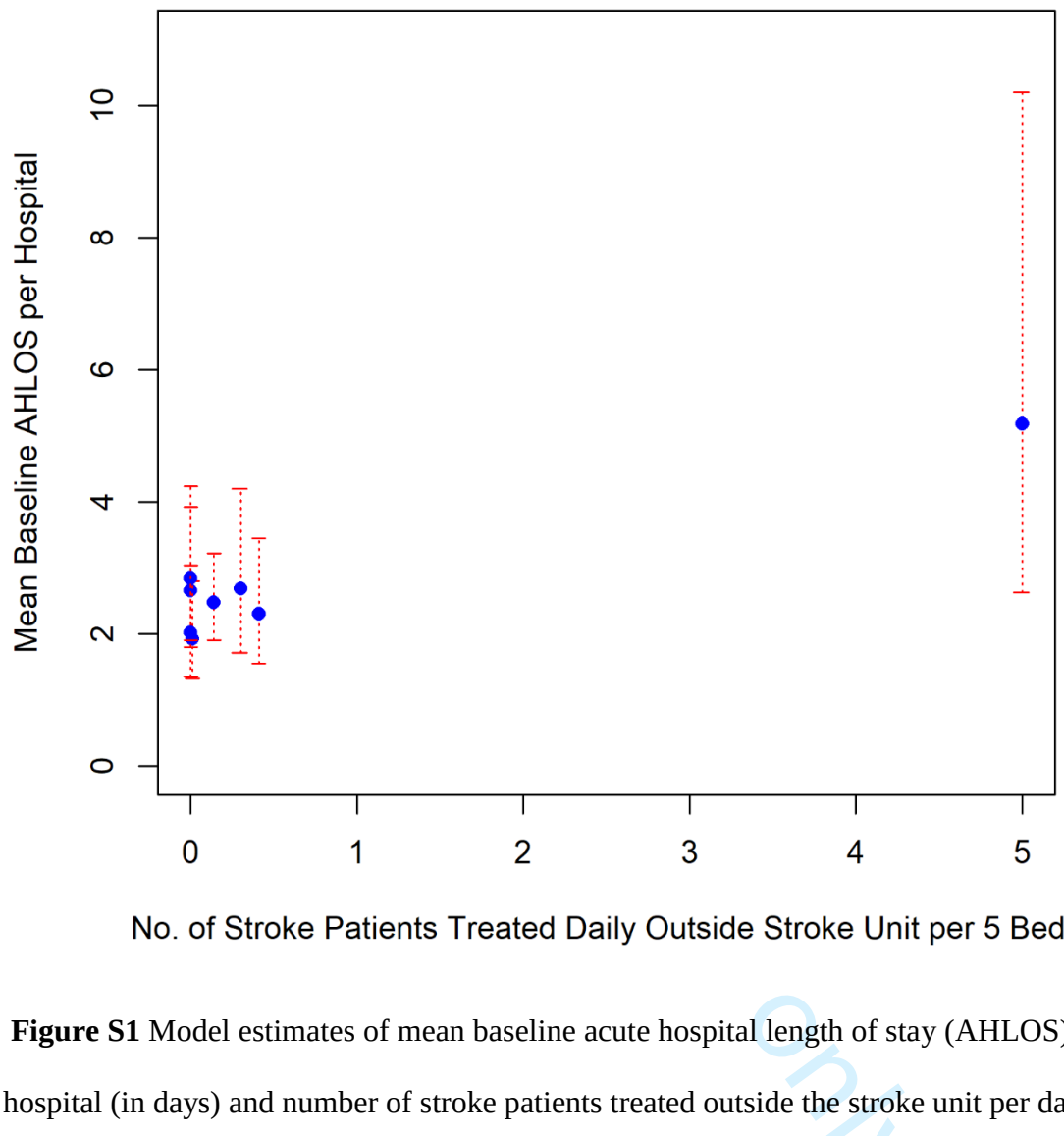


**Figure S1** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of stroke patients treated outside the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

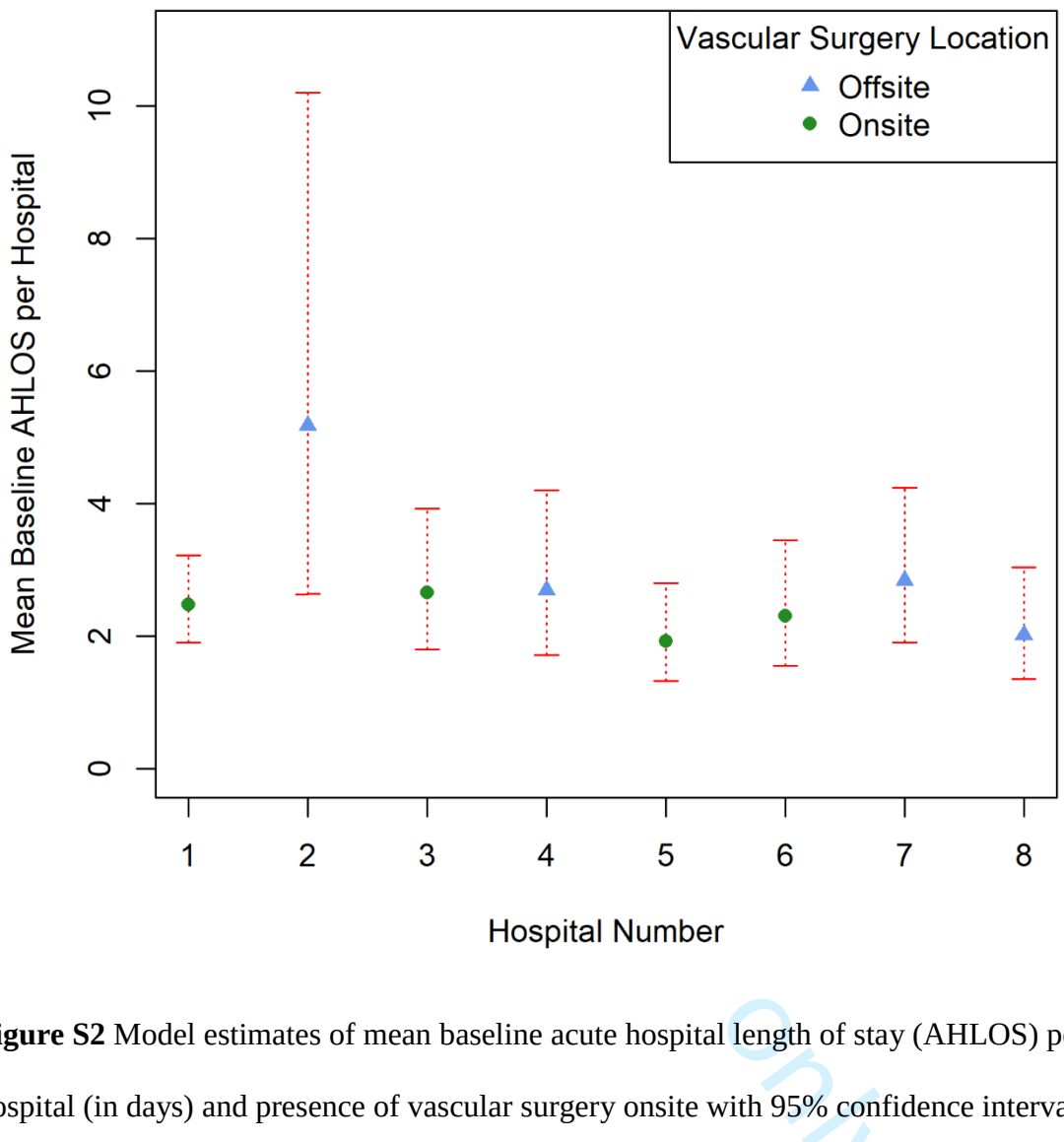


**Figure S2** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of vascular surgery onsite with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

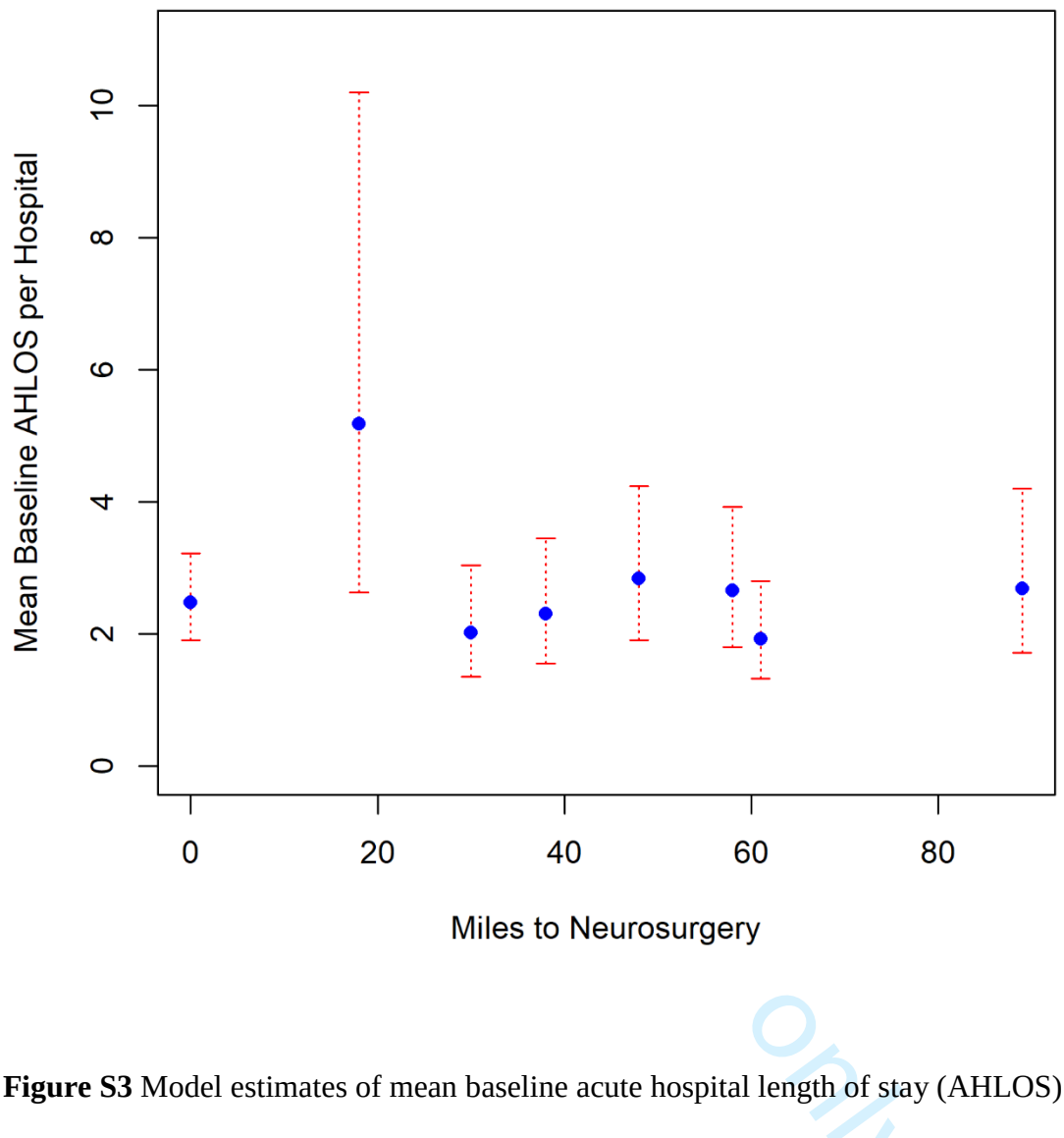


**Figure S3** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and distance to neurosurgical facility with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

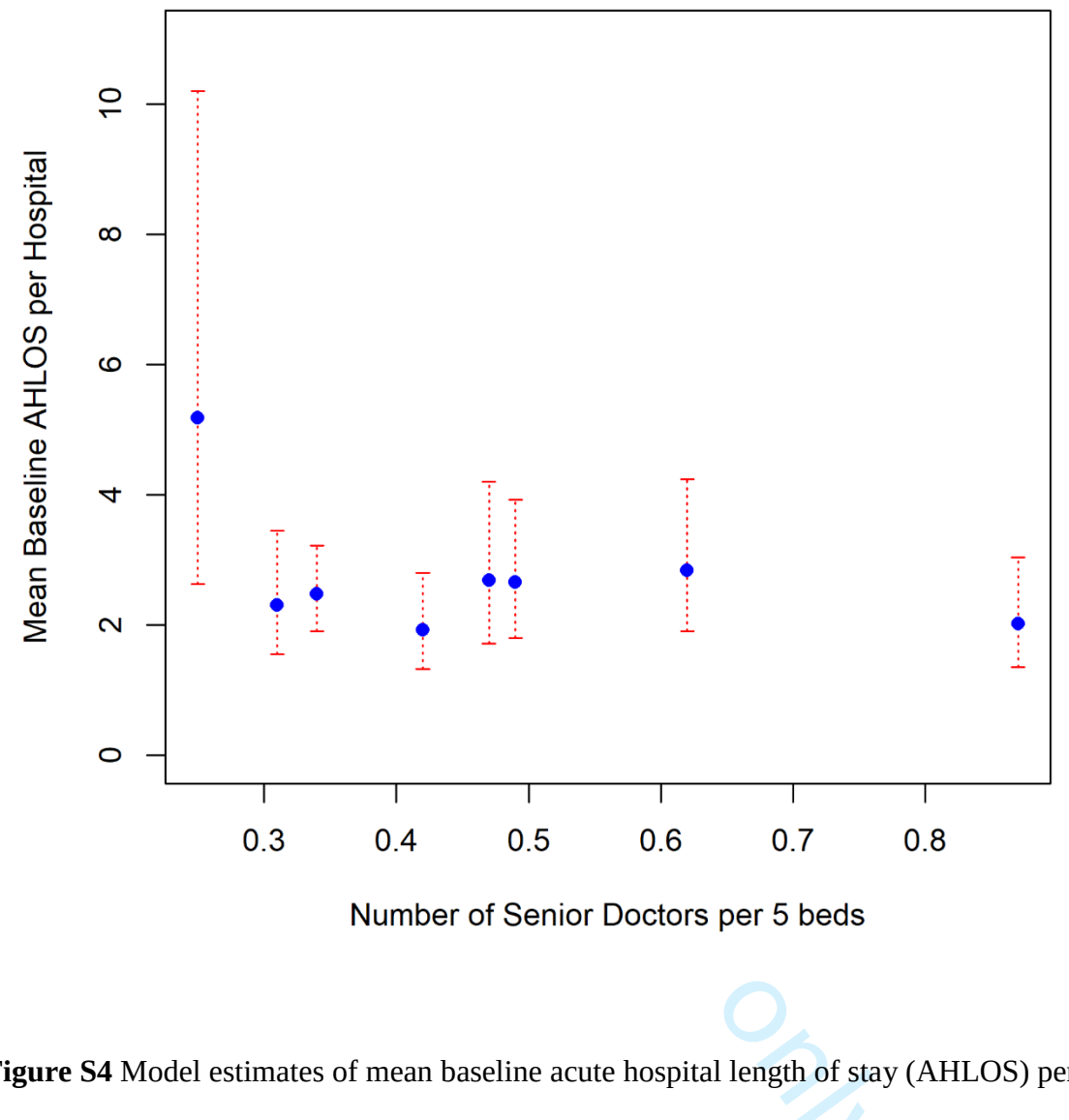


**Figure S4** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte senior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

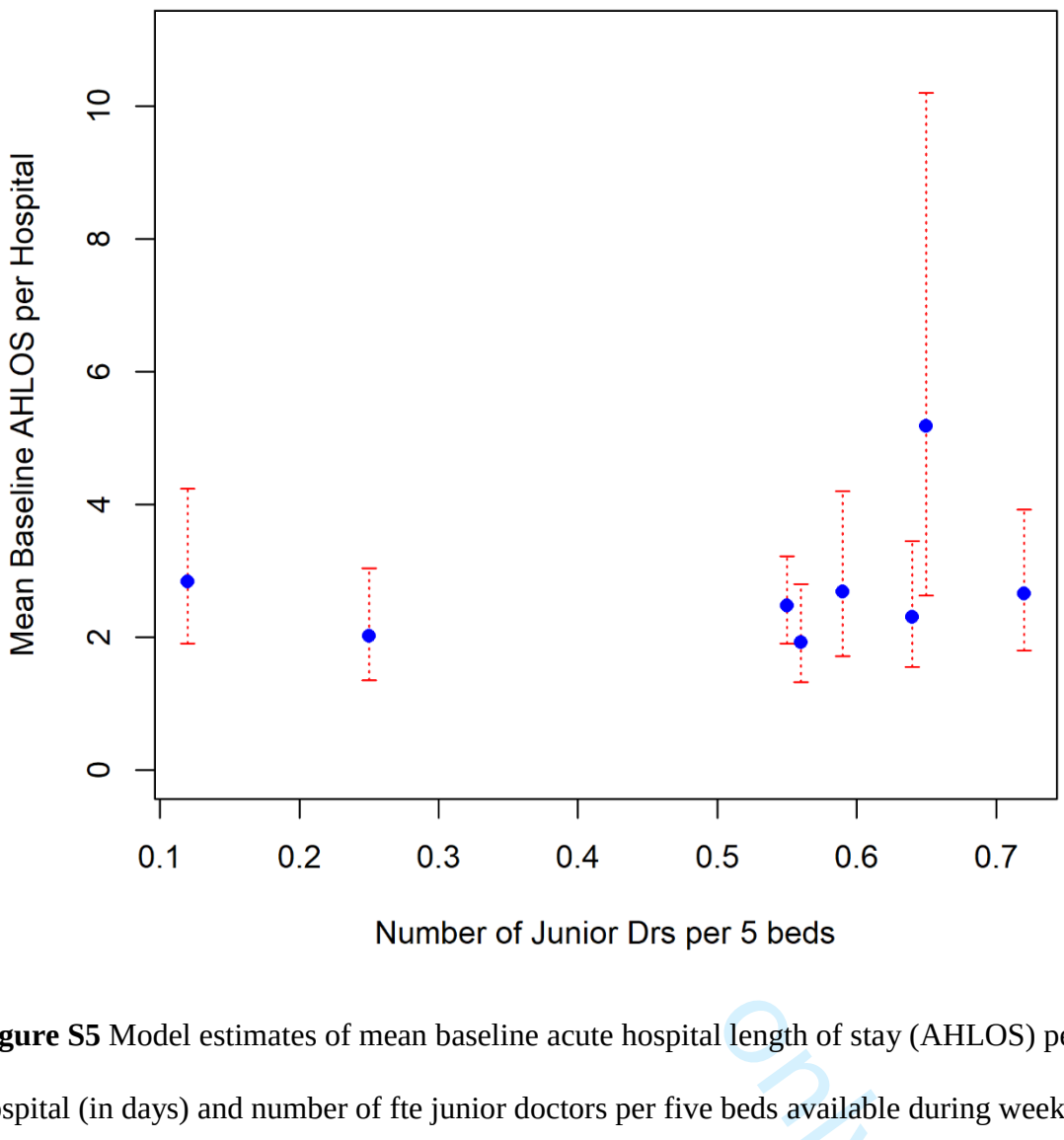


**Figure S5** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte junior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

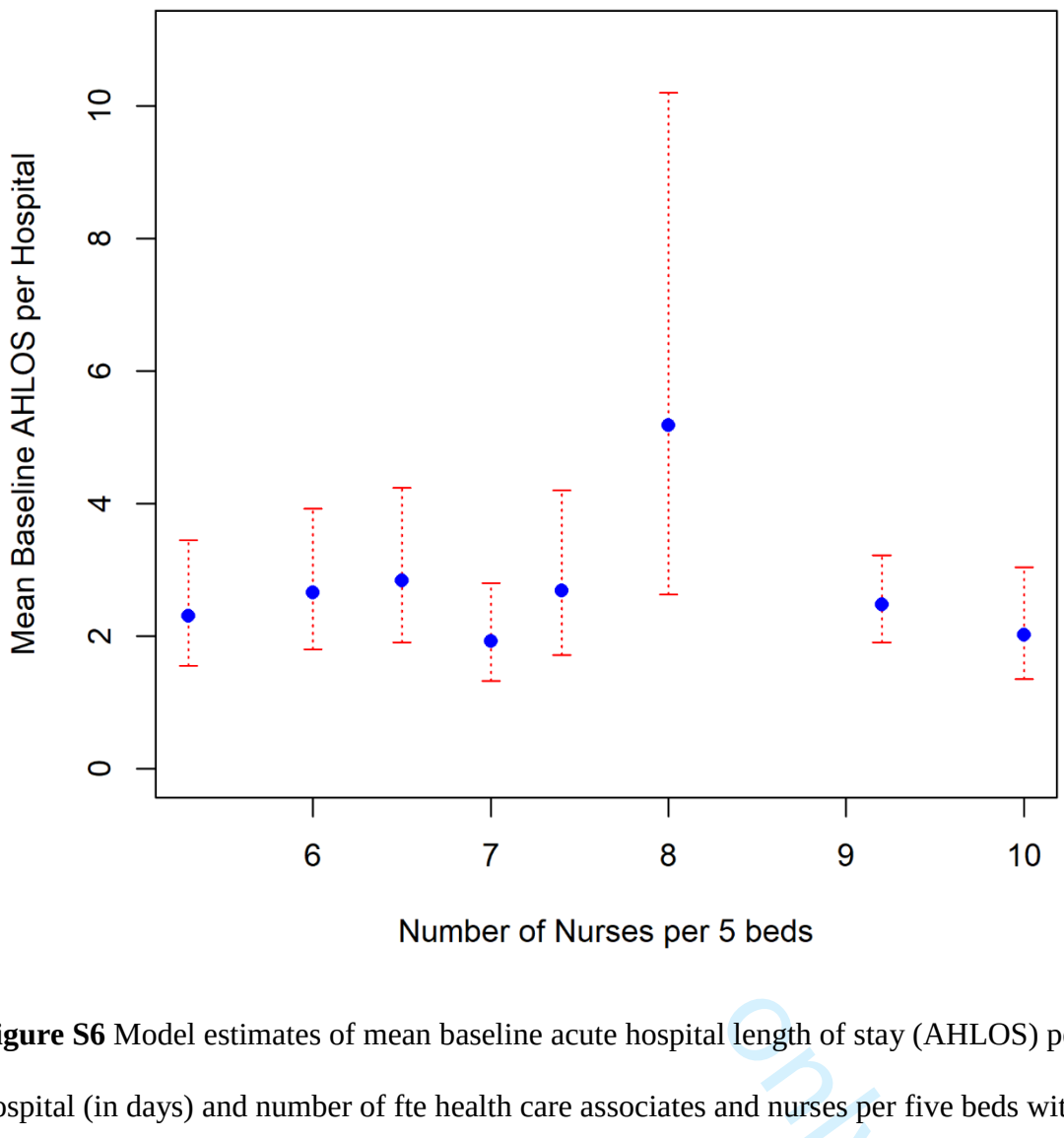


**Figure S6** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte health care associates and nurses per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

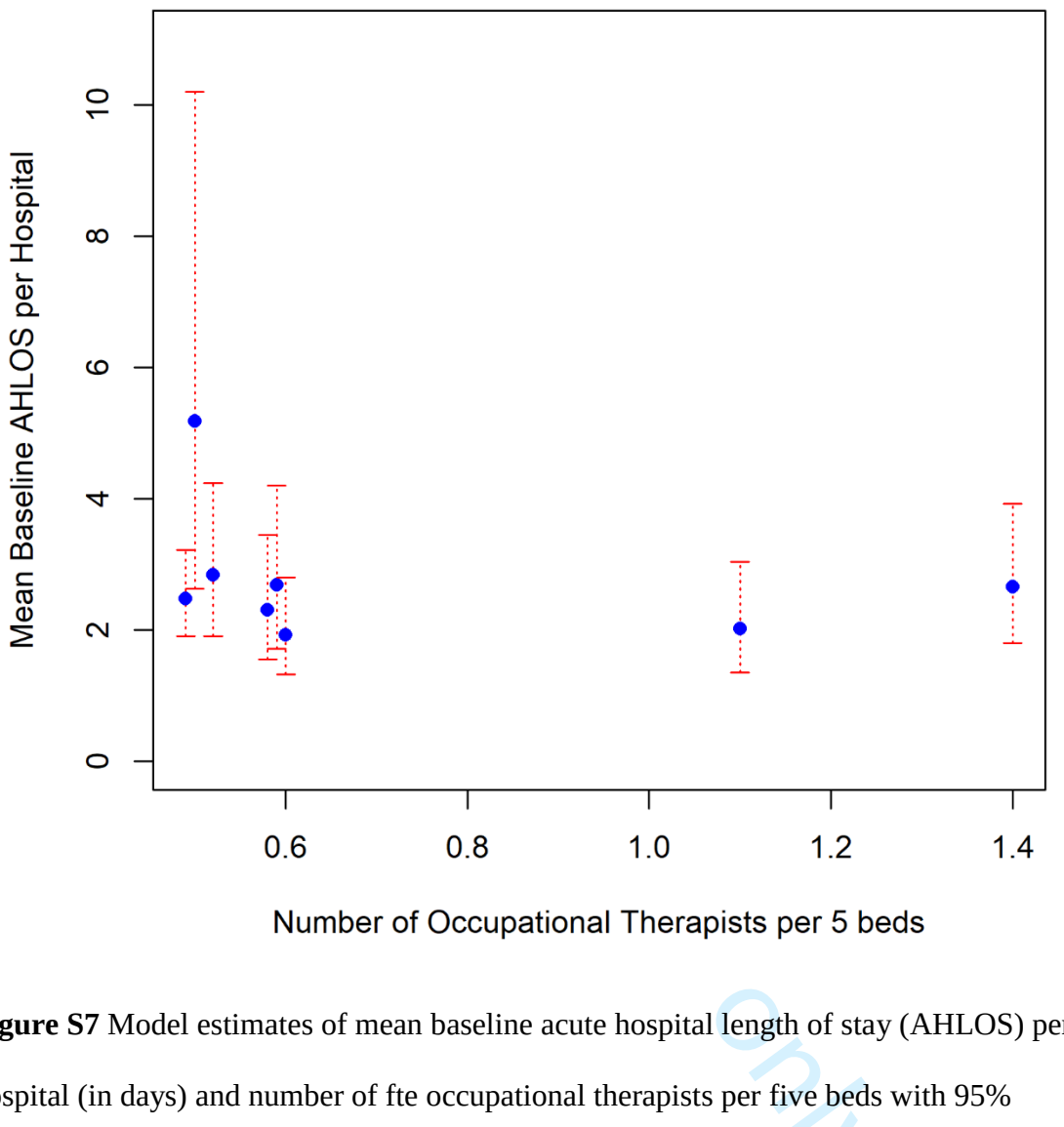


**Figure S7** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte occupational therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

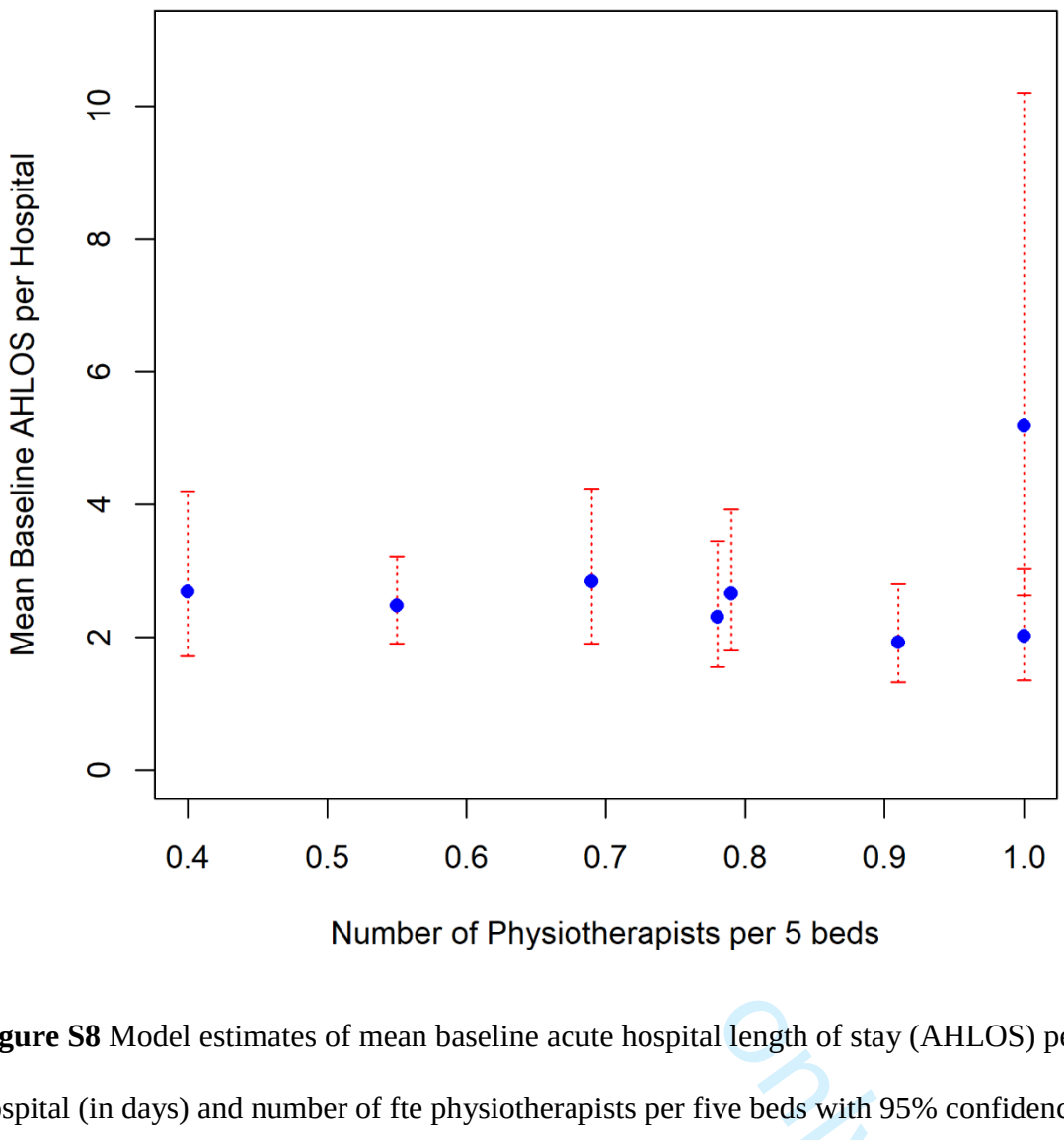


**Figure S8** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte physiotherapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

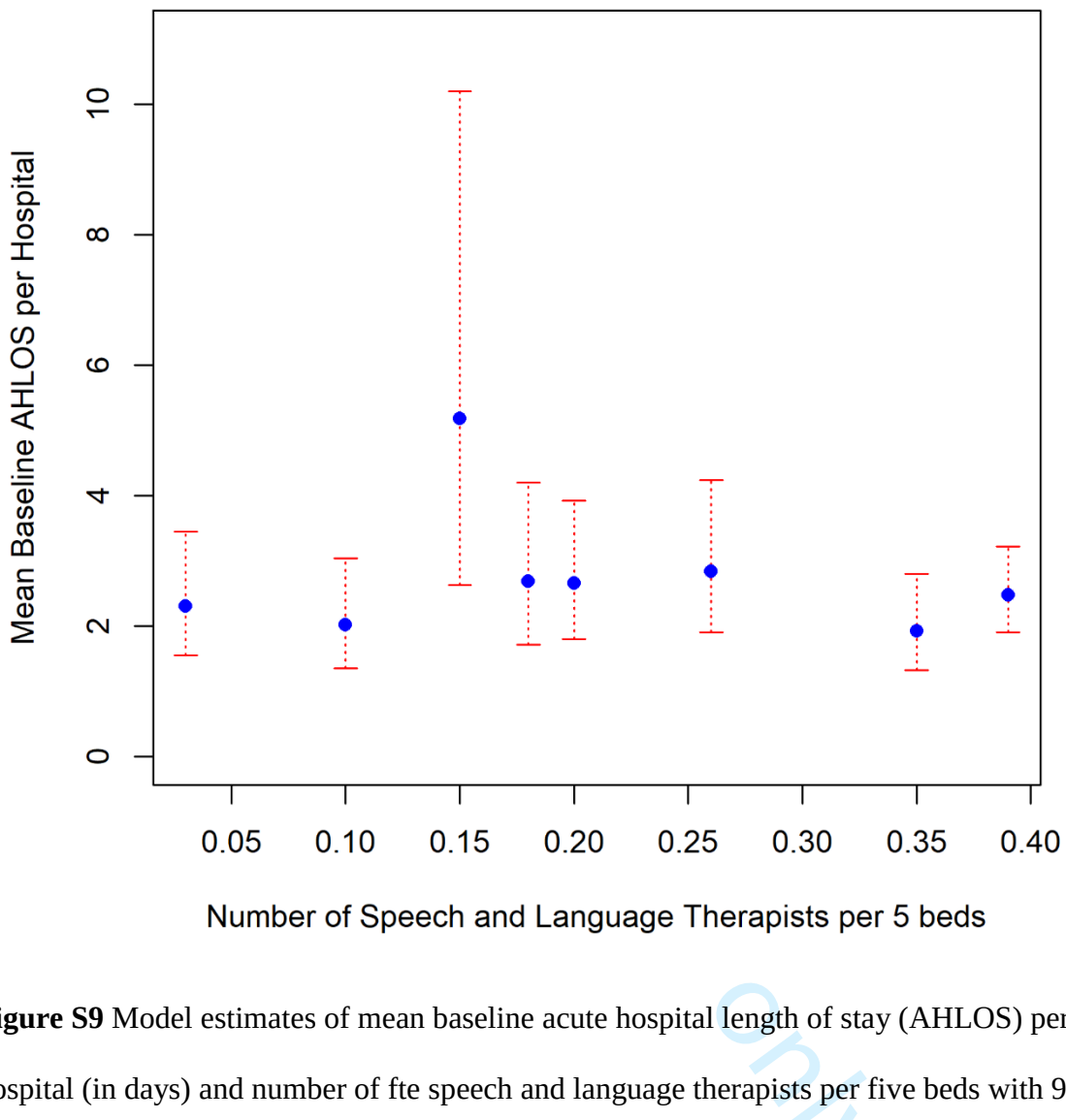


**Figure S9** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte speech and language therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

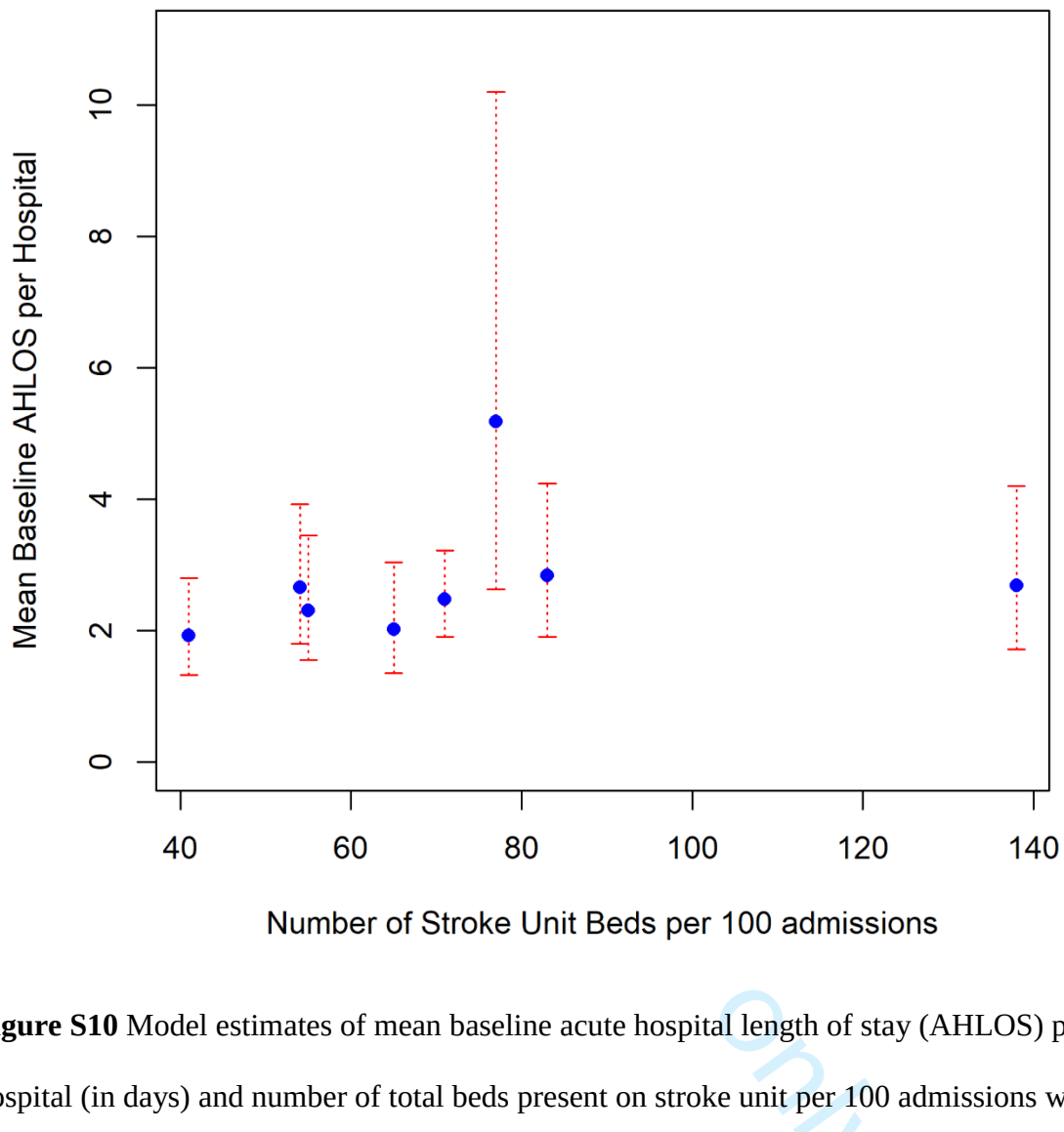


**Figure S10** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of total beds present on stroke unit per 100 admissions with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

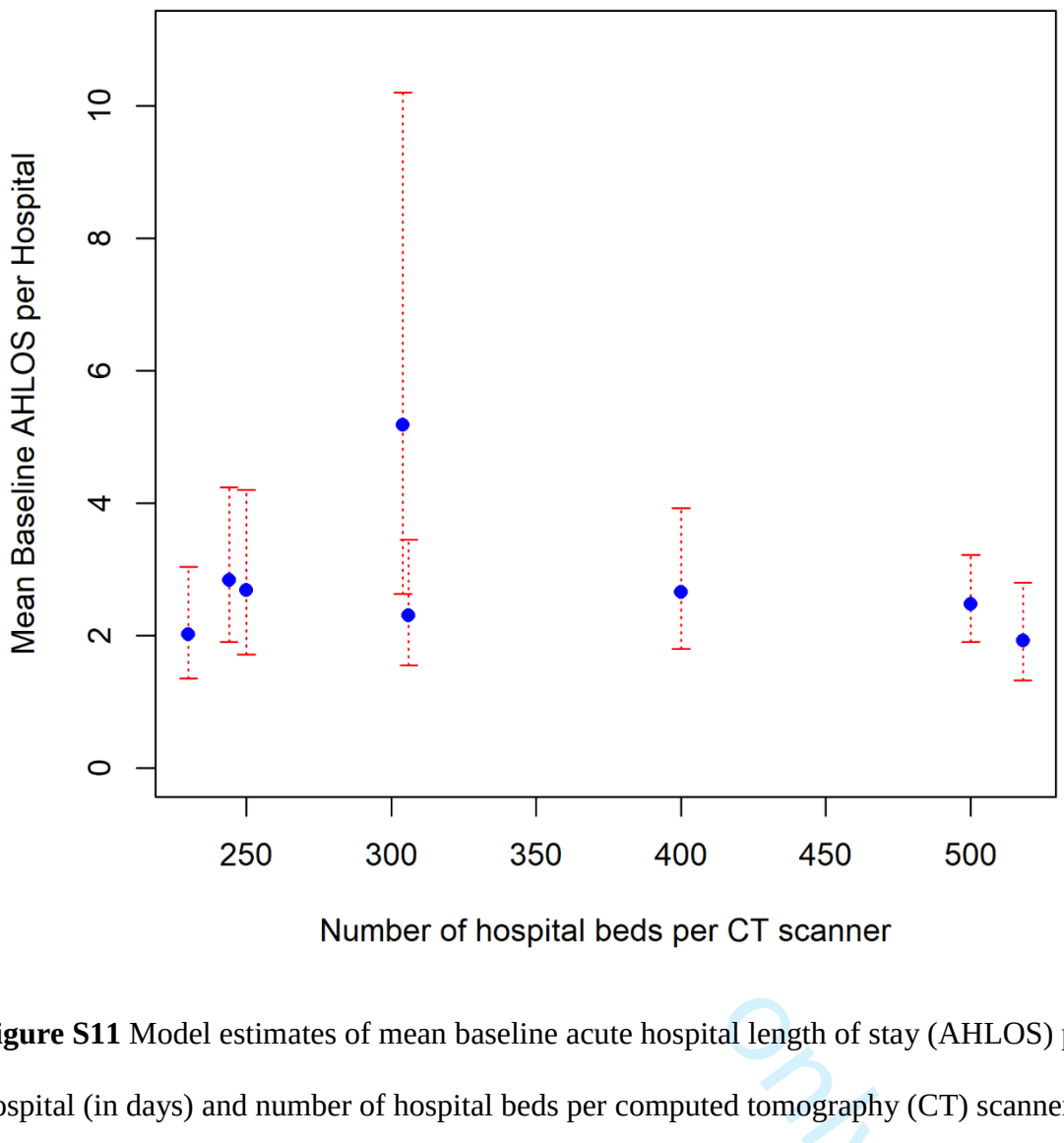


**Figure S11** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of hospital beds per computed tomography (CT) scanner with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

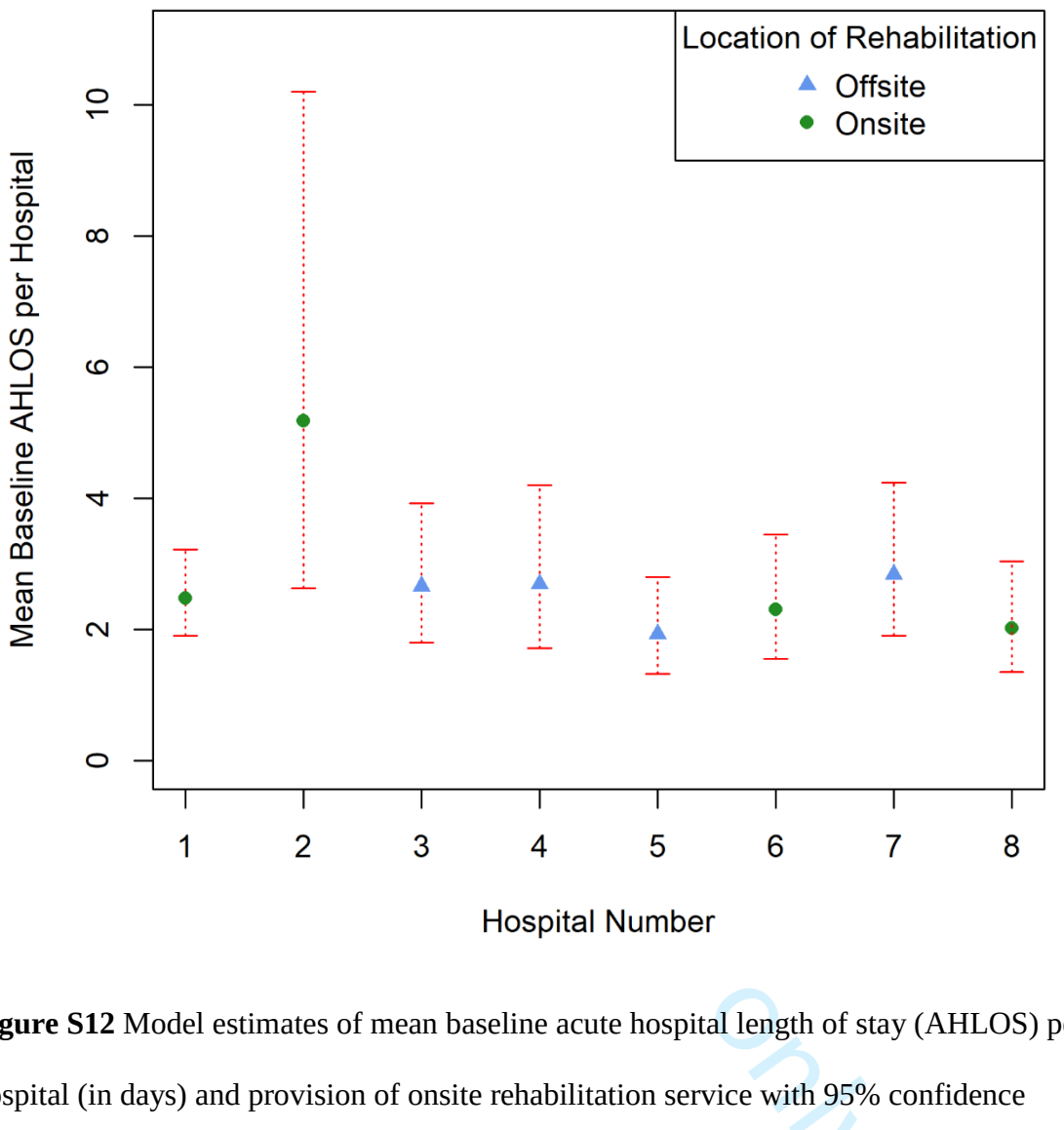


**Figure S12** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and provision of onsite rehabilitation service with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

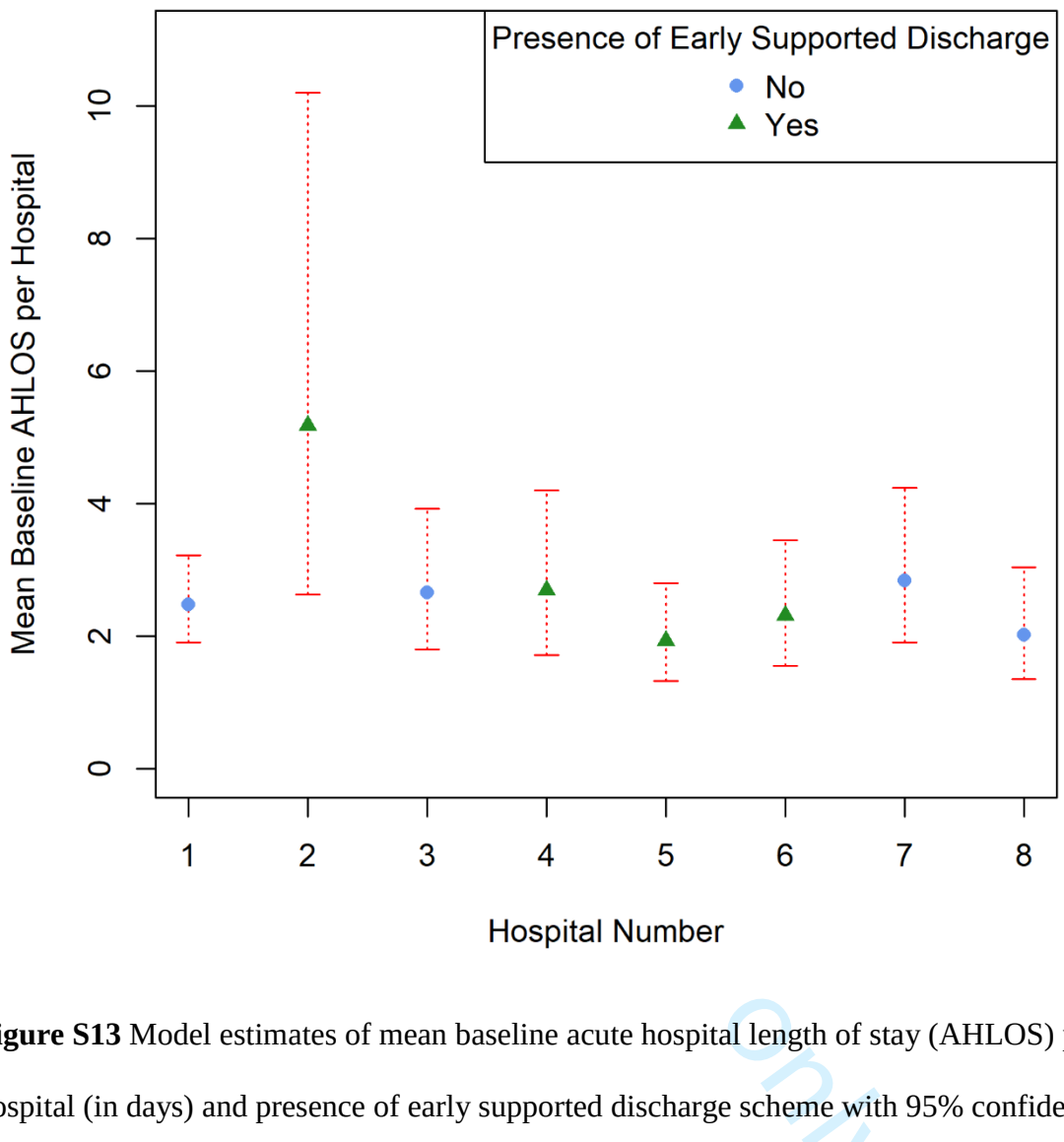


**Figure S13** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of early supported discharge scheme with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

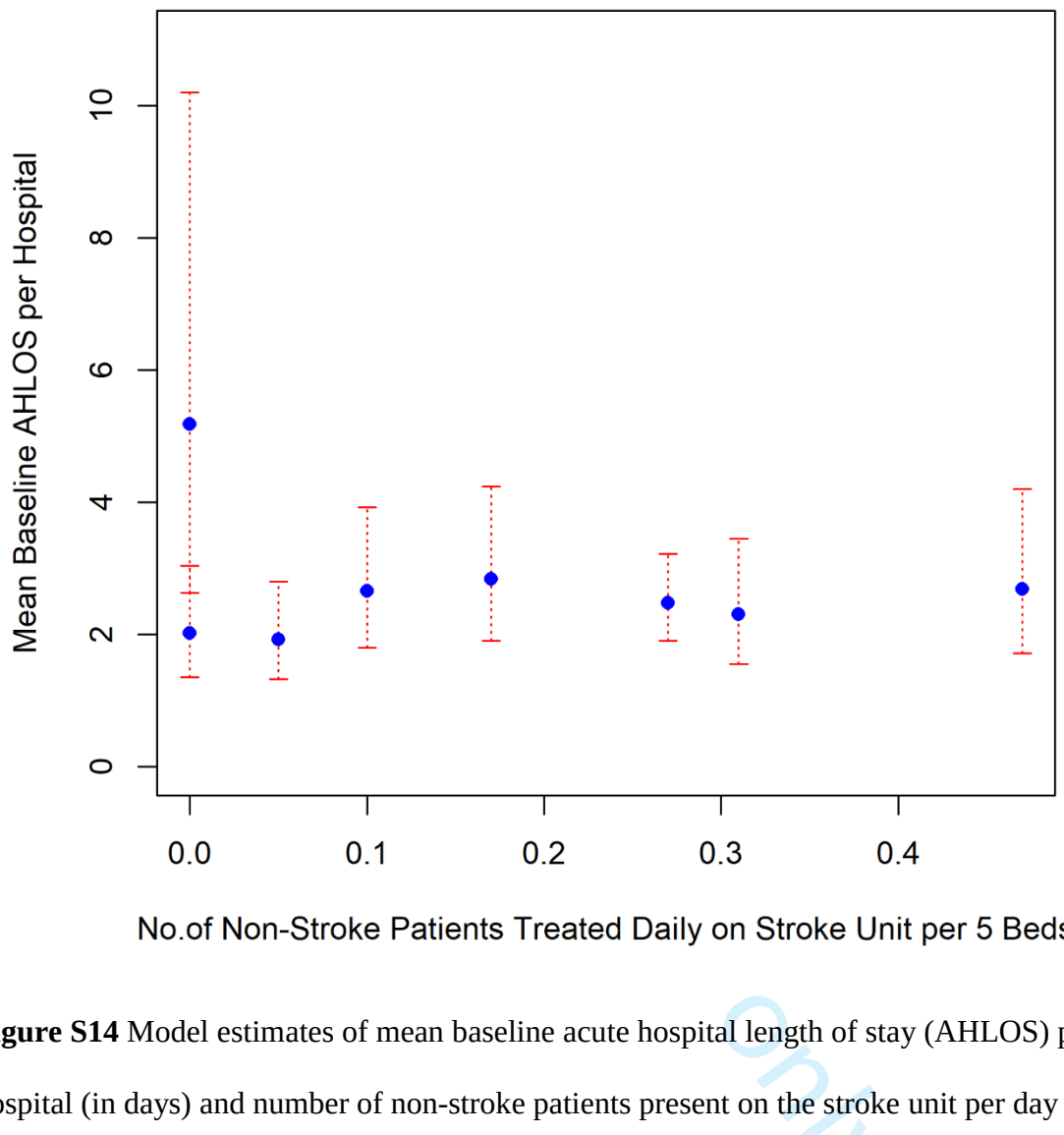


**Figure S14** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

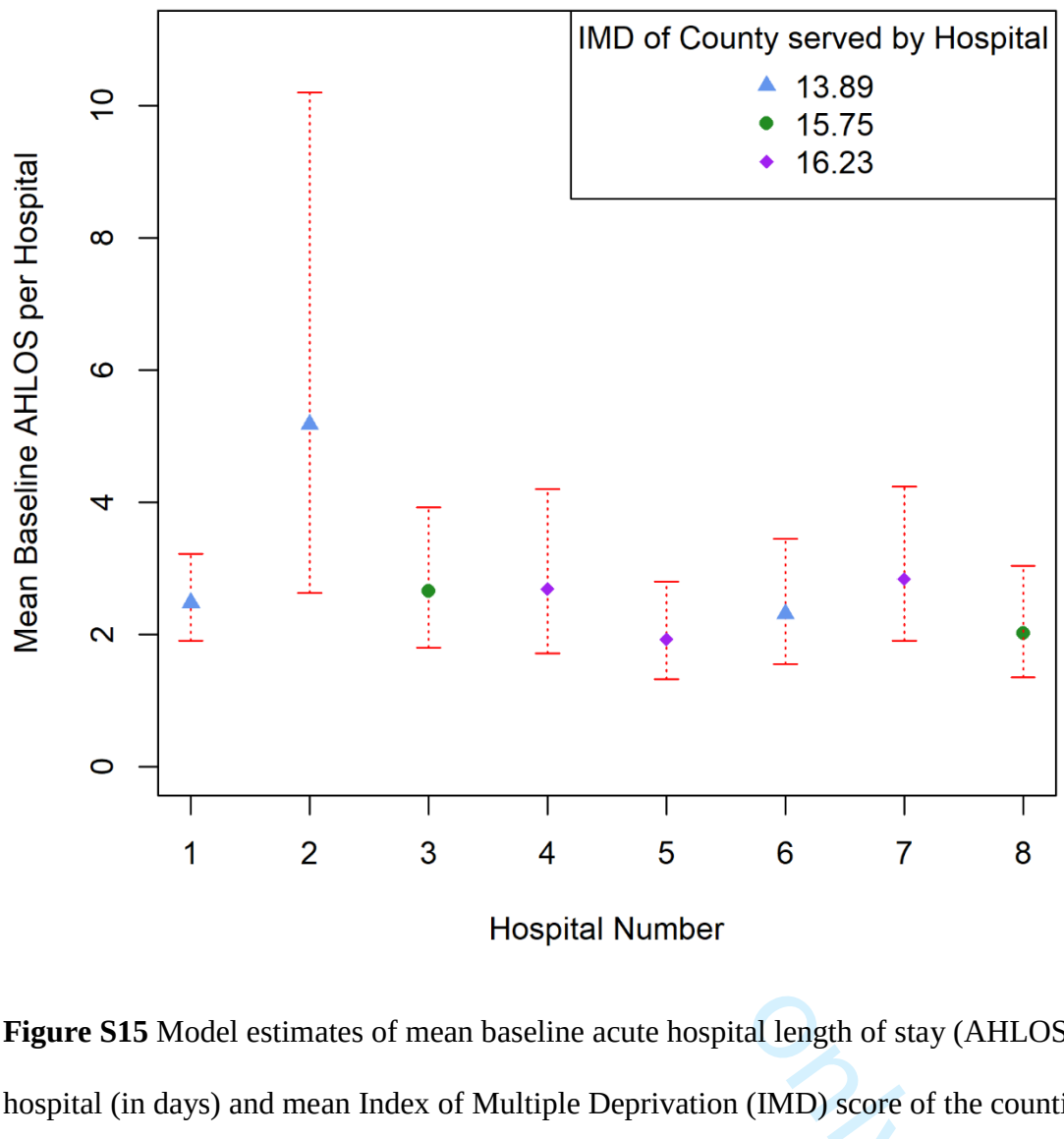


**Figure S15** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and mean Index of Multiple Deprivation (IMD) score of the counties in which the hospital serves with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies***

| Section/Topic | Item # | Recommendation | Reported on page # |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 & 2 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2-3 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 6 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 7 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 7-8 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 7 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 8-10 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 8 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 10-12 |
| Study size | 10 | Explain how the study size was arrived at | 7 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 8-10 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 11 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | NA |
| | | (*c*) Explain how missing data were addressed | 12 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | NA |
| | | (*e*) Describe any sensitivity analyses | 11-12 |
| **Results** | | | |

| | | | |
|---|---|---|---|
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 14 |
| | | (b) Give reasons for non-participation at each stage | 14 |
| | | (c) Consider use of a flow diagram | Fig 1 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 14 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 14 &15 |
| | | (c) Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | 16 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 19-21 (and Table S4) |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 22 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 23 |
| **Limitations** | | | |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 23-27 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 27 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 28 |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

# Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study

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| Primary Subject Heading: | Epidemiology |
| Secondary Subject Heading: | Health services research, Neurology, Geriatric medicine |
| Keywords: | Acute hospital, Health Services Research, Length of Stay, Outcome, Stroke < NEUROLOGY |
| | |

# Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study

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Word count: 4821

**Keywords:** Acute hospital, Health Services Research, Length of Stay, Outcome, Stroke

## ABSTRACT

**Objectives:** To determine whether stroke patients' acute hospital length of stay (AHLOS) varies between hospitals, over and above cases mix differences, and to investigate the hospital-level explanatory factors.

**Design:** A multicentre prospective cohort study.

**Setting:** Eight National Health Service acute hospital trusts within the Anglia Stroke & Heart Clinical Network in the East of England, UK.

**Participants:** The study sample was systematically selected to include all consecutive patients admitted within a month to any of the eight hospitals, diagnosed with stroke by an accredited stroke physician every third month between October 2009 and September 2011.

**Primary and secondary outcome measures:** AHLOS was defined as the number of days between date of hospital admission and discharge or death, whichever came first. We used a multiple linear regression model to investigate the association between hospital (as a fixed-effect) and AHLOS, adjusting for several important patient covariates, such as age, sex, stroke type, Modified Rankin Scale score (mRS), comorbidities, and inpatient complications. Exploratory data analysis was utilized to examine the hospital-level characteristics which may contribute to variance between hospitals. These included hospital type, stroke monthly case volume, service provisions (i.e. onsite rehabilitation), and staffing levels.

**Results:** A total of 2233 stroke admissions (52% female, median age (interquartile range (IQR)) 79 (70 to 86) years, 83% ischaemic stroke) were included. The overall median AHLOS (IQR) was 9 (4 to 21) days. After adjusting for patient covariates, AHLOS still differed significantly between hospitals ($p<0.001$). Furthermore, hospitals with the longest adjusted AHLOS's had predominantly smaller stroke volumes.

**Conclusions:** We have clearly demonstrated that AHLOS varies between different hospitals, and that the most important patient-level explanatory variables are discharge mRS, dementia, and inpatient complications. We highlight the potential importance of stroke volume in influencing these differences but cannot discount the potential effect of unmeasured confounders.

## ARTICLE SUMMARY

### Strengths and limitations of this study

- This is a comprehensive study that has used multi-centre data to determine whether acute hospital length of stay of patients with stroke varies across hospitals in the UK, after adjustment for patient-level covariates, such as age, sex, pre-stroke and discharge Modified Rankin Scale score, stroke type, residence prior to stroke, comorbidities, and inpatient complications.
- With a wealth of detailed patient data, we were able to adjust for the important covariates, inpatient complications and discharge Modified Rankin Scale score, which previous studies have not addressed when investigating hospital-level factors.
- Although hospital-level effect estimates were not calculated due to the limited hospital sample size of eight, we explored these factors descriptively and adjusted for clustering by including hospital as a fixed-effect.
- Although National Institute for Health Stroke Scale (NIHSS), which is used to measure the severity of stroke, is known to be associated with acute hospital length of stay, we were unable to take this variable into account since it was only calculated on admission for patients who were potentially eligible for thrombolysis, and would have introduced information bias.

## INTRODUCTION

Stroke is the second leading cause of mortality and the third leading cause of disability in the world, with a global incidence of 16.9 million in 2010.[1-2] While acute hospitalization for stroke in the US has been estimated at a cost of $31,667 per patient, total direct stroke-related annual medical costs are expected to triple, from $71.6 billion in 2012 to $184.1 billion by 2030.[3-4]

Considerable differences in stroke-related outcomes exist worldwide, with the highest age-standardized stroke-related mortality and disability adjusted life-years rates observed in Russia and Eastern European countries.[1] Stark regional disparities within countries are also apparent. In the UK, for example, there exists a clear north-south divide where the lowest stroke-related mortality rates are observed almost exclusively in the South of England.[5] Such differences in outcomes likely reflect underlying stroke incidence rates and variations in exposure to relevant risk factors.[5-6] However, we and others have demonstrated that some of the differences in post-stroke survival have also been explained by disparities in available resources and medical care.[7-11] Studies assessing the effect of stroke care heterogeneities have largely focused on mortality as the primary outcome.

However, it is possible that heterogeneities in stroke care also impact other important stroke-related outcomes, such as a patient's acute hospital length of stay (AHLOS). To date, researchers have mainly identified patient-related determinants of AHLOS,[12-15] with little exploration into hospital-level influences. Of the few studies that have investigated hospital-level variance, factors such as hospital type, size, teaching status and location have been implicated in partially explaining differences in AHLOS.[12,16-19] None such studies have been conducted in a UK National Health Service (NHS) setting.

During acute hospitalization, AHLOS is the main driver of acute care costs.[20] Determining the hospital-level factors influencing AHLOS therefore provides invaluable information to

service providers and policymakers who can develop optimal management strategies and enhance patient care by minimizing service deficiencies, costs and bed shortages.

The aim of this study was to investigate whether there are variations in stroke patients' AHLOS which can be partly explained by heterogeneities in characteristics of stroke care between hospitals in a UK NHS setting. We also aimed to explore which hospital-level factors explain such hospital variations in AHLOS.

## METHODS

### Study design

A multi-centre prospective cohort study was conducted at eight acute NHS Trusts within the Anglia Stroke & Heart Clinical Network (ASHCN) which covers the three counties of Suffolk, Norfolk and Cambridgeshire, in the East of England with a catchment population of approximately 2.5 million. The detailed study protocol has previously been published (see supplementary document 1).[21] Ethical approval was obtained from the NRES Committee East of England – Norfolk (REC Reference number 10/H0310/44).

### Participants

The study population included all patients, aged 18 years or older, admitted to any of the eight hospitals within the ASHCN diagnosed with stroke by an accredited stroke physician between October 2009 and September 2011. Stroke was defined as a focal neurological impairment of sudden onset and lasting more than 24 hours (or leading to death) as a consequence of an intracerebral ischaemic or haemorrhagic event. This definition excludes diagnoses of transient-ischaemic attacks (TIAs), subdural haematomas and subarachnoid haemorrhages. Stroke diagnosis was confirmed in all patients with stroke through cerebral imagining (either using computed tomography (CT) or magnetic resonance imaging (MRI)). Diagnoses by the stroke physician were coded using ICD-10. The study sample was systematically selected to include all consecutive patients with stroke admitted every third month of this 2-year period, resulting in a total of eight study months and sample size of 2656. The robustness of this sampling technique has been confirmed.[22]

### Participant Hospitals

The participating hospitals, although part of the same network, do not coordinate the care of patients or work together to provide regional care. They are independent NHS Trusts that

serve their local communities and therefore are individually responsible for managing patients with stroke. Admission, transfer and discharge policies should be similar across these hospitals. There are also no known differences in access to rehabilitation, home care or nursing homes.

Stroke services available at each site should be proportionate to the hospital's catchment population. However, as stroke volumes differ, some hospitals may experience greater pressure on their resources and facilities than others. Access to available resources also varies between the hospitals, with some providing onsite rehabilitation, neurosurgery and vascular surgery. Palliative care management may also differ between the sites.

**Data collection**

Clinical teams responsible for the care of patients with stroke in each of the hospitals prospectively recorded individual patient data. Patient data routinely collected by each participating site for the ASHCN surveys was used in this study. Additional baseline patient and outcome data were also retrieved from case records, discharge summaries and Patient Administrative Systems by the clinical teams. Data were anonymized and sent to the ASHCN coordinating centre where it was collated and sent to the research team. Any identifiable patient information was held only at the local NHS Trusts - the network and investigators did not have access to these details.

Data on health service characteristics were collected from clinical leads or service managers at each stroke unit and updated every six months over the 2-year study period by research staff.[21] No major changes in health service characteristics occurred during the study data collection period. Some changes that did occur included: minor fluctuations in staffing levels, number of non-stroke patients treated on the stroke unit, and number of patients with stroke treated outside the stroke unit. In the final year of study, Hospital 5 introduced a further CT scanner, increasing their total to three. Furthermore, for Hospitals 5 and 6 some

reconfigurations from acute stroke unit beds to hyperacute stroke unit beds were made. Hospital 4 also introduced hyperacute stroke unit beds in the final year of study, and increased the number of acute stroke unit beds available. We have accounted for these fluctuations by calculating and reporting the weighted average across the four study periods for these measures.

**Definition of variables**

Our outcome measure, AHLOS, was treated as a continuous variable and defined as the number of days from, and including, the patients' date of hospital admission to their date of discharge or death, whichever came first.

Patient level covariates adjusted for were: age (treated as a continuous variable), sex, pre-stroke Modified Rankin Scale (mRS) as an indicator of pre-stroke frailty, pre-stroke residence status, stroke type, Oxfordshire Community Stroke Project (OCSP) (a stroke classification system), presence or absence of lateralisation signs, acute inpatient complications (such as another stroke, pneumonia, urinary tract infection (UTI), seizures, myocardial infarction, acute coronary syndrome), established comorbidities (including previous stroke/TIA, previous myocardial infarction or ischaemic heart disease, previous cancer), presence of other relevant comorbidities (including diabetes mellitus, dementia, hypercholesterolemia, hypertension, cancer, depression, rheumatoid arthritis and chronic obstructive pulmonary disease), day and season of admission, and discharge mRS (including in-hospital death). An inpatient complication was defined as any disease, disorder or condition that developed after the index stroke i.e. during the acute admission, whereas comorbidities were defined as those that were known to have occurred prior to stroke.

Independent hospital-level variables of interest were: hospital type (secondary or tertiary), hospital stroke volume (mean number of patients with stroke admitted and treated in hospital

per month), presence of vascular surgery onsite, distance to neurosurgical facility, onsite rehabilitation service provision, presence of an early supported discharge scheme, number of full-time equivalent (fte) staff per five beds (senior doctors and junior doctors available during weekdays, healthcare associates and nurses, occupational therapists, physiotherapists and, speech and language therapists), number of total beds present on the stroke unit per 100 stroke admissions, total number of hospital beds per CT scanner, number of non-stroke patients treated daily on the stroke unit per five beds, number of patients with stroke treated daily on wards outside the stroke unit per day per five beds, and the mean index of multiple deprivation (IMD) of the county in which each hospital serves.

In NHS England, hospitals are either termed secondary or tertiary, dependent on the level of specialist service provided. Tertiary hospitals provide more specialised care in larger, regional or national centres, compared to their secondary counterparts e.g. neurosurgery unit where smaller units are not viable nor practical. These more centralised hospitals are usually dedicated in providing super-speciality care beyond sub-specialty (e.g. neuro-endocrine surgery is a super speciality of neurosurgery which is a sub-specialty of the specialty of Surgery), and therefore have access to more advanced equipment and expertise specific to the conditions in which it subspecialises. This doesn't apply to stroke directly, but it is relevant for those who have stroke and require neurosurgical intervention.

Five bed days was used as the denominator as this is how the 2016 national clinical guidelines for stroke reports the recommended staffing levels for UK stroke units, and therefore provides for a comparison.[23]

The IMD score was used as an aggregate measure of socioeconomic status in this study. This measure is based on several domains, including income, employment, education, health, crime, barriers to housing and services and the living environment, that are believed to provide an indication of deprivation. To assign an IMD score, England is sub-divided into 32,

844 smaller areas, with a score of 1 representing the area in England that is considered to be the most deprived and a score of 32, 844 the least deprived.[24] In our study we have taken the mean 2010 IMD scores of the areas that make up the counties of Suffolk, Norfolk and Cambridgeshire and assigned these to each of the hospitals to which they are located.[25]

We believe processes of care measures are intermediate variables that lie on the casual pathway between hospital-level factors and patient outcomes of stroke.[10] As such, we did not adjust for these covariates in the analyses. Including them in our regression model could otherwise lead to over-adjustment bias.[26,27]

**Statistical analyses**

Data were available from only eight hospitals which is below the suggested critical number required to reliably estimate hospital effects through multi-level modelling.[28] Therefore, a single-level multiple linear regression model using ordinary least squares was conducted with hospital as a fixed-effect and AHLOS as the outcome. To qualify for inclusion in the multivariable model, patient-level variables had to have a p-value<0.3 in univariable analysis. The standardized residuals of the model were positively skewed. However, a logarithmic transformation of AHLOS subsequently removed the skewness. Before reporting, we transformed the predicted logarithmic AHLOS values back to AHLOS, with exponentiated regression coefficients representing geometric means of AHLOS.

To explore hospital-level factors, we plotted the hospital intercept estimates of AHLOS from the regression model (mean baseline AHLOS of each hospital), against the hospital-level characteristics of interest. This is the recommended method to use on clustered data to explore hospital effects when the number of higher level units is small and hence are not interpretable in likelihood estimation.[28,29]

**Sensitivity analyses**

Due to limited resources, Hospital 2 failed to collect data for the full study period. Patient-level data were only collected in this hospital for October 2009 and January 2010, culminating in a small number of stroke cases for analysis (n=16). To investigate whether this small cluster may affect our results we performed a sensitivity analysis excluding Hospital 2. Furthermore, although we collected patient data on discharge destination, we did not include this as a covariate in our multiple regression model due to issues of multi-collinearity with discharge mRS (both had categories for inpatient death). We hypothesised that discharge mRS could more readily explain a patient's AHLOS indirectly through discharge destination (i.e. more severe disability increases the risk of institutionalisation which prolongs AHLOS due to associated waiting lists), and directly through patient recovery (i.e. a patient with more severe disability will likely take longer to recover than a patient with no disability, meaning it will take longer for a safe patient discharge). If we were to include discharge destination instead, AHLOS variance due to differences in disability and recovery time amongst patients with the same discharge placement would not be taken into account. To check the impact of excluding discharge destination on our findings we have performed a further sensitivity analysis replacing discharge mRS with discharge destination in our multiple regression model.

**Multiple imputation**

To increase power and reduce potential bias of complete case analysis, we performed multiple imputation by chained equations using the MICE package in R.[30] All the independent variables of interest, AHLOS and a number of auxiliary variables (i.e. variables in our dataset that were not used in our model) (Table S1 in the online supplementary document 2) informed the imputation. Sixty-four datasets were imputed as the inclusion of auxiliary variables increased the case wise missingness to 64%. Each dataset was pooled together using Rubin's rules.[31] The distribution of sample characteristics between individuals

with complete and incomplete data were compared using the appropriate hypothesis testing. Complete case analysis was also conducted so that any differences in results from the multiple imputation analysis could be reported.

All analyses were performed using R version 3.3.1 for Windows.[32]

**Patient and public involvement**

The project was managed by project leader (PKM) who worked in close partnership with the project group of the study and the project steering group. The project steering group included public and patient representatives, recruited through Patient and Public Involvement in Research (PPIRes). PPIRes members were invited to attend research steering group meetings over the study duration to oversee the project.

## RESULTS

### Description of sample characteristics

Of the 2656 patients admitted consecutively to the eight NHS hospitals during the inclusion period with an initial diagnosis of stroke, 278 were excluded for the following reasons: eventually diagnosed with a condition other than stroke (n=179), transferred between hospitals (both among the eight study hospitals and from or to outside the region) (n=101), had missing data for admission and discharge dates (n=8). This left a total of 2233 patients for the study analysis (Figure 1).

The median age (interquartile range (IQR)) of our cohort was 79 (70 to 86) years, 52% were female, and 83% had an ischaemic stroke (Table 1). The distributions of patient characteristics appeared to vary between hospitals (Table S2 in the online supplementary document 2). Although there were low proportions of missing data for each independent variable (Table 1), this compounded to 33% of patients having at least one variable missing. Hospital 4 did not collect data on pre-stroke mRS and 30 cases from Hospital 3 had missing data on all comorbidities. Patients with complete data were less likely to have a haemorrhagic stroke, be institutionalised prior to stroke and have an inpatient death, and more likely to have had a previous stroke or TIA, have hypercholesterolemia, hypertension, rheumatoid arthritis, have a lacunar stroke and have a discharge mRS of 6, than patients who had a least one missing variable. However, there were no significant differences in other patient characteristics such as age, sex, pre-stroke mRS score, brain lateralisation, inpatient complication and admission timing between the two groups (Table S3 in the online supplementary document 2).

**Table 1** Sample characteristics of patients included in analysis (n=2233) and missing data

| Patient Characteristic | Median (IQR) or No. (%) | Missing Data (%) |
|---|---|---|
| Age, y | 79 (70 to 86) | 2 (0.1) |
| Sex, female | 1165 (52) | 2 (0.1) |
| Recurrent Stroke* | 448 (20) | 30 (1) |
| Diabetes Mellitus* | 370 (17) | 30 (1) |
| Dementia* | 207 (9) | 30 (1) |
| Hypercholesterolemia* | 355 (16) | 30 (1) |
| Hypertensive* | 1483 (66) | 30 (1) |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 (23) | 30 (1) |
| TIA* | 340 (15) | 30 (1) |
| Previous Cancer* | 195 (9) | 30 (1) |
| Active Cancer* | 137 (6) | 30 (1) |
| Depression* | 137 (6) | 30 (1) |
| Rheumatoid Arthritis* | 154 (7) | 30 (1) |
| COPD* | 116 (5) | 30 (1) |
| Pre-stroke mRS Score | | 442 (20) |
| 0 | 914 (41) | |
| 1 | 335 (15) | |
| 2 | 191 (9) | |
| 3 | 184 (8) | |
| 4 & 5 | 167 (7) | |
| Pre-Stroke Residence | | 51 (2) |
| Independent living with formal care | 210 (9) | |
| Independent living without formal care | 1752 (78) | |
| Institution | 220 (10) | |
| Ischaemic Stroke | 1864 (83) | 96 (4) |
| Oxford Community Stroke Project Classification | | 260 (12) |
| LACS | 503 (23) | |
| PACS | 784 (35) | |
| POCS | 279 (12) | |
| TACS | 407 (18) | |
| No Brain Lateralisation | 244 (12) | 167 (8) |
| Inpatient Complication* | 655 (29) | 0 (0) |
| Discharge mRS Score | | 50 (2) |
| 0 | 260 (12) | 329 (15) |
| 1 | 352 (16) | |
| 2 | 212 (9) | |
| 3 | 291 (13) | |
| 4 | 238 (11) | |
| 5 | 137 (6) | |
| 6 | 414 (19) | |
| Winter Admission | 1159 (52) | 0 (0) |
| Weekend Admission | 614 (27) | 0 (0) |

IQR, Interquartile Range; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disorder; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

*No information was assumed to indicate absence of condition or complication

**Hospital service characteristics**

Service characteristics of each hospital are outlined in Table 2, with median AHLOS. After standardization, by taking account of stroke admission volume, number of stroke unit beds, and size of hospital, there was still extensive heterogeneity in bed capacity, staffing levels, and the number of CT scanners provided at each hospital, respectively. Variations between hospitals also existed in terms of service and facility provision. For example, a number of hospitals provided rehabilitation care, neurosurgery or vascular surgery onsite, whilst others did not. The overall median AHLOS (IQR) was 9 (4 to 21) days and there appeared to be crude variations in this outcome between hospitals.

**Table 2** Hospital characteristics per individual hospital self-reported by clinical leads or service managers at each hospital

| Hospital Characteristics | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| General Characteristics | | | | | | | | |
| Catchment Population | 400,000 | 160,000 | 350,000 | 230,000 | 680,000 | 300,000 | 240,000 | 275,000 |
| Hospital Type | Tertiary | Secondary | Secondary | Secondary | Tertiary | Secondary | Secondary | Secondary |
| Hospital Stroke Volume (No. of ASCNES admissions per month) | 52 | 13 | 46 | 19 | 88 | 57 | 35 | 31 |
| Facilities and Services | | | | | | | | |
| No. of hospital beds | 1000 | 304 | 800 | 500 | 123 | 611 | 488 | 460 |
| No. of stroke unit beds (per 100 admissions) | 71 | 77 | 54 | 138 | 41 | 55 | 83 | 65 |
| No. of hospital beds per CT scanners | 500 | 304 | 400 | 250 | 51 | 306 | 244 | 230 |
| Distance to Vascular Surgery (miles) | 0 | 18 | 0 | 25 | 0 | 0 | 43 | 30 |
| Distance to Neurosurgery (miles) | 0 | 18 | 58 | 89 | 61 | 38 | 48 | 30 |
| Rehabilitation Provision | Onsite | Onsite | Offsite | Offsite | Offsite | Onsite | Offsite | Onsite |
| Early Supported Discharge Provision | No | Yes | No | Yes | Yes | Yes | No | No |
| Stroke Unit Staffing Levels* | | | | | | | | |
| Senior doctors† | 0.34 | 0.25 | 0.49 | 0.47 | 0.4 | 0.31 | 0.62 | 0.87 |
| Junior doctors † | 0.55 | 0.65 | 0.72 | 0.59 | 0.5 | 0.64 | 0.12 | 0.25 |
| Health care associates and nurses (band 5-7) | 9.2 | 8 | 6 | 7.4 | 7 | 5.3 | 6.5 | 10 |
| Physiotherapists (band 2-8) | 0.55 | 1 | 0.79 | 0.4 | 0.9 | 0.78 | 0.69 | 1 |
| Occupational Therapists (band 3-8) | 0.49 | 0.5 | 1.4 | 0.59 | 0.6 | 0.58 | 0.52 | 1.1 |
| Speech and Language Therapists | 0.39 | 0.15 | 0.2 | 0.18 | 0.3 | 0.03 | 0.26 | 0.1 |
| No. of non-stroke patients treated daily on stroke unit (per five stroke unit beds) | 0.27 | 0 | 0.10 | 0.47 | 0.0 | 0.31 | 0.17 | 0 |
| No. of patients with stroke treated daily outside stroke unit (per five stroke unit beds) | 0.14 | 5 | 0 | 0.30 | 0.01 | 0.41 | 0 | 0 |
| Median AHLOS (IQR) | 8 (4 to 20) | 29 (24 to 42) | 11 (5 to 27) | 14 (4 to 30) | 8 (4 to 14) | 10 (5 to 22) | 11 (6 to 23) | 7 (3 to 20) |

ASCNES, Anglia Stroke Clinical Network Evaluation Study; CT, Computerised Tomography; AHLOS, Acute Hospital Length of Stay; IQR, Interquartile Range.

*Number of fte staff per five stroke unit beds (weighted average for the four study periods taken). NHS banding refers to the pay scale system of healthcare staff in the UK and relates to their level of experience. Higher bands reflect higher pay and experience.

† Weekday numbers only

**Univariable linear regression**

In univariable linear regression (Table S4 in the online supplementary document 2), patients who were older, female, had previous cancer, a previous stroke, had diabetes mellitus, had dementia , had a pre-stroke or discharge mRS score greater than 0, had a OCSP other than a lacunar infarct, had an inpatient complication, were living independently at home without formal care (compared to those who had formal care) prior to stroke, or were a winter admission had a significantly longer AHLOS ($p<0.05$). Patients who had a haemorrhagic stroke, hypercholesterolemia, or showed no signs of brain lateralisation were all shown to be significantly associated with a shorter AHLOS ($p<0.01$).

The strongest associations with AHLOS were seen for inpatients who developed a complication, who had a pre-stroke mRS score of 3, who were admitted to Hospital 2 or who had a discharge mRS score of ≥2. Inpatient complications were associated with twice as long an AHLOS compared to those without a complication. Similarly, patients with a pre-stroke mRS score of 3 were 94% more likely to have a longer AHLOS than those with an mRS of 0. Patients admitted to Hospital 2 had 2.69 times the AHLOS of those admitted to Hospital 1. Compared to patients with a discharge mRS score, those with a score of 2, 3, 4 or 5 had over a 2, 3, 4, and 5-fold increase in AHLOS, respectively. Unsurprisingly, discharge mRS score appeared to explain the majority of AHLOS variance ($R^2$=31.1%).

Being hypertensive, having a history of a myocardial infarction or ischaemic heart disease, having previously had a TIA, having active cancer, depression, rheumatoid arthritis or chronic obstructive pulmonary disease were not shown to be significantly associated with AHLOS. Furthermore, admissions to Hospitals 6 and 8 were also not shown to be significantly associated with a difference in AHLOS compared to Hospital 1 admissions.

**Multiple linear regression**

Multiple linear regression results for AHLOS are summarized in Table 3 and shows that 42.7% of the variation in AHLOS has been explained. Sex, recurrent stroke, diabetes mellitus, hypercholesterolemia, previous cancer, a pre-stroke mRS score of 1 to 3 (with reference to a score of 0) and living at home independently without formal care prior to stroke were no longer statistically associated with AHLOS in multiple regression ($p>0.05$). Furthermore, being admitted to Hospital 3 or 4 as opposed to Hospital 1 were no longer associated with a significant difference in AHLOS. No variables included from the univariable analysis with $p>0.05$ became statistically significant in the multivariable analysis, except for living in an institution prior to stroke which was associated with a 19% reduced AHLOS compared to those living independently without formal care. Developing an inpatient complication and having a discharge mRS score between 2 and 5 were still strongly positively related to AHLOS. After adjusting for patient covariates, AHLOS was still shown to significantly differ between hospitals, with the shortest and longest AHLOS observed for Hospitals 5 and 2, respectively.

There were no obvious differences between the results using complete cases only (Tables S5-6 in the online supplementary document 2) and multiple imputation.

**Table 3** Multiple regression analysis for AHLOS (n=2233; $R^2$=42.7%)

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 1.01 | 0.94 to 1.09 | 0.79 |
| Recurrent Stroke | 1.03 | 0.94 to 1.12 | 0.57 |
| Diabetes Mellitus | 1.06 | 0.97 to 1.17 | 0.21 |
| Dementia | 1.28 | 1.12 to 1.46 | <0.001 |
| Hypercholesterolemia | 0.94 | 0.85 to 1.05 | 0.27 |
| Myocardial Infarction or Ischaemic Heart | 1.00 | 0.92 to 1.09 | 0.98 |
| Previous Cancer | 1.12 | 0.99 to 1.27 | 0.08 |
| COPD | 0.90 | 0.77 to 1.06 | 0.21 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.06 | 0.95 to 1.19 | 0.28 |
| 2 | 0.90 | 0.77 to 1.04 | 0.15 |
| 3 | 0.94 | 0.80 to 1.11 | 0.47 |
| 4 & 5 | 0.71 | 0.59 to 0.86 | <0.001 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.07 | 0.94 to 1.23 | 0.92 |
| Institution | 0.81 | 0.69 to 0.95 | 0.01 |
| Haemorrhagic Stroke | 0.80 | 0.71 to 0.90 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.30 | 1.18 to 1.42 | <0.001 |
| POCS | 1.34 | 1.18 to 1.53 | <0.001 |
| TACS | 1.29 | 1.13 to 1.48 | <0.001 |
| No Brain Lateralisation | 0.85 | 0.75 to 0.96 | 0.01 |
| Inpatient Complication | 1.70 | 1.56 to 1.85 | <0.001 |
| Discharge mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.01 to 1.31 | 0.04 |
| 2 | 1.74 | 1.50 to 2.04 | <0.001 |
| 3 | 2.70 | 2.32 to 3.13 | <0.001 |
| 4 | 3.51 | 2.98 to 4.14 | <0.001 |
| 5 | 5.07 | 4.19 to 6.14 | <0.001 |
| 6 | 1.24 | 1.05 to 1.48 | 0.01 |
| Winter Admission | 1.15 | 1.08 to 1.24 | <0.001 |
| Weekend Admission | 1.03 | 0.95 to 1.11 | 0.50 |
| Hospital (reference 1) | | | <0.001 |
| 2 | 2.09 | 1.38 to 3.17 | 0.001 |
| 3 | 1.07 | 0.94 to 1.22 | 0.29 |
| 4 | 1.08 | 0.90 to 1.31 | 0.40 |
| 5 | 0.78 | 0.69 to 0.87 | <0.001 |
| 6 | 0.93 | 0.81 to 1.07 | 0.33 |
| 7 | 1.15 | 1.00 to 1.32 | 0.05 |
| 8 | 0.82 | 0.70 to 0.94 | 0.01 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Intervals; COPD, Chronic Obstructive Pulmonary Disorder; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

*β estimates and 95% confidence intervals were calculated for predicted log AHLOS. Prior to reporting they were transformed back to AHLOS through exponentiation and represent geometric mean AHLOS

**Graphical exploratory analysis**

Mean baseline AHLOS of each hospital (estimated from the multiple regression model) was plotted against hospital stroke volume and clustered by hospital type in Figure 2. It appears that hospitals (of either type) that have larger stroke volumes have a shorter AHLOS than those with smaller stroke volumes when patient covariates are taken into account. To note also, Hospital 2 deviates largely from all the other hospitals with respect to the number of patients with stroke treated daily outside the stroke unit (see Figure S1 in the online supplementary document 2).

No discernible patterns were seen for mean baseline hospital AHLOS and staffing levels, surgery facilities, number of non-stroke patients treated on the stroke unit, bed numbers, and IMD score (Figures S2-15 in the online supplementary document 2).

**Sensitivity analyses results**

Excluding Hospital 2 in our first sensitivity analysis did not alter our results (Table S7 in the online supplementary document 2). For our second sensitivity analysis, although the results were similar, the amount of variance explained reduced from an $R^2$ value of 42.7% to 40%. Furthermore, significant differences in AHLOS were shown between our reference hospital and Hospitals 3 and 4, which was not shown in our main analysis (Table S8 in the online supplementary document 2).

## DISCUSSION

This multi-centre cohort study has demonstrated that substantial heterogeneities exist in stroke hospital service and staff provision across three counties in the East of England. After adjusting for patient characteristics and confounding factors, we have shown that AHLOS significantly differed between hospitals. This suggests that the heterogeneities we see in stroke care between hospitals have an effect on AHLOS of these patients. It also appears from our exploratory analysis that the volume of patients with stroke admitted to hospital may play a role in partially explaining these hospital-level AHLOS differences. Furthermore, the large deviation in AHLOS of Hospital 2 seems to be related to the number of patients with stroke that were not being treated in their stroke unit.

In agreement with our findings, two previous studies in Japan and Denmark have shown that hospitals with larger stroke volumes are those in which AHLOS is shorter.[16,19] The reason larger volume hospitals lead to more favourable outcomes may simply be down to the fact that "practice makes perfect" i.e. the stroke physicians in these hospitals treat a greater number of patients and are hence, more experienced and able to deliver higher quality care.[16,33-34] Svendsen *et al*., 2012 also demonstrated that patients with stroke admitted to high-volume stroke units have significantly greater odds of being treated and assessed earlier than those admitted to smaller-volume units, which could also explain their better outcomes.[19]

To translate these findings into practice may mean the centralisation of stroke services. Although this has been successfully implemented in urban centres such as Manchester and London,[35-36] this may not be feasible in more rural areas where travel times would compromise timely thrombolysis treatment.[10,37] Alternatively, a hub and spoke model of stroke care could be introduced whereby patients are first treated in their local hospital, and when stable for transfer are re-directed to larger hub centres where they can gain access to

more specialised care.[38] Specifically, patients with severe stroke or with complex health needs could be redirected to these better performing larger-volume centres.

Any recommendations that would lead to changes in stroke volume for the benefit of a reduced AHLOS should not compromise the quality of care. However, it has previously been reported that larger stroke volumes are independently associated with a lower risk of mortality.[10-11,39-40] Therefore modifying this hospital factor may not only lead to a potential modest decrease in inpatient costs and more available bed days but could also be beneficial to the health outcomes of patients.

The large variation in AHLOS between Hospital 2 and the other hospitals in our study is also interesting to note. This coincides with a stark contrast in the number of patients with stroke that were not treated in a stroke unit in Hospital 2 compared to the others. It could therefore be surmised that the large deviation in AHLOS of this hospital is driven by a lack of access to stroke unit care. This would be unsurprising given that stroke unit care has been consistently found to improve outcomes, including AHLOS, possibly due to a greater intensity of physiological monitoring, therapy and early mobilisation implemented in these discrete units.[41-44]

Other hospital-level factors that have been shown to influence a stroke patient's AHLOS include hospital size and teaching status.[12,16-18] However, these relationships were not apparent in our exploratory analysis. To investigate these and other hospital characteristics further, we require a larger sample of hospitals. This issue with sample size is also apparent when we study Hospital 8 which, although has one of the lowest AHLOS, also has one of the smallest volumes of stroke patients in the study, and therefore contradicts our previous finding. Such a discrepancy is likely a reflection of the small number of hospitals assessed, as there are likely to be several competing factors playing a role in determining hospital-level

AHLOS variance. For example, although Hospital 8 has one of the lowest stroke volumes it has the highest number of fte senior doctors, health care associates and nurses, and physiotherapists per five beds, and the lowest number of hospital beds per CT scanners out of all the hospitals studied. Staffing levels may be what is responsible for this supposed contradiction as they are likely to be an important determinant of AHLOS, given that higher nurse: bed ratios have been shown to be important in reducing other stroke-related outcomes, such as mortality.[7,10]

Although not the focus of our study, we have also demonstrated several important patient variables that influence AHLOS, specifically discharge mRS, having dementia or having an inpatient complication. Other researchers have confirmed the strength of these relationships. For example, Fujinio *et al*., 2013 showed that mRS before discharge was associated with a difference in 5.77 days in AHLOS,[16] whilst another study showed that dementia increased AHLOS by 6.5 days.[14] Complications such as congestive heart failure, falls, UTI and pneumonia have also been shown to prolong a patient's AHLOS.[15,45-46] It is therefore important for any future studies exploring hospital-level factors to properly adjust for these patient variables, in addition to NIHSS which is another important covariate. This is especially pertinent given that the studies examining hospital-level factors and AHLOS in stroke to date have failed to adjust for these specifically. Finally, our findings in relation to other patient factors such as age, sex, stroke type and pre-stroke residence are in general agreement with other literature.[12-14,47-48]

The main strength of our study is its prospective design and the detailed patient-level data we obtained. This allowed us to gain a better understanding of the extent to which the variation in AHLOS exists over and above patient characteristics. We have optimised the use of available NHS data as the starting block for informing future pragmatic real-world setting RCTs by first identifying potential health service factors that could lead to important

interventions. Furthermore, the findings of this study can presently be used to inform clinicians, healthcare service providers, commissioners and policy makers as to where improvements can be achieved in stroke care. The robust statistical analysis has allowed easy and quick visualization of notable patterns in the dataset and provides a candid assessment of the research objectives by considering the limits of inference due to the small number of hospitals. Multiple imputation has also reduced potential bias that may have otherwise been introduced from complete case analysis alone.

The major limitation of this study was the small number of hospitals that has restricted the conclusions we can make from our exploratory analysis of hospital characteristics. Furthermore, although NIHSS and a patient's discharge destination has been shown to be associated with stroke patients' AHLOS,[14,20] they were excluded as covariates from the main analysis. As NIHSS scores were only calculated for those who were potentially eligible for thrombolysis at the time of our study, the incompleteness was not missing at random and would have introduced information bias into our results. As discharge mRS and discharge destination both included a categorical factor representing inpatient death only one of these variables could be included into the analysis due to issues of multi-collinearity. However, we hypothesized that discharge mRS score could more readily explain a patient's AHLOS whilst also serving as a proxy for discharge destination. In addition, socioeconomic status which has also been shown to relate to AHLOS in patients with stroke,[18] and differences in palliative care policies were not known. This means that any remaining difference in AHLOS between hospitals may not only be due to hospital-level factors but may also be due to other unmeasured confounders. We also did not collect data on patient ethnicity, although this has previously been associated with AHLOS.[49-51] Whilst we cannot provide exact ethnic mix, the region where the study was conducted serves mainly a white British Caucasian population, with other races making up a very small minority.[52]

A further limitation of this study is that the hospital characteristics were self-reported by clinical leads or service managers at each hospital. This may have introduced information bias, especially with regard to the reported fte staffing levels, and the number of patients treated within or outside the stroke unit.

Furthermore, as this study covers eight NHS hospitals in the East of England that span both urban and rural regions, and as NHS policies are fairly standard, we believe these sites are generally representative of others across the UK. However, as we lacked an adequate number of hospitals to run a multi-level model with hospital as a random effect, our findings cannot be generalised to other healthcare settings outside the UK with differing national policies.

In summary, the heterogeneities that exist in stroke care at the regional UK level have the ability to lead to differences in stroke-patient outcomes such as, AHLOS. This provides a powerful message for patients, clinicians, service providers and policymakers – that there are modifiable hospital factors that may determine better outcomes in stroke. For example, a hub and spoke model of care could be advocated to increase efficiencies whilst also providing for more beneficial stroke health outcomes. Countries that are in the process of developing their healthcare systems can use these findings to inform their decision making in delivering optimal care.

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**Author Contributions:** M.T cleaned the data, undertook the statistical analysis and interpretation of results, reviewed the literature and, prepared the manuscript. D.M and P.K.M supervised the study. D.M provided statistical analysis advice and assistance. M.O.B, E.A.W, J.F.P and P.K.M conceptualized and designed the use of ASCNES and obtained funding. S.D.M was ASCNES study coordinator and managed the data. All authors reviewed the manuscript and contributed in critical revision and final manuscript preparation.

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**Data sharing statement:** The datasets generated and analysed during the current study are available from the ASCNES team on reasonable request.

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**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

**Figure 2** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) against hospital stroke volume and clustered by hospital type with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

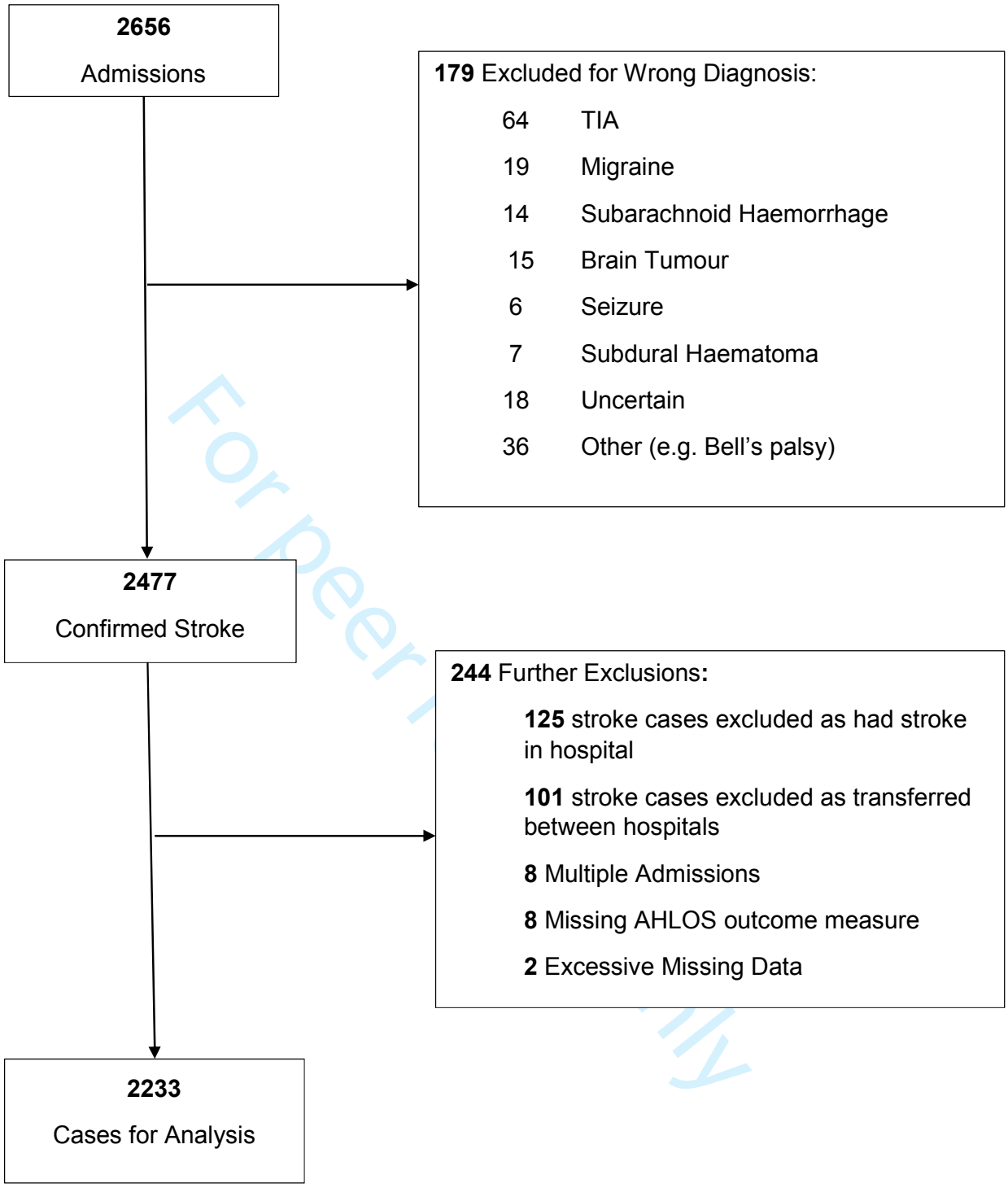


**Figure 1** Flow chart of patient participation inclusion and exclusion for study analysis

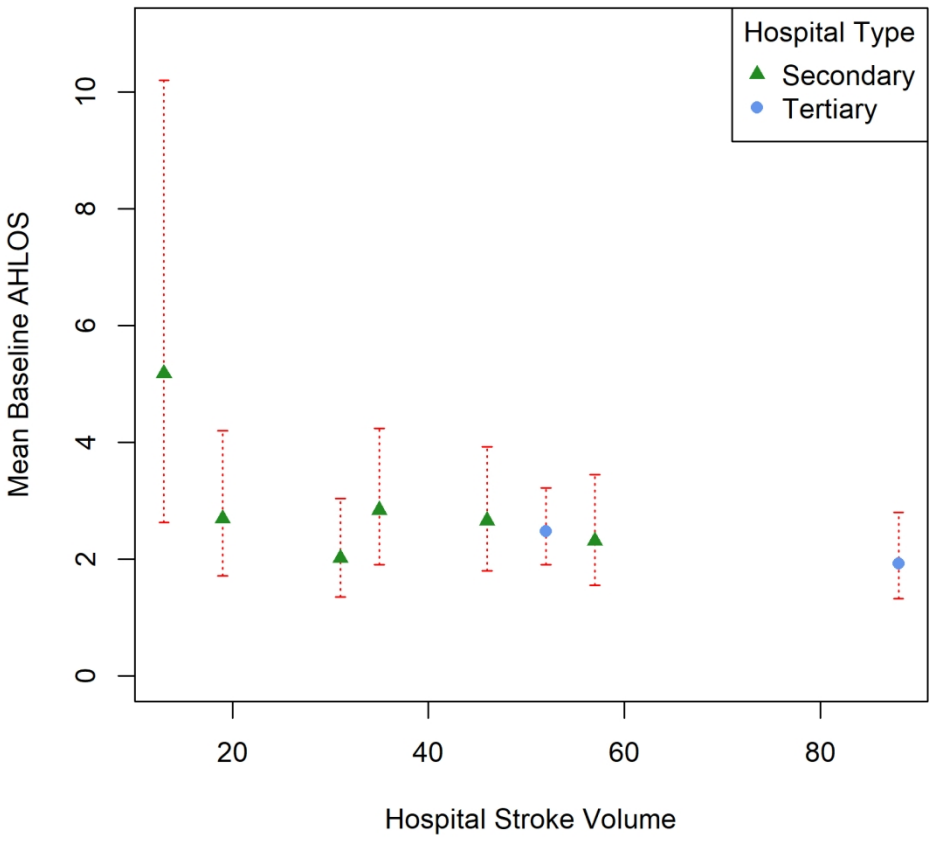


Figure 2 Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) against hospital stroke volume and clustered by hospital type with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

152x152mm (300 x 300 DPI)

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STUDY PROTOCOL Open Access

# Evaluation of stroke services in Anglia stroke clinical network to examine the variation in acute services and stroke outcomes

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## Abstract

**Background:** Stroke is the third leading cause of death in developed countries and the leading cause of long-term disability worldwide. A series of national stroke audits in the UK highlighted the differences in stroke care between hospitals. The study aims to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes, after accounting for case mix differences and individual prognostic factors.

**Methods/Design:** We will conduct a cohort study in eight acute NHS trusts within East of England, with at least one year of follow-up after stroke. The study population will be a systematically selected representative sample of patients admitted with stroke during the study period, recruited within each hospital. We will collect individual patient data on prognostic characteristics, health care received, outcomes and costs of care and we will also record relevant characteristics of each provider organisation. The determinants of one year outcome including patient reported outcome will be assessed statistically with proportional hazards regression models. Self (or proxy) completed EuroQol (EQ-5D) questionnaires will measure quality of life at baseline and follow-up for cost utility analyses.

**Discussion:** This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services which will bring direct benefit to the patients.

## Background

Stroke is the third leading cause of mortality and the number one cause of long-term disability in the UK. More than 150,000 people suffer a stroke in the UK each year [1]. It costs the NHS approximately £ 7 billion per annum [2]. Stroke incidence rises sharply with age and despite better primary and secondary preventative measures, the total number of strokes is set to rise in the UK [3]. Nevertheless, stroke care in UK is far from ideal: patients having a worse outcome in terms of death and dependency than many other European countries [4-6], at least in part due to differences in care provided [7]. There is also variation in outcome between different localities within the UK [8-11], these local differences being highlighted in the most recent publication of the National Sentinel Stroke Audit in 2009 [12]. These differnces probably arise as a result of substantial variations in how the stroke services are provided across the UK. Examples of such differences are access to neurovascular/neurosurgical service, early supported

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discharge, and stroke specialist on call rota for thrombolysis. The presence or absence of variations in stroke outcomes as a result of variation in care and how much the observed variations in patients' outcomes including patient reported outcome measure (PROM) are determined by the differences in service delivery have not been examined previously.

We hypothesise that variation in patient outcomes including mortality, length of stay, institutionalisation rate, and patient reported outcomes between care providers can partly be explained by the different ways in which stroke services are delivered. The main objectives of the study are (1) to describe variation in outcomes following stroke and to identify the characteristics of services that are associated with better outcomes after accounting for case mix differences and individual prognostic factors, and (2) to obtain preliminary data to identify sample size and inform future pragmatic real world setting RCTs in the area of health service delivery in stroke.

## Methods/Design

A prospective cohort study will be conducted to identify characteristics of services that are associated with the best outcomes including patient reported outcomes, taking into account case-mix and patients' prognostic features. The study will consist of two components (1) consecutive stroke admissions in selected months (a total of 8 months) and (2) a prospective study of patient reported outcome in some of these selected months.

### Sample Population

For the first component, the sample population will be stroke patients who are admitted to any of the hospitals within the Anglia region of Stroke & Heart Clinical Network between October 2009 and September 2011. Baseline data are already recorded, prior to the study commencement, as part of routine clinical data collection by Anglia Stroke Clinical Network (as described in detail below). The study sample will be a systematically selected sample (every third month) rather than a consecutive cohort of patients admitted to eight acute NHS hospital trusts. Therefore, this is not a consecutive case study; instead it seeks to be representative of the catchment population of the hospital and has taken into account the seasonal variation in stroke incidence and outcome [13].

For the patient reported outcome component of the study the following inclusion and exclusion criteria will be used. Inclusion criteria are (1) age > = 18 years, (2) admitted to hospital with stroke (diagnosed by stroke physicians) during the study months, (3) able to provide informed consent or patient's personal consultee agrees to study participation. Exclusion criteria include (1) age <18 years, (2) patients with pre-existing diagnosis of dementia (for PROM component only).

The Anglia Stroke Network was funded through the NHS Improvement Programme, following the publication of the National Stroke Strategy in December 2007. The Network was established in April 2008 to support the development of stroke services in Norfolk, Suffolk and Cambridgeshire regions. Since its inception, the Network regularly collected data to capture clinical service activities of the eight acute hospital trusts in the Network for the purpose of monitoring of services benchmarked by National targets and guidance from National Institute of Health & Clinical Excellence (NICE) in England and Wales. Data collection commenced in January 2009 and involves the individual trusts collecting clinical data which is fed back to the network by monthly reports. The total number of strokes admitted to the 8 acute trusts within the Network is approximately 4,000 per annum in 2009. The stroke cases were identified prospectively data were collected by the clinical team who looked after the patients and anonymised raw clinical data were sent to the network on monthly basis. The network collates and analyses the data for above mentioned purposes.

### Sample size

Since this is an exploratory study designed to provide information for further analytic research, sample size will be determined partly pragmatically rather than on particular hypothesis tests. For illustration purposes, a total sample of 2264 patients would provide 80% power to detect a constant Hazard ratio (HR) of 0.76 for one-year mortality between two groups of roughly equal size, based on the log-rank test. This assumes a 20% one-year mortality rate in the reference group, no loss to follow-up before one year and 2-sided type I error of 5%. If one-year mortality is 30%, then 2264 patients would provide 76% power to detect a HR of 0.81.

### Plan of investigation

The study will have a cohort design. We will follow up a cohort of patients systematically selected from each trust. For pragmatic purposes we will sample all patients who are admitted every third month, starting from October 2009. Over one calendar month, there will be ~ 300-350 stroke cases entered into the Network Clinical Data. Between October 2009 and September 2011, the Clinical Network would have collected a total of eight 3-monthly datasets per trust (i.e. 8 study months in total: Oct 2009, Jan 2010, April 2010, July 2010, October 2010, Jan 2011, April 2011, July 2011). Therefore, the estimated total cohort size with baseline clinical data will be ~ 2,400 stroke cases

during this exercise (30% of 4000 patients admitted annually in 8 trusts = 1200 × 2 yrs).

We will collect patient data by hospital trusts and conduct a questionnaire survey of patients' outcomes. Due to the nature of the study we would need 100% follow-up in randomly selected populations. Because we will be using a partially historical cohort, to avoid selection bias for mortality outcome, informed consent from all eligible participants will not be feasible. Therefore, it is most appropriate for the clinical team to collect the outcome data to comply with current ethical guidance in the UK. Therefore, the identifiable patient data will only be held at the local NHS trusts.

Neither the network nor the investigators will have access to any identifiable patient information (e.g. name, address). For outcome data we will utilise death certificate and hospital episode data from the Patient Administrative System (PAS) as described previously [14,15]. This approach will be used in conjunction with telephone and postal follow-up for questionnaire surveys such as EQ-5 D, and Stroke Impact Scale. These data will be counter-checked using discharge coding records, which record each hospital episode.

The clinical teams will retrieve case records to collect (1) baseline measures which were not recorded in baseline Network surveys and (2) outcome measures including mortality and hospital length of stay. At study commencement (October 2010) one year follow up data can be collected immediately for October 2009 cohorts (follow up complete at end September 2010). The follow up will be completed in September 2012 as the stroke patients included in the last survey for the study conducted by the Network in July 2011 will complete one year follow-up in June 2012 and data collection of the study will be completed by July-August 2012 with the view of final cohort data arrival to research team by the end of December 2012.

Due to multi-centre nature of the study the individual sites are expected to join the study at different time points (after their respective NHS Research & Development Committees' approval). We will collect characteristics of stroke services, patient related factors, prognostic indicators, treatment options and trial/study participation. Missing prognostic data will be imputed statistically, to ensure that all eligible patients are included in the primary analysis (see also Statistical Methods).

The service characteristics of interest include:

***At hospital level***

- staffing (including junior doctors and therapists (whole time equivalent), physicians characteristics
- university or district general hospital
- distance from tertiary referral centre
- availability of vascular surgery on site, neuro-surgery and neuro ITU on site
- monitoring beds
- physician on call rota
- compliance with NICE guidelines

***At patient level***

- provision of thrombolysis and CT
- medication

### Outcome measurements

Primary outcome of the study will be one year mortality comparison between services with different characteristics. The secondary outcomes will include (1) final discharge destination (good or poor outcome) [16], (2) length of acute hospital stay, (3) length of stay in rehabilitation, (4) complications during acute and rehab-hospital stay and significant procedures (e.g. aspiration pneumonia, myocardial infarction), (5) readmissions, (6) composite cardiovascular events (recurrent TIA/Stroke/Acute Coronary Syndrome, Myocardial infarction).

### Patient Reported Outcome Measures (PROM)

PROM will consist of (1) Stroke Impact Scale, (2) health related quality of life: EQ-5 D at one year in those who completed questionnaire at the baseline, (3) modified RANKIN, (4) Barthel score and (5) health service use.

### Statistical analysis

Quantitative data will be analysed by multivariate Cox-proportional hazards to examine the relationships between different aspects of health services and time to death, adjusting for prognostic characteristics. Multiple logistic or linear regression models will be constructed as appropriate for dichotomised and continuous outcome variables respectively. T tests for normally distributed data and Mann-Whitney U tests for non-normally distributed data will be used to compare continuous outcomes. Volume-outcome relationships will be investigated. Missing prognostic and EQ-5 D data will be imputed, based on each patient's other prognostic characteristics. Clustering of data by hospital trust will be investigated and, if necessary, taken into account, and intra-class correlation coefficients calculated to inform future research.

### Economic evaluation

Health care resources are scarce and it is therefore important to ensure that evaluations are undertaken in order to ensure that services provided by the NHS constitute value for money. Within this study we will thereby seek to estimate the cost-effectiveness of different stroke service deliveries.

Costs will first be calculated from the perspective of the NHS and personal social services (PSS). Thus, levels

of resources use will be recorded during the follow-up period, including the length of original hospital stay, input by the multi-disciplinary team, other investigations (e.g. x-ray) and any complications (including details of any further hospital admissions). Unit costs will subsequently be assigned to each of these resource items, enabling both the total mean cost in participants and the incremental cost between two different service deliveries (chosen to compare the cost effectiveness, e.g. traditional on call rota vs. telemedicine) to be calculated after adjusting for other factors. The main measure of effectiveness to be used in the economic analysis will the EQ-5 D [17], where responses will be sought at baseline, and at 12 month as mentioned above. This will enable the overall effect of each mode of service delivery, and the incremental effect of services to be estimated.

***Outcome***

As the National Institute of Health and Clinical Excellence [18] recommends use of the EQ-5 D [17] within cost-effectiveness analysis this will be our primary measure within the economic analyses. EQ-5 D data will be collected at two University Hospitals and two district general hospitals within the clinical network. We will use "mapping" strategy to estimate the cost-effectiveness analyses across the region. The use of mapping, where scores from a condition-specific (non preference-based) measure are 'converted' into a utility (preference-based) score using a pre-defined formulae, has been advocated (in certain instances) by the UK National Institute of Health and Clinical Excellence (NICE) [18], and has been used to estimate the utility scores, and in turn cost-effectiveness, of a number of health care interventions [19]. Mapping presents the possibility of not asking all participants to complete the EQ-5 D. In this study we propose to take advantage of this by developing a mapping algorithm based on the response from participants participating in this component to predict the EQ-5 D for participants in retrospective cohorts and those who did not participate in PROM component.

Because the quality of life measure (EQ-5D) which can be used to estimate health utility and calculate QALYs (Quality Adjusted Life Years) for economic evaluation is outside the remit of routine data collection and cannot be done retrospectively, we will collect EQ-5 D data in only the second year of the study (October 2010 and January, April and July 2011 cohorts and one year follow up data to be collected September and December 2011, and March and June 2012) in those who provide informed consent to the study (we estimate that the sample will be approximately 15-20% of the whole sample after excluding the one year pre-study period (between October 2009-September 2010) and after taking into account of refusal rate (estimated ~ 30%) in trusts with Stroke or Comprehensive Local Research Network Research Nurses.

**Economic Analysis**

In the Economic analysis if one option is shown to be less costly and more effective than another option (for example, telemedicine vs. on call system) then that option will 'dominate' the other and be deemed cost-effective. Alternatively, the incremental cost-effectiveness ratio (ICER) associated with a particular option will be estimated and assessed in relation to a range of cost-effectiveness thresholds. The associated level of uncertainty will also be characterised by e.g. estimating the cost-effectiveness acceptability curve (CEAC) for each intervention and conducting value of information analysis [20]. Sensitivity analysis will also be undertaken to assess the robustness of conclusions to key assumptions. We will also seek to identify what resource items should be monitored in a future study (i.e. what are the big cost drivers which are likely to be affected by the intervention) and how these items should be identified.

The study is funded by the NIHR Research for Patient Benefit Programme (PB-PG-1208-18240) and obtained ethical approval from the Norfolk Research Ethics Committee.

## Discussion

In this study we specifically aim to identify services that are associated with the best clinical outcomes including mortality and hospital length of stay including patient reported outcome adjusting for patient prognostic factors and potential confounders. Our study will be able to provide useful information in stroke service provision in UK and beyond. Furthermore, inclusion of patient reported outcome is novel and exciting component of our study.

Studies which have examined the delivery of specific services such as rapid imaging, have shown improvement in patients' outcome in stroke [21]. A recent report from Germany suggested that a telestroke network may be a useful strategy to implement in their non-urban stroke services [22]. Lees et al (2008) [23] highlighted that there is room for improvement in terms of acute services for stroke. Interestingly, one of the observations was that centres with higher workload performed better. There is also existing evidence in Cancer literature that centres with higher surgical caseload have better outcomes [24]. There has also been a recent evaluation of the impact on stroke outcome by evidence-based practice in an Australian setting [25]. Examples of service delivery that are associated with better outcomes include organised stroke unit care [26], thrombolysis treatment and appropriate secondary prevention [27], and early supported discharge

in selected patients [28,29]. However, the cost-effectiveness of such services has yet to be fully examined.

Rodgers et al [30] highlighted the need for improvement in hospital-based stroke services e.g. stroke unit staffing levels were lower than was available in RCTs. The accumulating body of evidence has been a major driving force behind the UK Government's strategy to improve stroke care (National Stroke Strategy, 2007) [31]. A key strand of the strategy was to set up stroke networks to deliver stroke service development across geographically defined areas. The stroke networks have worked to agree minimum standards for stroke care and they have worked with commissioners to assist the commissioning process for stroke services. The acute stroke services are currently delivered by different NHS trusts and there is therefore a wide range of inequality in service availability and provision with differeing structure and local support systems.

This research aims to utilise NHS data in the most meaningful and innovative way and we aim to maximize the benefit with minimum investment to produce best research output for patient care by collaborating with clinical teams and the network in providing excellent value for money. This observational study seeks to identify areas of clinical practice which merit future randomised controlled trials (RCTs) to identify best practice in improving stroke care which will be of maximum benefit to patients. We also aim to obtain preliminary data to estimate sample sizes and conduct value of information analyses to design future pragmatic RCTs of innovative ways of delivering stroke care.

As we include eight diverse NHS trusts, the findings are likely to be generalisable in the UK setting and beyond. This study will provide observational data about health service factors associated with variations in patient outcomes and health care costs following hospital admission for acute stroke. This will form the basis for future RCTs by identifying promising health service interventions, assessing the feasibility of recruiting and following up trial patients, and provide evidence about frequency and variances in outcomes, and intra-cluster correlation of outcomes, for sample size calculations. The results will also inform clinicians, public, service providers, commissioners and policy makers to drive further improvement in health services and bring direct benefit to patients.

The study will describe the variation in outcomes between different stroke services, and identify the characteristics of services associated with better outcomes after accounting for case-mix. We will also estimate the relative costs of and health gain estimated as Quality Adjusted Life Year (QALY) gain that may be demonstrated by different services. The commissioners of services will be informed as to which service delivery structures are likely to provide value for money to make purchasing decisions. They will also be better informed about the types of service associated with better patient reported outcome. Hospital trusts will be able to evaluate their services systematically and plan their care appropriately to meet local and regional needs and demands based on our study findings. Professionals will be able to reflect on the impact of services they are delivering to help improve their performance and the way services are organised by adopting the most effective and cost effective approaches. As an observational study, the study limitations include inability to control for unknown confounders and residual confounding effect of known confounders which are adjusted for. The causal relationship cannot be implied but as we stated the findings will provide knowledge about areas that requires further evaluation in clinical trial setting.

There is very little work which assesses service provision robustly against patients' own reported outcomes. This exciting study may lead to a clearer drive for patients to define what makes a good service. We hope that the best clinical practices are adopted to suit the local populations' needs and demand. As we included eight diverse NHS trusts, the findings will be generalisable in the UK setting and likely to be applicable in international setting. All these will become drivers of improvement in stroke services for the benefit of stroke sufferers.

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**Manuscripts that are under submission based on this protocol**
None.

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**Authors' contributions**
PKM, DJD, MOB designed the outline of the study. PKM, JFP, MOB, EAW, GMP, GAB and AKM obtained the funding for the study. SDM & RH contributed in protocol preparation. All authors contributed in writing of the paper. All authors read and approved the final manuscript. PKM is the guarantor.

**Competing interests**
The authors declare that they have no competing interests.

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Supplementary document to:

**Does service heterogeneity have an impact on acute hospital length of stay in stroke? A UK-based multi-centre prospective cohort study**

Michelle Tørnes, David McLernon, Max O Bachmann, Stanley D Musgrave, Elizabeth A Warburton, John F Potter, Phyo Kyaw Myint: On behalf of the Anglia Stroke Clinical Network Evaluation Study (ASCNES) Group

**CONTENT**

**Figure S3** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and distance to neurosurgical facility with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S4** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte senior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S5** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte junior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S6** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte health care associates and nurses per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S7** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte occupational therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S8** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte physiotherapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S9** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte speech and language therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S10** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of total beds present on stroke unit per 100 admissions with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S11** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of hospital beds per computed tomography (CT) scanner with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S12** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and provision of onsite rehabilitation service with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S13** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of early supported discharge scheme with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S14** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Figure S15** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and mean Index of Multiple Deprivation (IMD) score of the counties in which the hospital serves with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**Table S1** Variables used to inform multiple imputation of missing data

| Variable | Measure |
|---|---|
| I. Independent Variables | |
| Trust | 0=Trust 1 1 =Trust 2 2 =Trust 3 3=Trust 4 4=Trust 5 4=Trust 6 5=Trust 7 6=Trust 8 |
| Sex | 0=Male 1=Female |
| Age | Continuous, years |
| Recurrent Stroke | 0=No 1=Yes |
| Diabetes Mellitus | 0=No 1=Yes |
| Dementia | 0=No 1=Yes |
| Hypercholesterolemia | 0=No 1=Yes |
| Myocardial Infarction or Ischaemic Heart Disease | 0=No 1=Yes |
| Transient Ischaemic Attack | 0=No 1=Yes |
| Previous Cancer | 0=No 1=Yes |
| Active Cancer | 0=No 1=Yes |
| Depression | 0=No 1=Yes |
| Rheumatoid Arthritis | 0=No 1=Yes |
| Chronic Obstructive Pulmonary Disease | 0=No 1=Yes |
| Pre-Stroke modified Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 & 5 |
| Pre-Stroke Residence | 0=Independent living without formal care 1=Independent living with formal care 2=Institutional care |
| Stroke Type | 0=Ischaemic 1=Haemorrhagic |
| Oxfordshire Community Stroke Classification | 0=LACS 1=PACS 2=POCS 3=TACS |
| Brain Lateralisation | 0=Yes 1=No |
| Inpatient Complication | 0=No 1=Yes |
| Discharge modified Rankin Score (mRS) | 0=0 1=1 2=2 3=3 4=4 5=5 6=6 |
| Season of Admission | 0=Summer 1=Winter |
| Day of Admission | 0=Weekday 1=Weekend |
| II. Dependent Variable | |
| Logarithmic acute hospital LOS | Continuous, days |
| III. Auxiliary Variables | |
| Discharge Destination | 0=Independent living without formal care 1=Independent living with formal care 2=Institutional care 3=Interim or rehabilitation setting 4=Death |
| Atrial Fibrillation | 0=No 1=Yes |
| Baseline Systolic Blood Pressure | Continuous, mmHg |
| Baseline Diastolic Blood Pressure | Continuous, mmHg |
| Glucose Concentration on Admission | Continuous, mmol/L |
| Weight | Continuous, kg |
| Heart Rate | Continuous, beats per minute |
| Temperature | Continuous, ˚C |
| Oxygen Saturation | Continuous, % |
| ITU or HDU admission | 0. No 1. Yes |
| Systolic Blood Pressure at Discharge | Continuous, mmHg |
| Diastolic Blood Pressure at Discharge | Continuous, mm Hg |

LOS, Length of Stay; ITU, Intensive Care Unit; HDU, High Dependency Unit.

**Table S2** Sample characteristics of the 2333 patients included in analysis per individual hospital (n (%) unless otherwise stated)

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Age, y, median (IQR) | 78<br>(68 to 85) | 87<br>(81 to 92) | 79<br>(72 to 86) | 79<br>(70 to 86) | 79<br>(71 to 85) | 78<br>(71 to 85) | 80<br>(68 to 85) | 80<br>(71 to 87) |
| Sex, female | 180 (52) | 9 (56) | 197 (56) | 76 (53) | 309 (50) | 155 (55) | 116 (46) | 123 (55) |
| Recurrent Stroke | 50 (14) | 5 (31) | 61 (17) | 19 (17) | 143 (23) | 62 (22) | 66 (26) | 42 (19) |
| Diabetes Mellitus | 48 (14) | 1 (6) | 59 (17) | 17 (15) | 92 (15) | 66 (23) | 44 (17) | 43 (19) |
| Dementia | 26 (7) | 1 (6) | 35 (10) | 10 (9) | 58 (9) | 29 (10) | 23 (9) | 25 (11) |
| Hypercholesterolemia | 48 (14) | 3 (19) | 24 (7) | 7 (6) | 61 (10) | 80 (28) | 38 (15) | 94 (42) |
| Hypertensive | 225 (64) | 8 (50) | 202 (58) | 56 (50) | 446 (72) | 200 (71) | 187 (74) | 159 (71) |
| Myocardial Infarction or Ischaemic Heart Disease | 45 (13) | 3 (19) | 87 (25) | 30 (27) | 142 (23) | 80 (28) | 49 (19) | 81 (36) |
| Transient Ischaemic Attack | 32 (9) | 3 (19) | 58 (17) | 17 (15) | 113 (18) | 40 (14) | 47 (19) | 30 (13) |
| Previous Cancer | 33 (9) | 1 (6) | 38 (11) | 12 (11) | 41 (7) | 18 (6) | 21 (8) | 31 (14) |
| Active Cancer | 24 (7) | 2 (12) | 8 (2) | 10 (9) | 49 (8) | 9 (3) | 20 (8) | 15 (7) |
| Depression | 13 (4) | 0 (0) | 17 (5) | 8 (7) | 33 (5) | 11 (4) | 18 (7) | 17 (8) |
| Rheumatoid Arthritis | 11 (3) | 1 (6) | 43 (12) | 3 (3) | 83 (13) | 2 (1) | 7 (3) | 4 (2) |
| COPD | 15 (4) | 1 (6) | 20 (6) | 6 (5) | 26 (4) | 20 (7) | 11 (4) | 17 (8) |
| Pre-stroke mRS Score | | | | | | | | |
| 0 | 84 (43) | 3 (19) | 117 (36) | - | 330 (56) | 126 (64) | 136 (56) | 118 (53) |
| 1 | 60(31) | 3 (19) | 75 (23) | - | 87 (15) | 16 (8) | 61 (25) | 33 (15) |
| 2 | 24 (12) | 3 (19) | 51 (16) | - | 56 (9) | 17 (9) | 16 (7) | 24 (11) |
| 3 | 21 (11) | 2 (12) | 38 (12) | - | 60 (10) | 20 (10) | 15 (6) | 28 (13) |
| 4 & 5 | 7 (4) | 5 (31) | 44 (14) | - | 57 (10) | 18 (9) | 16 (7) | 20 (9) |
| Pre-Stroke Residence | | | | | | | | |
| Independent living with formal care | 21 (6) | 4 (25) | 23 (7) | 15 (14) | 62 (10) | 30 (11) | 34 (13) | 21 (10) |
| Independent living w/o formal care | 292 (86) | 9 (56) | 285 (82) | 86 (77) | 493 (80) | 215 (77) | 193 (77) | 179 (82) |
| Institution | 28 (8) | 3 (19) | 40 (11) | 10 (9) | 63 (10) | 35 (12) | 23 (9) | 18 (8) |

| Variables | Hospital 1<br>350<br>(16) | Hospital 2<br>16<br>(1) | Hospital 3<br>350<br>(16) | Hospital 4<br>143<br>(6) | Hospital 5<br>618<br>(28) | Hospital 6<br>281<br>(13) | Hospital 7<br>252<br>(11) | Hospital 8<br>223<br>(10) |
|---|---|---|---|---|---|---|---|---|
| Stroke Type | | | | | | | | |
| Ischaemic | 293 (85) | 14 (100) | 286 (87) | 90 (91) | 541 (88) | 233 (85) | 213 (87) | 194 (88) |
| Haemorrhagic | 50 (15) | 0 (0) | 43 (13) | 9 (9) | 73 (12) | 40 (15) | 32 (13) | 26(12) |
| Oxford Community Stroke Project Classification | | | | | | | | |
| LACS | 64 (24) | 1 (7) | 95 (29) | 20 (28) | 149 (25) | 51 (18) | 39 (19) | 84 (39) |
| PACS | 117 (43) | 11 (79) | 109 (33) | 38 (54) | 216 (37) | 147 (53) | 80 (39) | 66 (30) |
| POCS | 51 (19) | - | 29 (9) | 3 (4) | 117 (20) | 21 (8) | 33 (16) | 25 (12) |
| TACS | 38 (14) | 2 (14) | 99 (30) | 10 (14) | 107 (18) | 57 (21) | 52 (25) | 42 (19) |
| No Brain Lateralisation | 50 (15) | 2 (13) | 14 (4) | 9 (9) | 129 (21) | 1 (0.4) | 30 (12) | 9 (4) |
| Inpatient Complication | 108 (31) | 4 (25) | 34 (10) | 36 (25) | 229 (37) | 109 (39) | 83 (33) | 52 (23) |
| Discharge mRS Score | | | | | | | | |
| 0 | 37 (15) | 0 (0) | 11 (3) | 0 (0) | 114 (19) | 44 (16) | 42 (17) | 22 (10) |
| 1 | 65 (25) | 2 (12) | 55 (17) | 0 (0) | 97 (16) | 25 (12) | 55 (23) | 53 (24) |
| 2 | 36 (14) | 1 (6) | 46 (14) | 0 (0) | 57 (10) | 20 (9) | 33 (14) | 19 (9) |
| 3 | 41 (16) | 4 (25) | 40 (12) | 0 (0) | 87 (15) | 36 (17) | 34 (14) | 49 (22) |
| 4 | 19 (7) | 3 (19) | 57 (17) | 0 (0) | 89 (15) | 25 (12) | 16 (7) | 29 (13) |
| 5 | 4 (2) | 1 (6) | 47 (14) | 0 (0) | 40 (7) | 14 (7) | 16 (7) | 15 (7) |
| 6 | 53 (21) | 5 (31) | 77 (23) | 29 (100) | 110 (19) | 58 (27) | 47 (19) | 35 (16) |
| Winter Admission | 172 (49) | 16 (100) | 181 (52) | 73 (51) | 332 (54) | 140 (50) | 131 (52) | 114 (51) |
| Weekend Admission | 113 (32) | 3 (19) | 98 (28) | 43 (30) | 177 (29) | 74 (26) | 55 (22) | 51 (23) |

IQR, Interquartile Range; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S3** Sample characteristics of complete cases and those with at least one variable missing

| Patient Characteristic | Complete Cases (n=1496) | Cases with at least one missing variable | *P* |
|---|---|---|---|
| | Median (IQR) or No. (%) | | |
| Age, y* | 79 (71 to 86) | 79 (70 to 86) | 0.34 |
| Sex, female† | 781 (52) | 384 (52) | 1 |
| Comorbidities† | | | |
| Recurrent Stroke | 328 (22) | 120 (17) | 0.01 |
| Diabetes Mellitus | 259 (17) | 111 (16) | 0.38 |
| Dementia | 138 (9) | 69 (10) | 0.75 |
| Hypercholesterolemia | 264 (18) | 91 (13) | 0.01 |
| Hypertensive | 1054 (70) | 429 (61) | <0.001 |
| Myocardial Infarction or Ischaemic Heart Disease | 362(24) | 155 (22) | 0.26 |
| TIA | 248 (17) | 92 (13) | 0.04 |
| Previous Cancer | 140 (9) | 55 (8) | 0.25 |
| Active Cancer | 93 (6) | 44 (6) | 1 |
| Depression | 79 (5) | 38 (5) | 1 |
| Rheumatoid Arthritis | 129 (9) | 25 (3) | <0.001 |
| COPD | 76 (5) | 40 (6) | 0.64 |
| Pre-stroke mRS Score‡ | | | 0.62 |
| 0 | 765 (51) | 149 (51) | |
| 1 | 284 (19) | 51 (17) | |
| 2 | 167 (11) | 24 (8) | |
| 3 | 149 (10) | 35 (12) | |
| 4 & 5 | 131 (9) | 36 (12) | |
| Pre-stroke Residence† | | | <0.001 |
| Independent living with formal care | 145 (10) | 65 (9) | |
| Independent living without formal | 1215 (81) | 537 (78) | |
| Institution | 136 (9) | 84 (12) | |
| Haemorrhagic Stroke† | 138 (9) | 135 (21) | <0.001 |
| Oxford Community Stroke Project‡ | | | 0.05 |
| LACS | 411 (27) | 92 (19) | |
| PACS | 570 (38) | 214 (45) | |
| POCS | 214 (14) | 65 (14) | |
| TACS | 301 (20) | 106 (22) | |
| No Brain Lateralisation† | 174 (12) | 70 (12) | 0.74 |
| Inpatient Complication† | 421 (28) | 234 (32) | 0.09 |
| Discharge mRS Score‡ | | | 0.02 |
| 0 | 218 (15) | 42 (10) | |
| 1 | 295 (20) | 57 (14) | |
| 2 | 177 (12) | 35 (9) | |
| 3 | 243 (16) | 48 (12) | |
| 4 | 209 (14) | 29 (7) | |
| 5 | 121 (8) | 16 (4) | |
| 6 | 233 (16) | 181 (44) | |

| | | | |
|---|---|---|---|
| Winter Admission† | 770 (51) | 389 (53) | 0.59 |
| Weekend Admission† | 401 (27) | 213 (29) | 0.32 |

IQR, Interquartile Range; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Two sample t-test*

*† $\mathcal{X}^2$ test*

*ǂ $\mathcal{X}^2$ test for trend*

**Table S4** Univariable regression analysis for multiple imputed dataset for AHLOS (n=2233)

| Patient Characteristic | β | 95% CI | *P* | $R^2$ |
|---|---|---|---|---|
| Age, y | 1.02 | 1.02 to 1.02 | <0.001 | 4.8 |
| Sex, female | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 1.17 | 1.05 to 1.31 | 0.01 | 0.4 |
| Diabetes Mellitus | 1.16 | 1.03 to 1.31 | 0.02 | 0.3 |
| Dementia | 1.46 | 1.25 to 1.70 | <0.001 | 1.1 |
| Hypercholesterolemia | 0.84 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1.02 | 0.93 to 1.12 | 0.66 | 0 |
| Myocardial Infarction/ Ischaemic Heart Disease* | 1.07 | 0.96 to 1.19 | 0.23 | 0.1 |
| TIA | 1.07 | 0.94 to 1.21 | 0.30 | 0.1 |
| Previous Cancer | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 0.97 | 0.80 to 1.16 | 0.72 | 0 |
| Depression | 1.06 | 0.86 to 1.29 | 0.59 | 0 |
| Rheumatoid Arthritis | 1.10 | 0.92 to 1.31 | 0.31 | 0.1 |
| COPD | 0.86 | 0.71 to 1.06 | 0.15 | 0.1 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 | 5.5 |
| 1 | 1.57 | 1.38 to 1.79 | <0.001 | |
| 2 | 1.63 | 1.39 to 1.91 | <0.001 | |
| 3 | 1.94 | 1.65 to 2.28 | <0.001 | |
| 4 & 5 | 1.32 | 1.13 to 1.55 | <0.001 | |
| Pre-stroke Residence (reference Independent living w/o formal care) | | | <0.001 | 1.4 |
| Independent living with formal care | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 1.13 | 0.97 to 1.31 | 0.11 | |
| Haemorrhagic Stroke | 0.83 | 0.73 to 0.96 | 0.01 | 0.3 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 | 4.0 |
| PACS | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 1.22 | 1.05 to 1.42 | 0.01 | |
| TACS | 1.66 | 1.45 to 1.90 | <0.001 | |
| Brain Lateralisation | 0.69 | 0.60 to 0.80 | <0.001 | 1.2 |
| Inpatient Complication | 2.13 | 1.94 to 2.34 | <0.001 | 10.3 |
| Discharge mRS Score (reference 0) | | | <0.001 | 31.1 |
| 1 | 1.24 | 1.07 to 1.42 | 0.003 | |
| 2 | 2.04 | 1.75 to 2.39 | <0.001 | |
| 3 | 3.35 | 2.90 to 3.87 | <0.001 | |
| 4 | 4.20 | 3.60 to 4.90 | <0.001 | |
| 5 | 6.67 | 5.62 to 7.91 | <0.001 | |
| 6 | 1.57 | 1.37 to 1.80 | <0.001 | |
| Winter Admission | 1.20 | 1.09 to 1.31 | <0.001 | 0.7 |
| Weekend Admission | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | <0.001 | 2.4 |
| 2 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 1.18 | 1.00 to 1.41 | 0.05 | |

| Patient Characteristic | β | 95% CI | *P* | $R^2$ |
|---|---|---|---|---|
| 8 | 0.86 | 0.72 to 1.03 | 0.11 | |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S5** Univariable linear regression complete case analysis for AHLOS

| Patient Characteristic | N | β | 95% CI | *P* | % $R^2$ |
|---|---|---|---|---|---|
| Age, y | 2231 | 1.02 | 1.02 to 1.02 | <0.001 | 4.7 |
| Sex, female | 1165 v. 1066 | 1.20 | 1.10 to 1.31 | <0.001 | 0.7 |
| Recurrent Stroke | 448 v. 1755 | 1.17 | 1.05 to 1.31 | 0.005 | 0.3 |
| Diabetes Mellitus | 370 v. 1833 | 1.16 | 1.03 to 1.31 | 0.02 | 0.2 |
| Dementia | 207 v. 1996 | 1.46 | 1.25 to 1.70 | <0.001 | 1.0 |
| Hypercholesterolemia | 355 v. 1848 | 0.85 | 0.75 to 0.95 | 0.01 | 0.3 |
| Hypertensive | 1483 v. 720 | 1.03 | 0.93 to 1.13 | 0.57 | 0 |
| Myocardial Infarction or Ischaemic Heart Disease* | 517 v. 1686 | 1.07 | 0.96 to 1.19 | 0.23 | 0 |
| TIA | 340 v. 1863 | 1.06 | 0.94 to 1.20 | 0.32 | 0 |
| Previous Cancer | 195 v. 2008 | 1.23 | 1.05 to 1.44 | 0.01 | 0.3 |
| Active Cancer | 137 v. 2066 | 0.96 | 0.80 to 1.15 | 0.65 | 0 |
| Depression | 117 v. 2086 | 1.05 | 0.86 to 1.28 | 0.65 | 0 |
| Rheumatoid Arthritis | 154 v. 2049 | 1.10 | 0.92 to 1.31 | 0.31 | 0 |
| COPD | 116 v. 2087 | 0.86 | 0.70 to 1.05 | 0.14 | 0.1 |
| Pre-stroke mRS Score (reference 0) | | | | <0.001 | 5.8 |
| 1 | 335 v. 914 | 1.58 | 1.39 to 1.80 | <0.001 | |
| 2 | 191 v. 914 | 1.62 | 1.38 to 1.90 | <0.001 | |
| 3 | 184 v. 914 | 1.97 | 1.67 to 2.31 | <0.001 | |
| 4 & 5 | 167 v. 914 | 1.45 | 1.22 to 1.71 | <0.001 | |
| Pre-stroke Residence (reference Independent living without formal care) | | | | <0.001 | 1.3 |
| Independent living with formal care | 210 v. 1752 | 1.52 | 1.31 to 1.77 | <0.001 | |
| Institution | 220 v. 1752 | 1.14 | 0.98 to 1.32 | 0.09 | |
| Haemorrhagic Stroke | 273 v. 1864 | 0.85 | 0.74 to 0.97 | 0.02 | 0.2 |
| Oxford Community Stroke Project Classification (reference LACS) | | | | <0.001 | 4.3 |
| PACS | 784 v. 503 | 1.62 | 1.44 to 1.82 | <0.001 | |
| POCS | 279 v. 503 | 1.24 | 1.06 to 1.44 | 0.01 | |
| TACS | 407 v. 503 | 1.75 | 1.53 to 2.01 | <0.001 | |
| No Brain Lateralisation | 244 v. 1822 | 0.68 | 0.59 to 0.79 | <0.001 | 1.3 |
| Inpatient Complication | 655 v. 1578 | 2.13 | 1.94 to 2.34 | <0.001 | 10 |
| Discharge mRS Score (reference 0) | | | | <0.001 | 30.1 |
| 1 | 352 v. 260 | 1.25 | 1.08 to 1.44 | 0.002 | |
| 2 | 212 v. 260 | 2.01 | 1.72 to 2.36 | <0.001 | |
| 3 | 291 v. 260 | 3.30 | 2.84 to 3.82 | <0.001 | |
| 4 | 238 v. 260 | 4.17 | 3.57 to 4.87 | <0.001 | |
| 5 | 137 v. 260 | 6.97 | 5.81 to 8.37 | <0.001 | |
| 6 | 414 v. 260 | 1.58 | 1.38 to 1.81 | <0.001 | |
| Winter Admission | 1159 v. 1074 | 1.20 | 1.09 to 1.31 | <0.001 | 0.6 |
| Weekend Admission | 614 v. 1619 | 1.08 | 0.98 to 1.20 | 0.12 | 0.1 |
| Hospital (reference 1) | | | | <0.001 | 2.1 |
| 2 | 16 v. 350 | 2.69 | 1.58 to 4.58 | <0.001 | |
| 3 | 350 v. 350 | 1.19 | 1.02 to 1.39 | 0.03 | |
| 4 | 143 v. 350 | 1.24 | 1.01 to 1.53 | 0.04 | |
| 5 | 618 v. 350 | 0.86 | 0.75 to 0.99 | 0.03 | |
| 6 | 281 v. 350 | 1.11 | 0.94 to 1.31 | 0.22 | |
| 7 | 252 v. 350 | 1.18 | 1.00 to 1.41 | 0.05 | |

| Patient Characteristic | N | β | 95% CI | *P* | % $R^2$ |
|---|---|---|---|---|---|
| 8 | 223 v. 350 | 0.86 | 0.72 to 1.03 | 0.11 | |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; TIA, Transient Ischaemic Attack; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S6** Multiple *l*inear *r*egression *c*omplete *c*ase *a*nalysis for AHLOS (n=1496, $R^2$=44.7%).

| Patient Characteristic | N | β | 95% CI | *P* |
|---|---|---|---|---|
| Age, y | 1496 | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 781 v. 715 | 0.98 | 0.90 to 1.07 | 0.66 |
| Recurrent Stroke | 328 v. 1168 | 1.06 | 0.96 to 1.17 | 0.27 |
| Diabetes Mellitus | 259 v. 1237 | 0.99 | 0.89 to 1.11 | 0.91 |
| Dementia | 138 v. 1358 | 1.32 | 1.13 to 1.53 | <0.001 |
| Hypercholesterolemia | 264 v. 1232 | 0.92 | 0.82 to 1.02 | 0.13 |
| Myocardial Infarction or Ischaemic Heart Disease* | 362 v. 1134 | 1.00 | 0.91 to 1.10 | 0.97 |
| Previous Cancer | 140 v. 1356 | 1.16 | 1.01 to 1.33 | 0.03 |
| COPD | 76 v. 1420 | 0.91 | 0.76 to 1.09 | 0.31 |
| Pre-stroke mRS Score (reference 0) | | | | <0.001 |
| 1 | 284 v. 765 | 1.08 | 0.96 to 1.20 | 0.21 |
| 2 | 167 v. 765 | 0.93 | 0.80 to 1.08 | 0.33 |
| 3 | 149 v. 765 | 1.00 | 0.84 to 1.19 | 0.99 |
| 4 & 5 | 131 v. 765 | 0.77 | 0.63 to 0.93 | 0.01 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | | <0.001 |
| Independent living with formal care | 145 v. 1215 | 1.02 | 0.88 to 1.19 | 0.78 |
| Institution | 136 v. 1215 | 0.83 | 0.69 to 0.98 | 0.03 |
| Haemorrhagic Stroke | 138 v. 1358 | 0.83 | 0.72 to 0.96 | 0.01 |
| Oxford Community Stroke Project Classification | | | | <0.001 |
| PACS | 570 v. 411 | 1.27 | 1.15 to 1.40 | <0.001 |
| POCS | 214 v. 411 | 1.29 | 1.13 to 1.47 | <0.001 |
| TACS | 301 v. 411 | 1.36 | 1.19 to 1.57 | <0.001 |
| No Brain Lateralisation | 174 v. 1322 | 0.93 | 0.81 to 1.05 | 0.24 |
| Inpatient Complication | 421 v. 1075 | 1.67 | 1.51 to 1.84 | <0.001 |
| Discharge mRS Score (reference 0) | | | | <0.001 |
| 1 | 295 v. 218 | 1.15 | 1.00 to 1.32 | 0.05 |
| 2 | 177 v. 218 | 1.60 | 1.36 to 1.88 | <0.001 |
| 3 | 243 v. 218 | 2.45 | 2.10 to 2.87 | <0.001 |
| 4 | 209 v. 218 | 3.39 | 2.86 to 4.02 | <0.001 |
| 5 | 121 v. 218 | 4.78 | 3.89 to 5.88 | <0.001 |
| 6 | 233 v. 218 | 1.34 | 1.11 to 1.61 | 0.002 |
| Winter Admission | 770 v. 726 | 1.16 | 1.07 to 1.25 | <0.001 |
| Weekend Admission | 401 v. 1095 | 1.06 | 0.97 to 1.15 | 0.23 |
| Hospital (reference1) | | | | <0.001 |
| 2 | 14 v. 111 | 2.08 | 1.35 to 3.21 | 0.001 |
| 3 | 278 v. 111 | 1.20 | 1.01 to 1.44 | 0.04 |
| 4 | - | - | - | - |
| 5 | 558 v. 111 | 0.84 | 0.71 to 0.98 | 0.03 |
| 6 | 142 v. 111 | 1.03 | 0.85 to 1.26 | 0.75 |
| 7 | 191 v. 111 | 1.35 | 1.13 to 1.62 | 0.001 |
| 8 | 202 v. 111 | 0.94 | 0.78 to 1.13 | 0.49 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S7** Multiple linear regression sensitivity analysis for AHLOS, excluding Hospital 2 using multiple imputed dataset (n=2217, $R^2$=44.7%).

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 1.01 | 0.94 to 1.08 | 0.86 |
| Recurrent Stroke | 1.02 | 0.93 to 1.12 | 0.68 |
| Diabetes Mellitus | 1.07 | 0.97 to 1.17 | 0.19 |
| Dementia | 1.30 | 1.13 to 1.48 | <0.001 |
| Hypercholesterolemia | 0.95 | 0.86 to 1.05 | 0.33 |
| Myocardial Infarction or Ischaemic Heart Disease* | 1.00 | 0.91 to 1.08 | 0.92 |
| Previous Cancer | 1.13 | 0.99 to 1.27 | 0.06 |
| COPD | 0.90 | 0.77 to 1.06 | 0.21 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.08 | 0.96 to 1.21 | 0.19 |
| 2 | 0.90 | 0.78 to 1.04 | 0.16 |
| 3 | 0.94 | 0.79 to 1.10 | 0.47 |
| 4 & 5 | 0.69 | 0.58 to 0.83 | <0.001 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.01 | 0.88 to 1.16 | 0.91 |
| Institution | 0.81 | 0.69 to 0.95 | 0.01 |
| Haemorrhagic Stroke | 0.80 | 0.71 to 0.90 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.30 | 1.18 to 1.43 | <0.001 |
| POCS | 1.34 | 1.18 to 1.53 | <0.001 |
| TACS | 1.29 | 1.13 to 1.47 | <0.001 |
| No Brain Lateralisation | 0.85 | 0.75 to 0.95 | 0.01 |
| Inpatient Complication | 1.70 | 1.57 to 1.85 | <0.001 |
| Discharge mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.00 to 1.32 | 0.04 |
| 2 | 1.74 | 1.48 to 2.04 | <0.001 |
| 3 | 2.72 | 2.34 to 3.16 | <0.001 |
| 4 | 3.56 | 3.02 to 4.20 | <0.001 |
| 5 | 5.12 | 4.22 to 6.22 | <0.001 |
| 6 | 1.25 | 1.05 to 1.48 | 0.01 |
| Winter Admission | 1.15 | 1.08 to 1.24 | <0.001 |
| Weekend Admission | 1.03 | 0.95 to 1.11 | 0.48 |
| Hospital (reference 1) | | | <0.001 |
| 3 | 1.08 | 0.94 to 1.22 | 0.29 |
| 4 | 1.07 | 0.89 to 1.29 | 0.40 |
| 5 | 0.78 | 0.70 to 0.87 | <0.001 |
| 6 | 0.93 | 0.81 to 1.07 | 0.33 |
| 7 | 1.15 | 1.00 to 1.32 | 0.05 |
| 8 | 0.82 | 0.70 to 0.95 | 0.01 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

**Table S8** Multiple linear regression sensitivity analysis for AHLOS, including discharge destination using multiple imputed dataset (n=2233, $R^2$=40%).

| Patient Characteristic | $e^{\beta}$* | 95% CI* | *P* |
|---|---|---|---|
| Age, y | 1.01 | 1.00 to 1.01 | <0.001 |
| Sex, female | 0.99 | 0.92 to 1.07 | 0.80 |
| Recurrent Stroke | 1.00 | 0.91 to 1.10 | 1.00 |
| Diabetes Mellitus | 1.08 | 0.98 to 1.19 | 0.12 |
| Dementia | 1.20 | 1.05 to 1.38 | 0.01 |
| Hypercholesterolemia | 0.94 | 0.85 to 1.04 | 0.25 |
| Myocardial Infarction or Ischaemic Heart | 1.01 | 0.93 to 1.10 | 0.83 |
| Previous Cancer | 1.17 | 1.03 to 1.33 | 0.01 |
| COPD | 0.91 | 0.77 to 1.07 | 0.23 |
| Pre-stroke mRS Score (reference 0) | | | <0.001 |
| 1 | 1.15 | 1.03 to 1.28 | 0.02 |
| 2 | 1.15 | 1.00 to 1.33 | 0.05 |
| 3 | 1.33 | 1.13 to 1.56 | <0.001 |
| 4 & 5 | 1.15 | 0.96 to 1.38 | 0.12 |
| Pre-Stroke Residence (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 0.86 | 0.75 to 0.99 | 0.04 |
| Institution | 0.52 | 0.44 to 0.62 | <0.001 |
| Haemorrhagic Stroke | 0.84 | 0.75 to 0.95 | <0.001 |
| Oxford Community Stroke Project Classification (reference LACS) | | | <0.001 |
| PACS | 1.34 | 1.22 to 1.48 | <0.001 |
| POCS | 1.44 | 1.26 to 1.63 | <0.001 |
| TACS | 1.49 | 1.31 to 1.70 | <0.001 |
| No Brain Lateralisation | 0.82 | 0.73 to 0.93 | <0.001 |
| Inpatient Complication | 1.72 | 1.58 to 1.87 | <0.001 |
| Discharge Destination (reference Independent living without formal care) | | | <0.001 |
| Independent living with formal care | 1.99 | 1.74 to 2.27 | <0.001 |
| Institution | 3.58 | 3.09 to 4.15 | <0.001 |
| Interim/Rehab Setting | 2.18 | 1.94 to 2.46 | <0.001 |
| Death | 0.85 | 0.74 to 0.97 | 0.02 |
| Winter Admission | 1.15 | 1.07 to 1.24 | <0.001 |
| Weekend Admission | 1.04 | 0.96 to 1.13 | 0.30 |
| Hospital (reference 1) | | | <0.001 |
| 2 | 2.76 | 1.80 to 4.22 | <0.001 |
| 3 | 1.24 | 1.09 to 1.42 | <0.001 |
| 4 | 1.36 | 1.15 to 1.61 | <0.001 |
| 5 | 0.85 | 0.75 to 0.95 | 0.01 |
| 6 | 1.06 | 0.92 to 1.22 | 0.42 |
| 7 | 1.19 | 1.03 to 1.37 | 0.02 |
| 8 | 0.99 | 0.85 to 1.14 | 0.84 |

AHLOS, Acute Hospital Length of Stay; CI, Confidence Interval; COPD, Chronic Obstructive Pulmonary Disease; mRS, modified Rankin Scale; LACS, Lacunar Anterior Circulation Stroke; PACS, Partial Anterior Circulation Stroke; POCS, Posterior Circulation Stroke; TACS, Total Anterior Circulation Stroke.

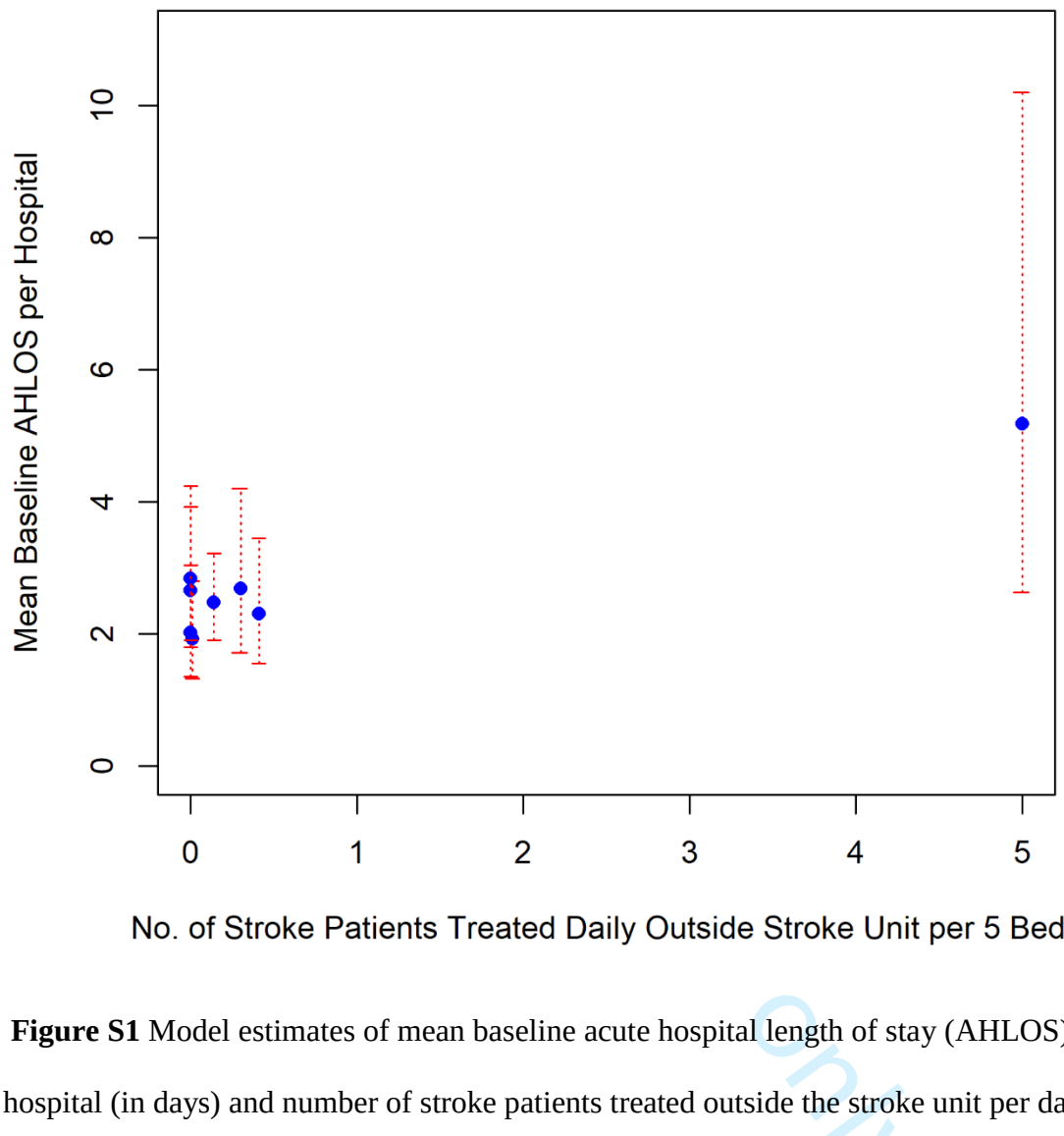


**Figure S1** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of stroke patients treated outside the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

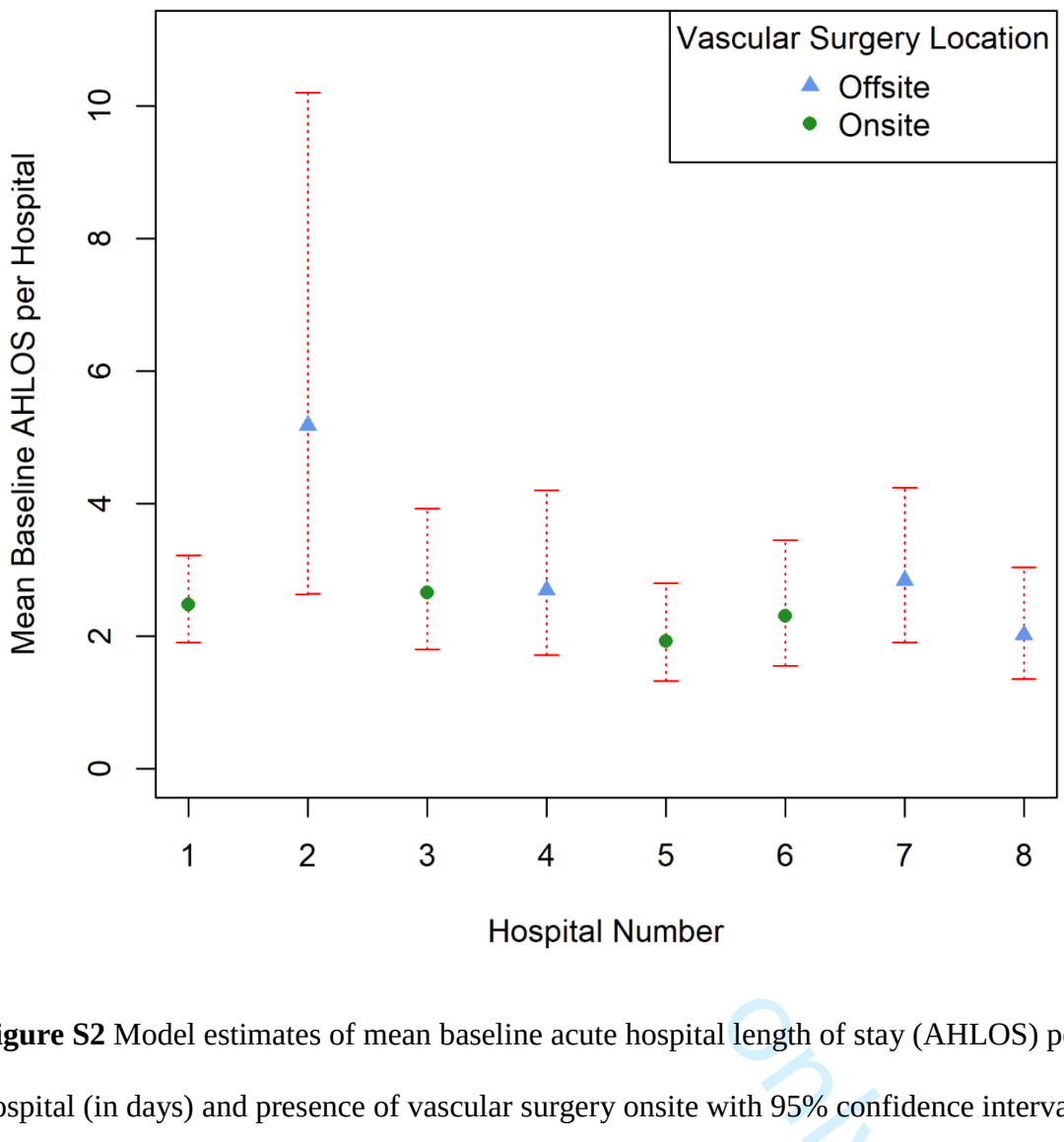


**Figure S2** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of vascular surgery onsite with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

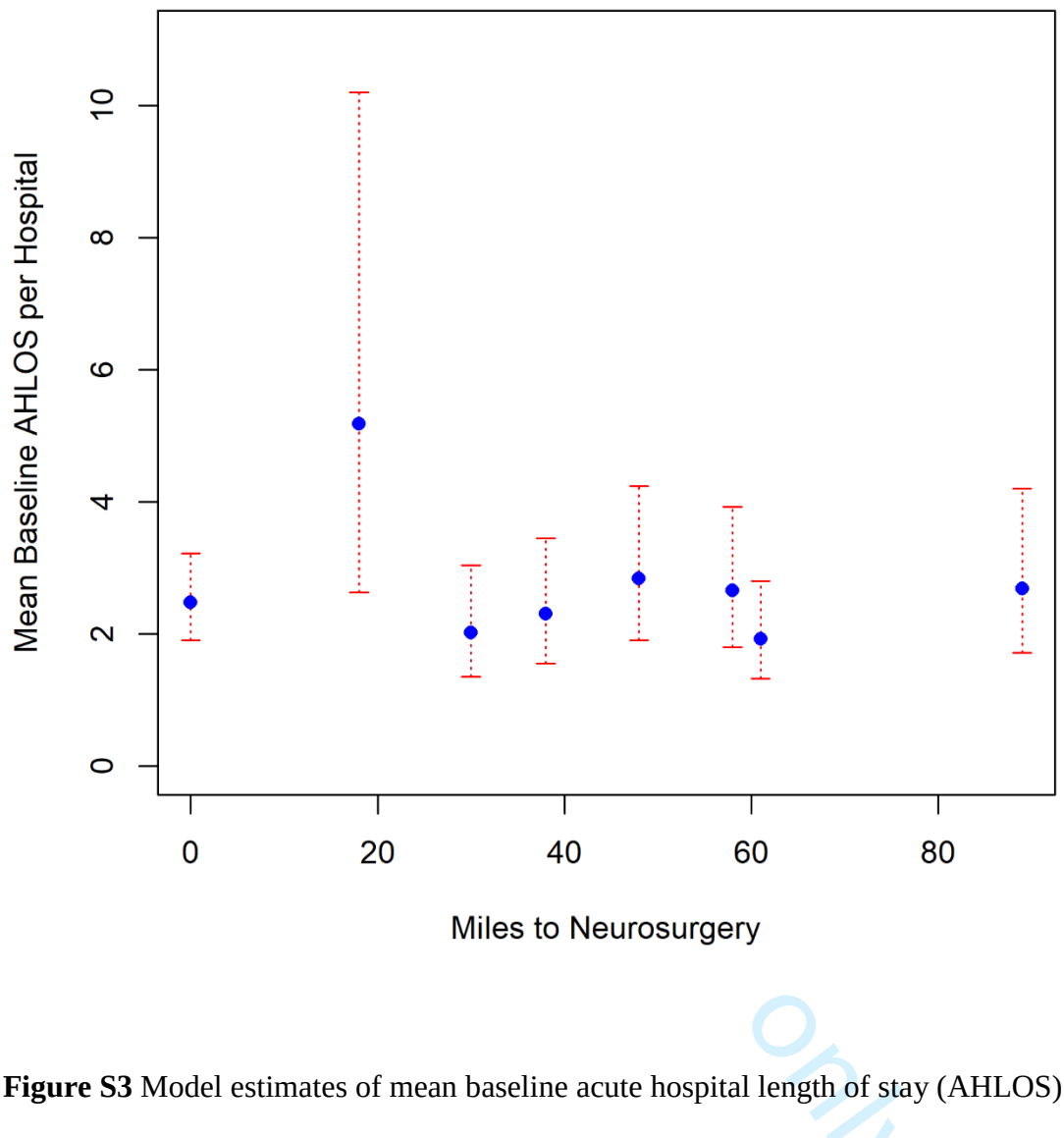


**Figure S3** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and distance to neurosurgical facility with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

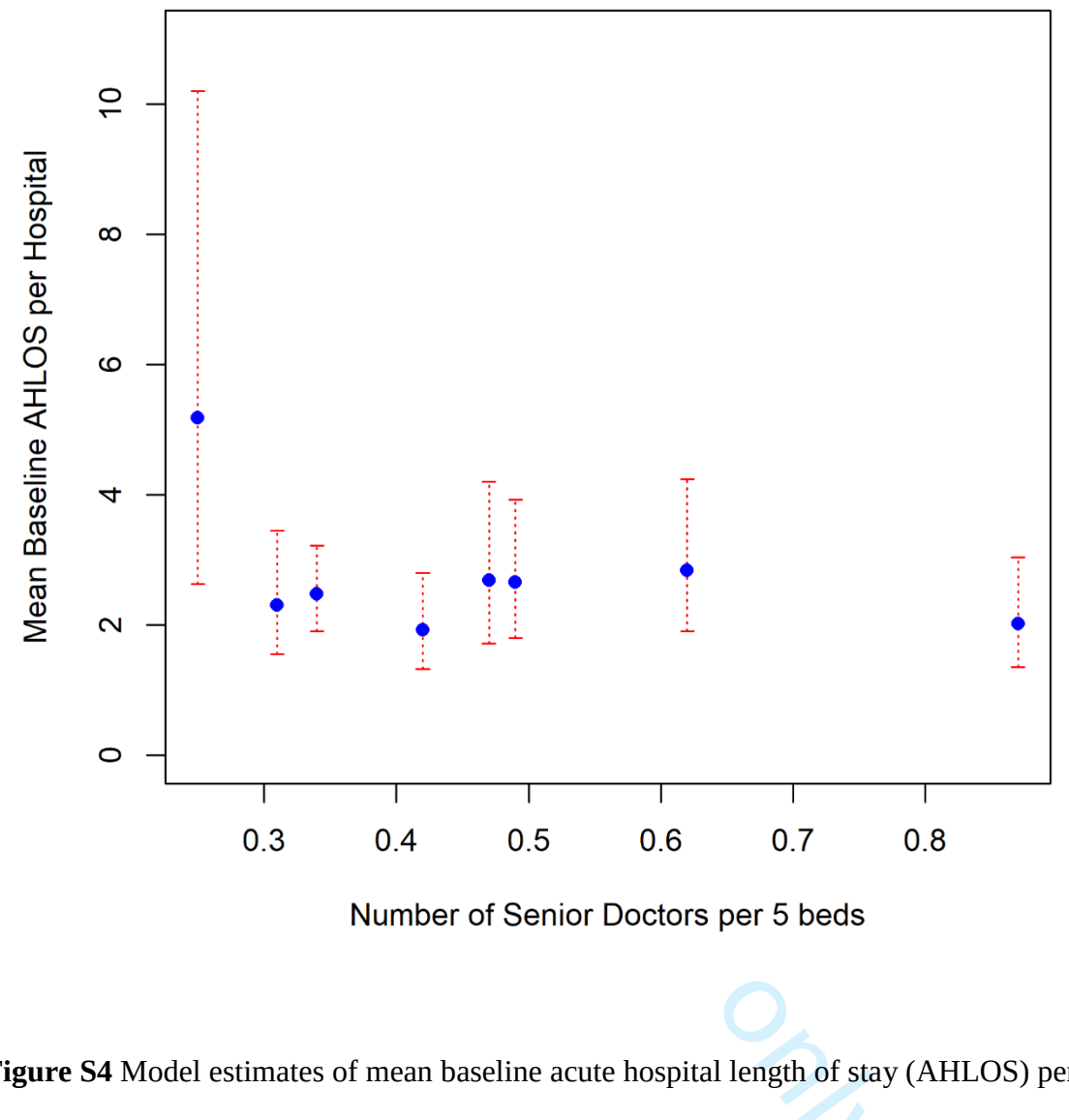


**Figure S4** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte senior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

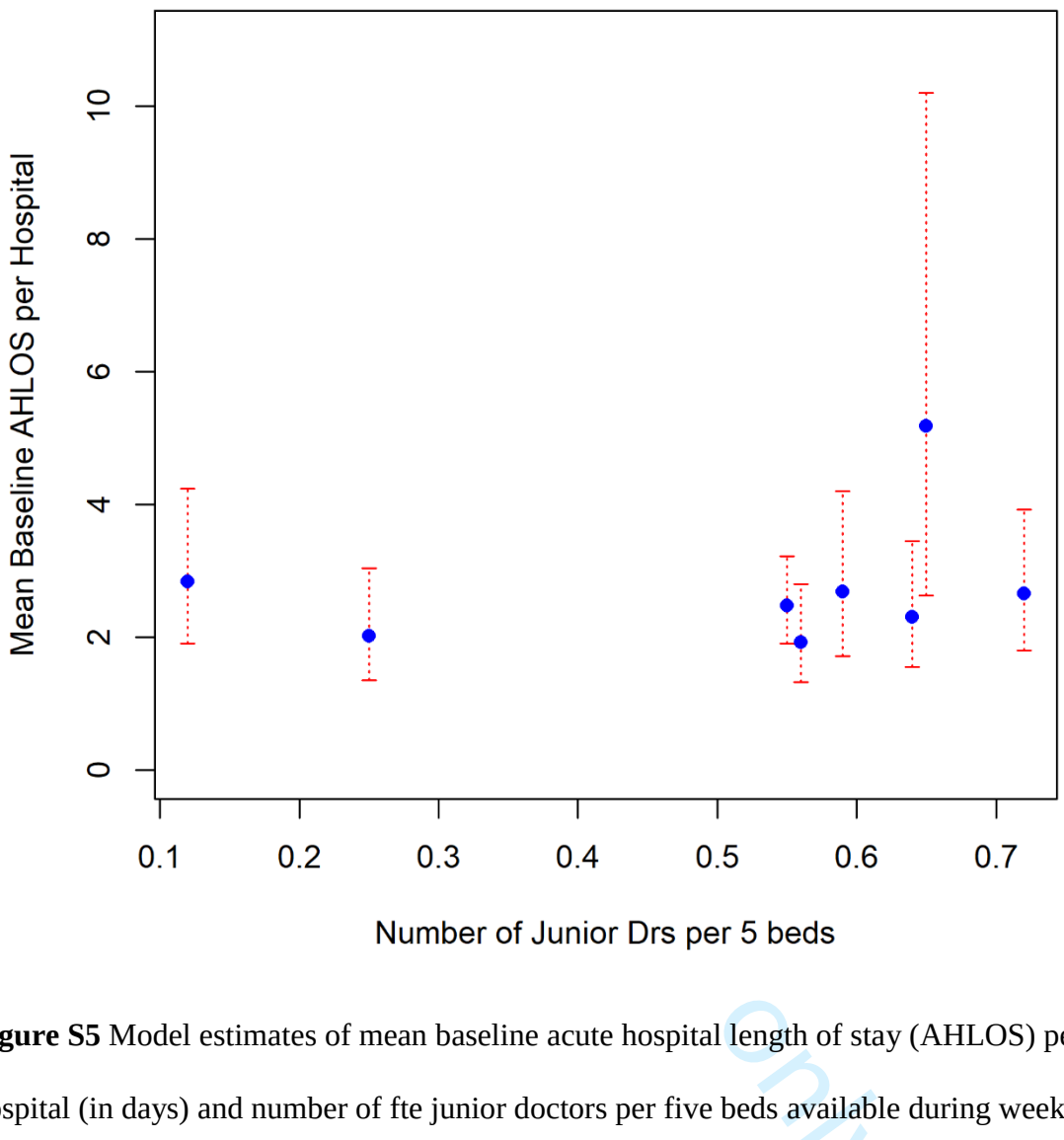


**Figure S5** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte junior doctors per five beds available during weekdays with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

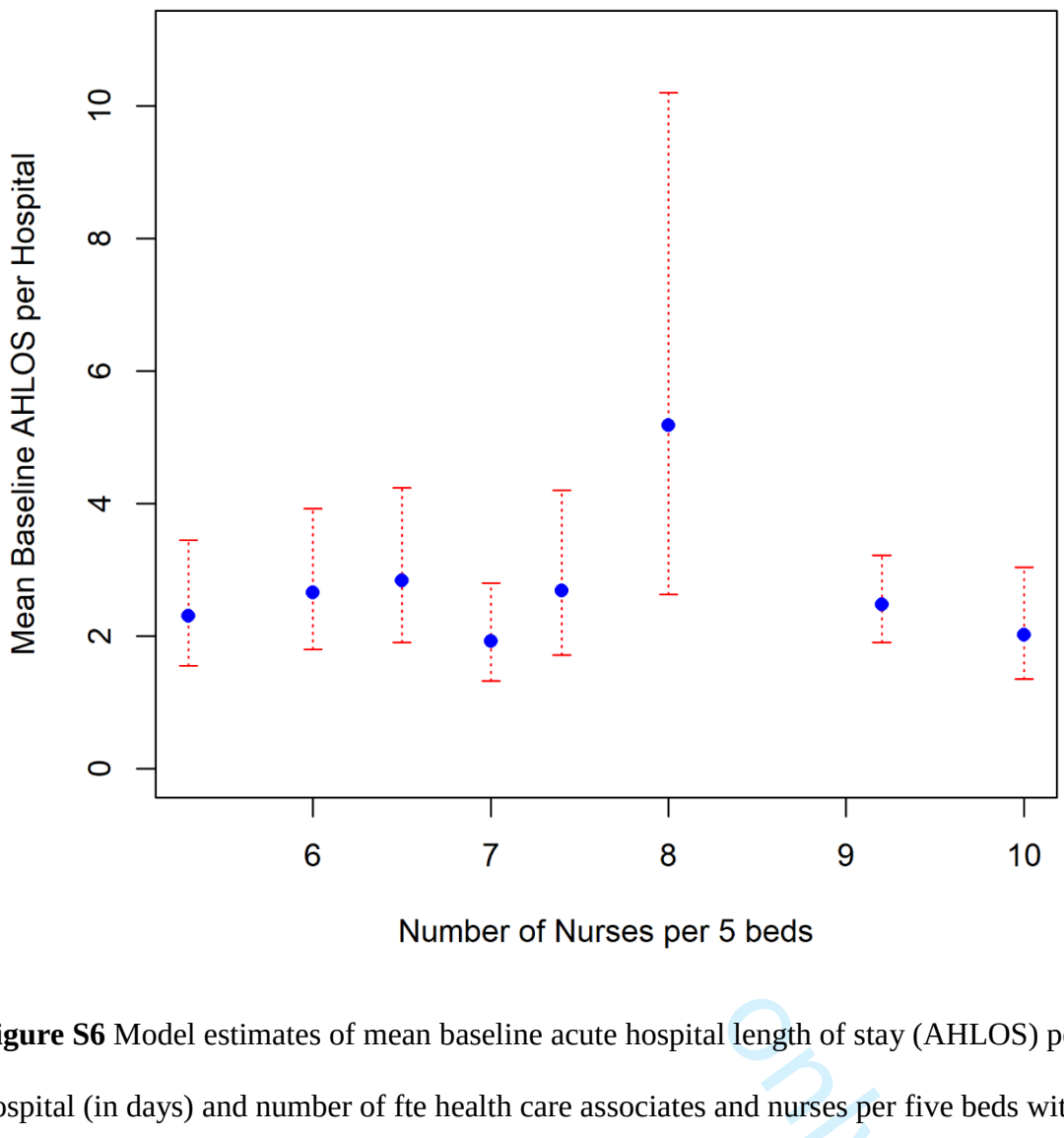


**Figure S6** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte health care associates and nurses per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

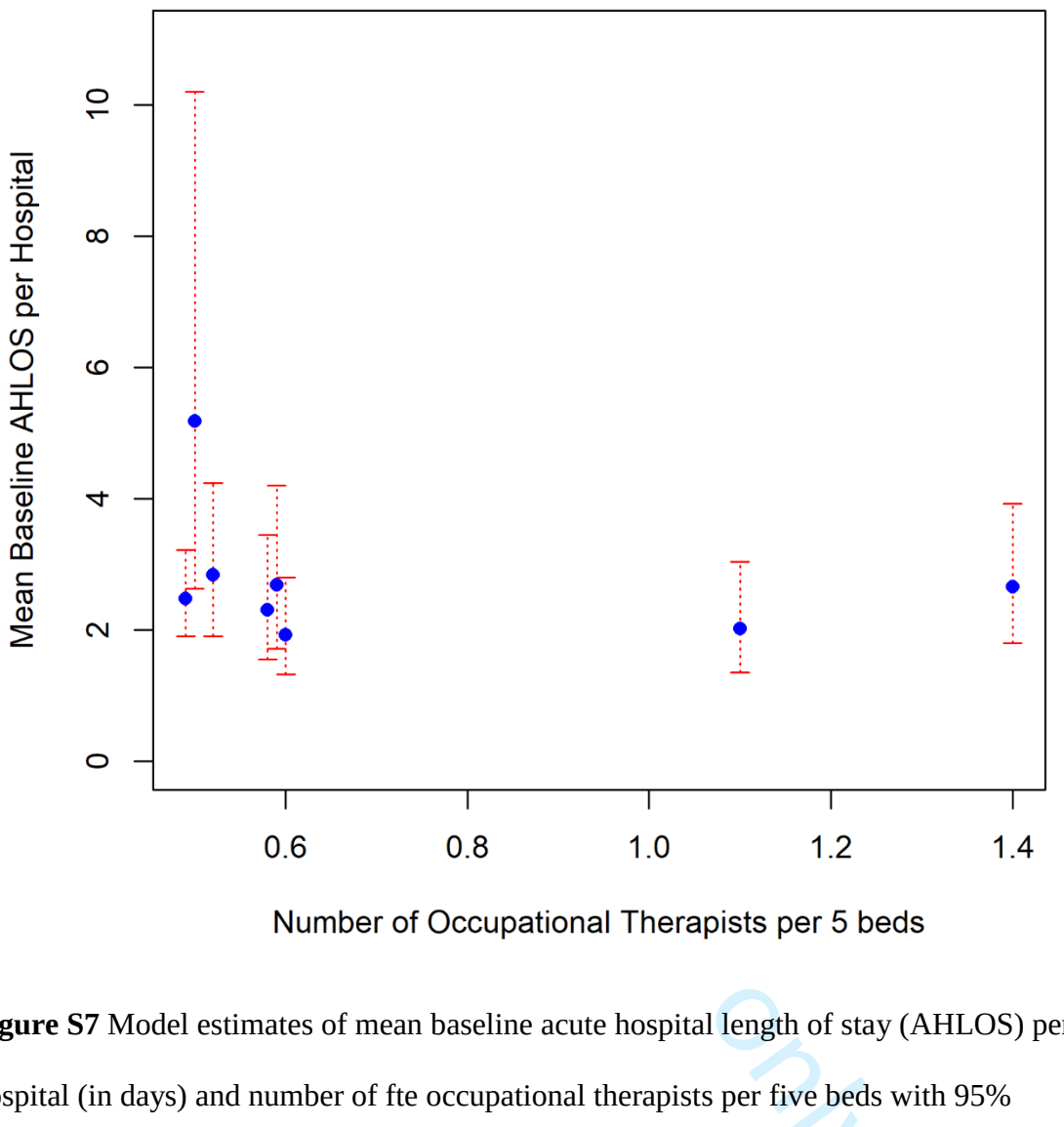


**Figure S7** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte occupational therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

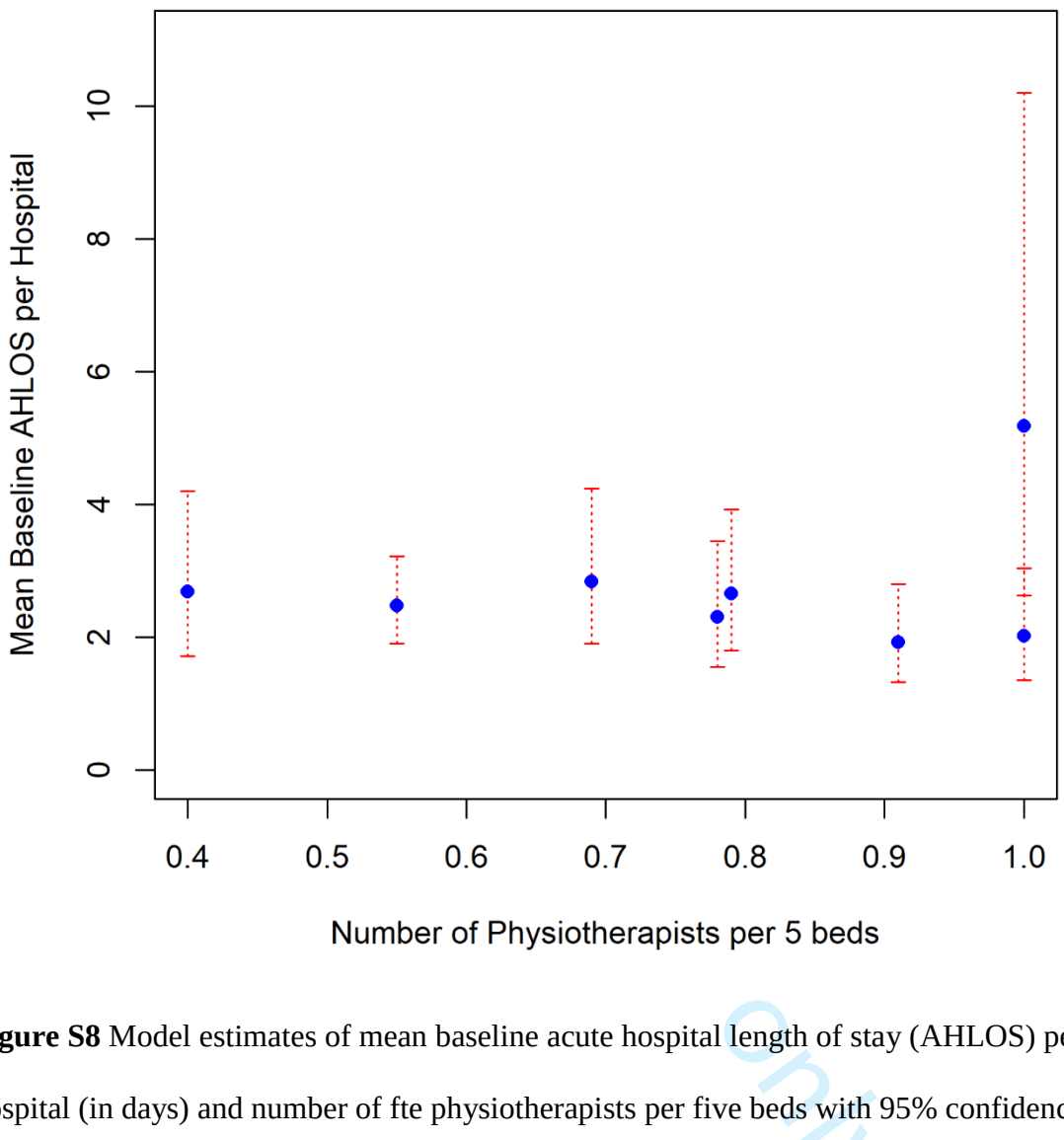


**Figure S8** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte physiotherapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

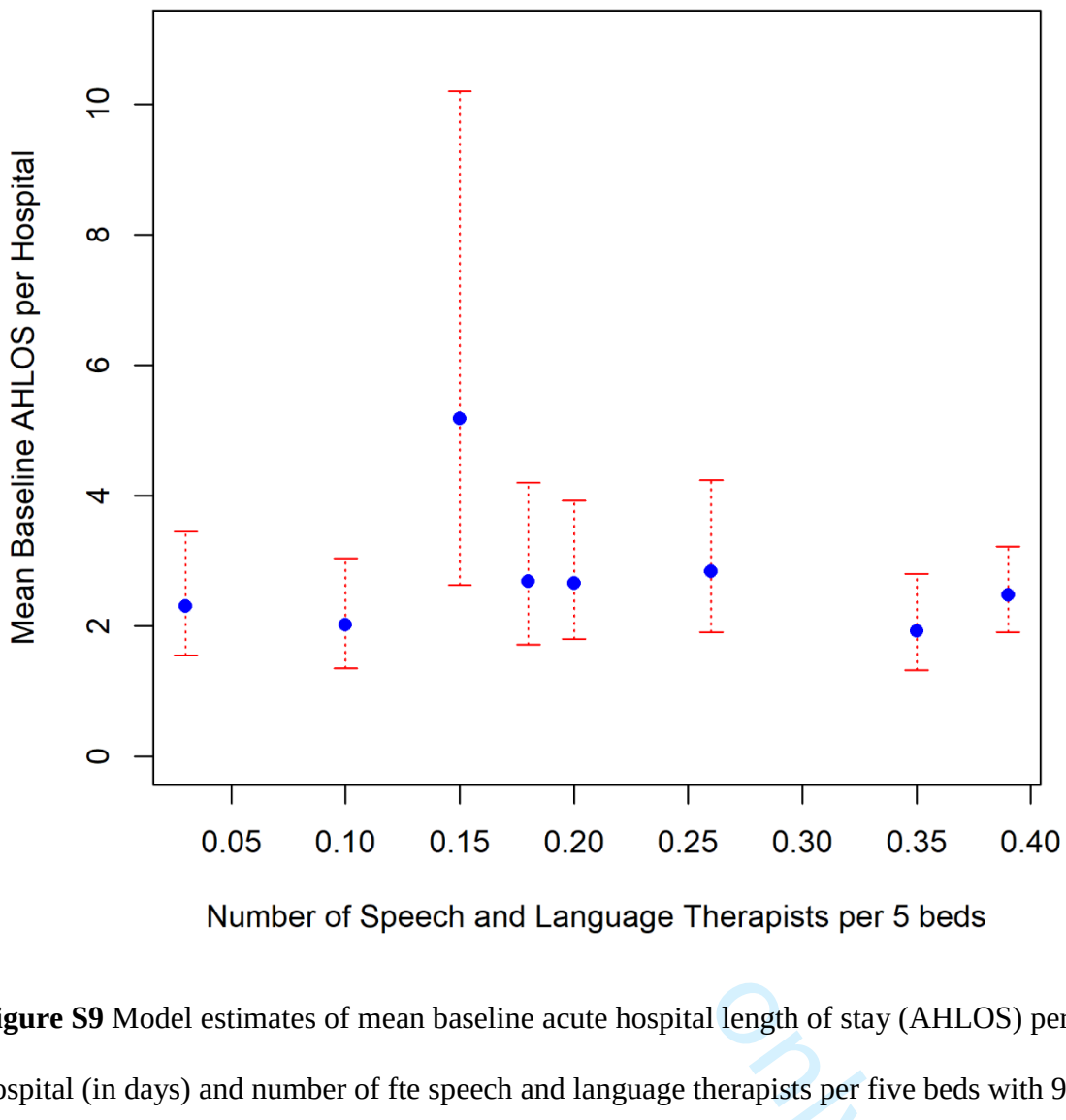


**Figure S9** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of fte speech and language therapists per five beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

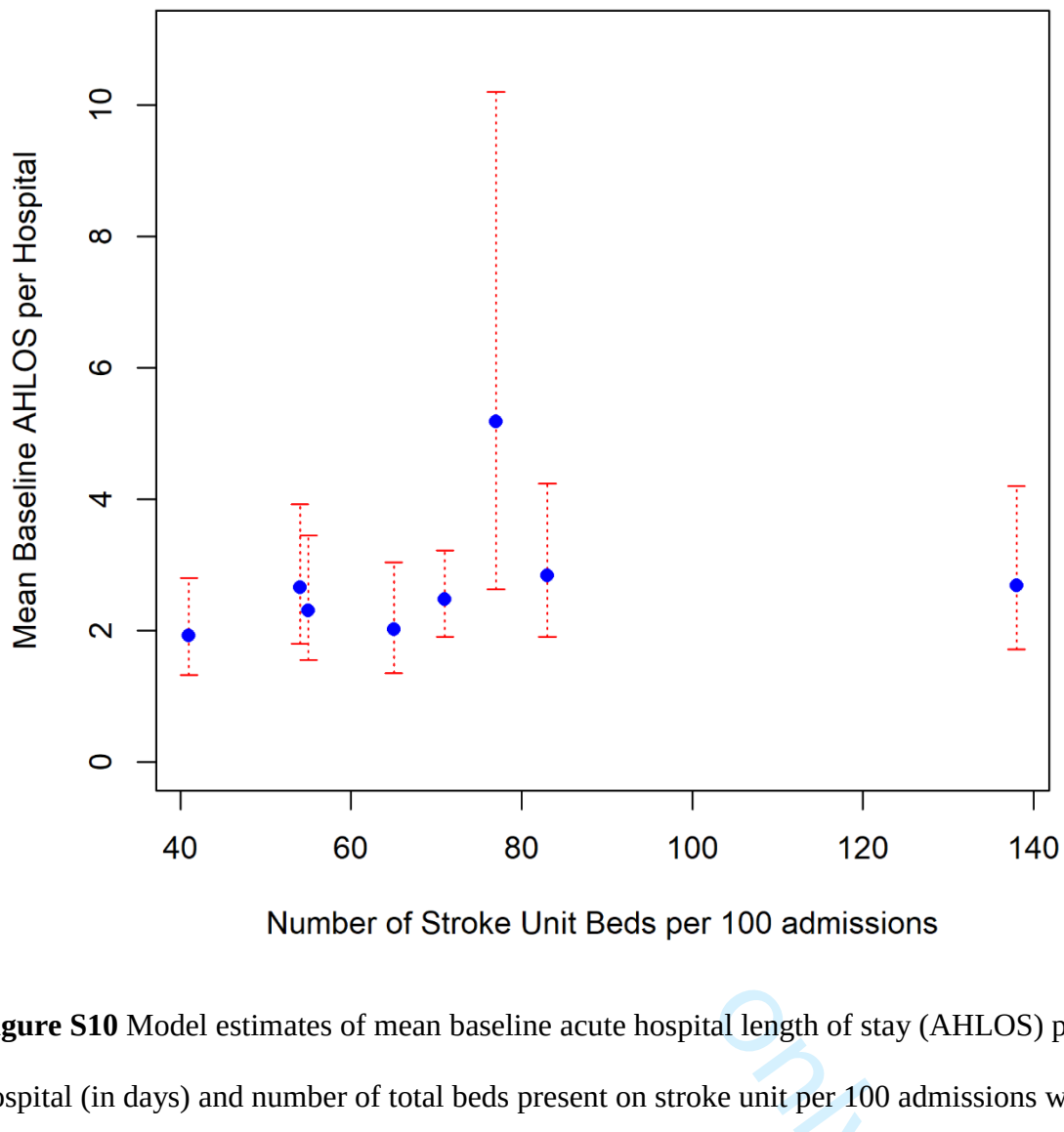


**Figure S10** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of total beds present on stroke unit per 100 admissions with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

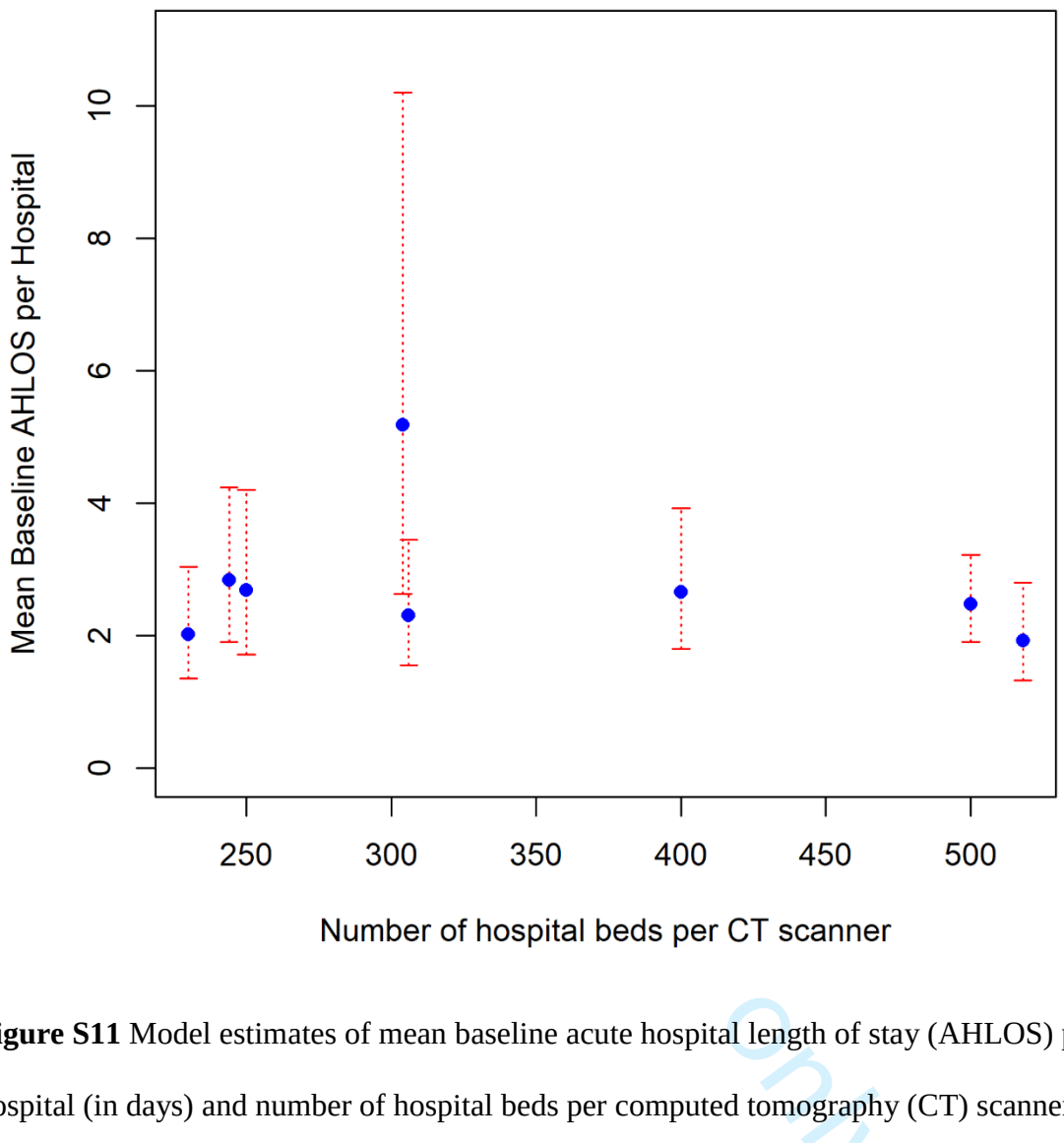


**Figure S11** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of hospital beds per computed tomography (CT) scanner with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

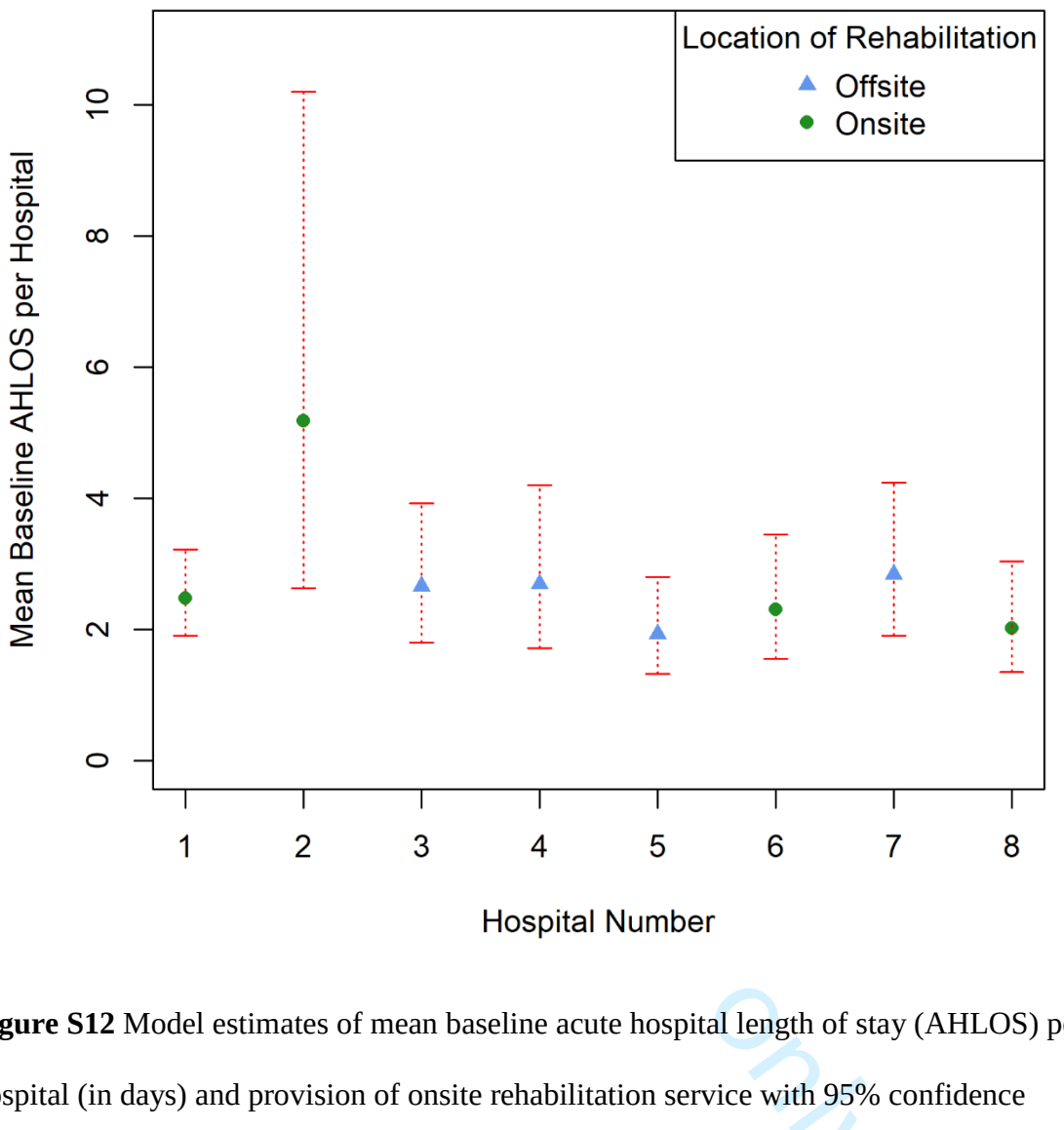


**Figure S12** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and provision of onsite rehabilitation service with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

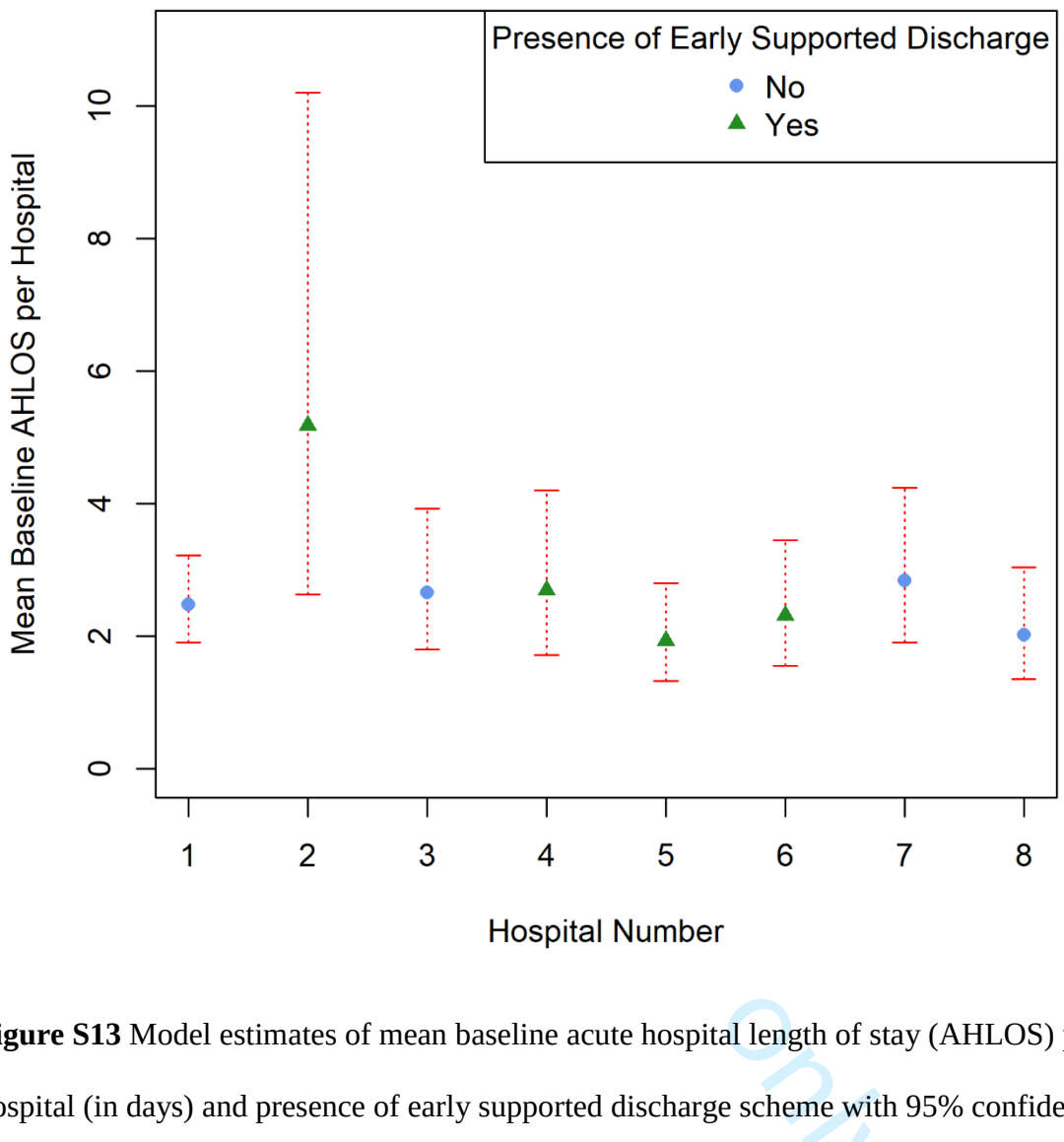


**Figure S13** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and presence of early supported discharge scheme with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

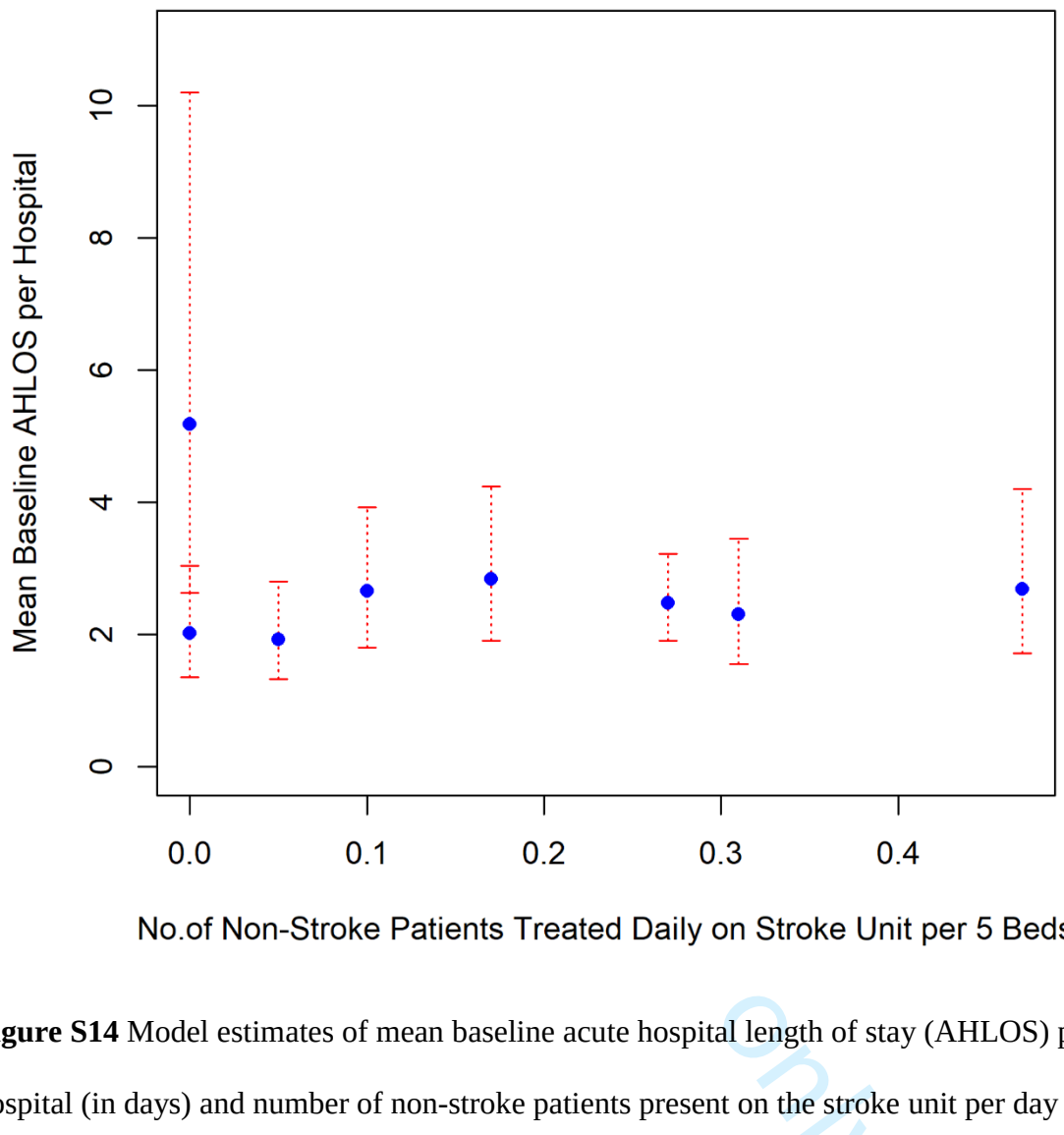


**Figure S14** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and number of non-stroke patients present on the stroke unit per day per five stroke unit beds with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

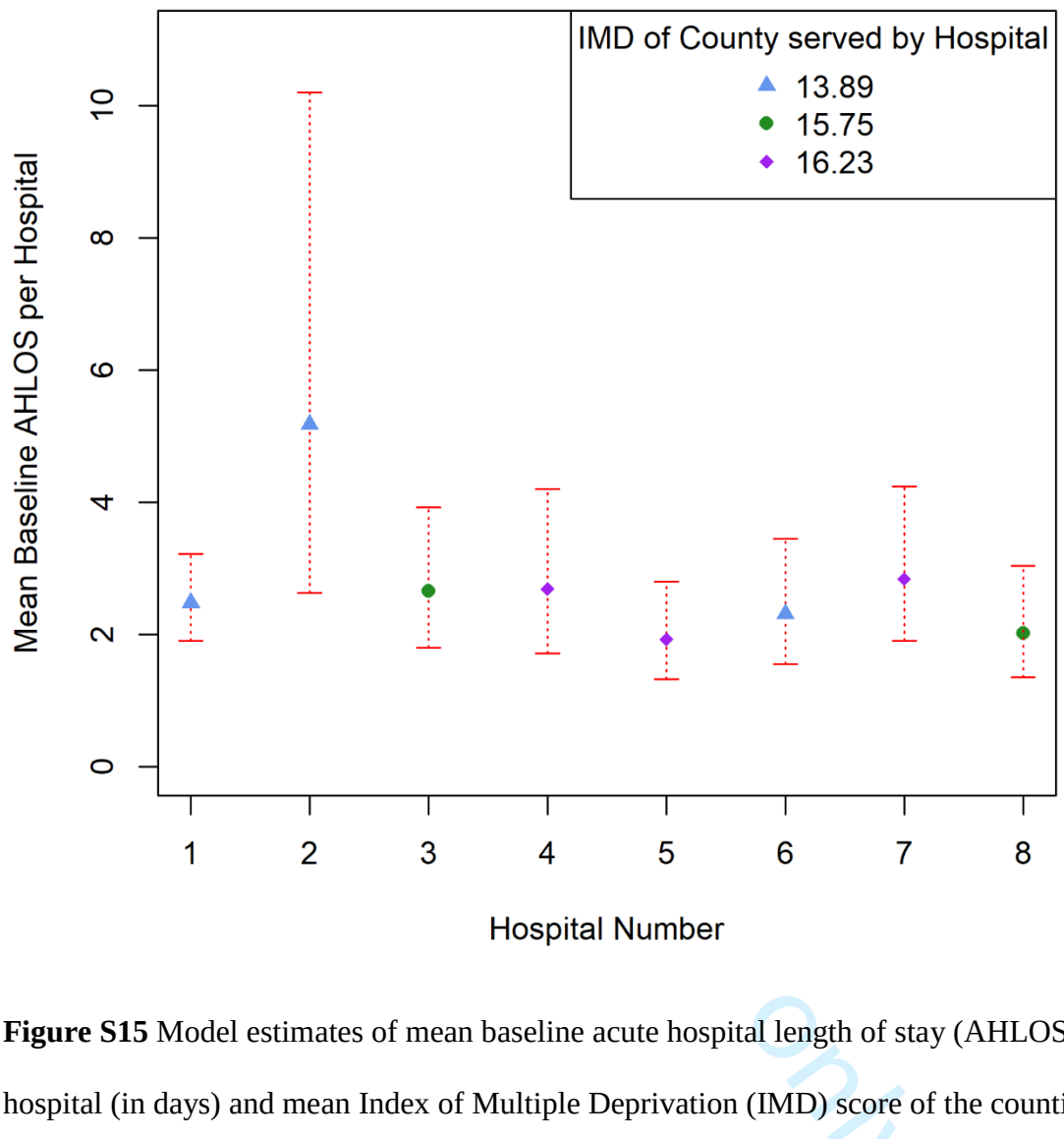


**Figure S15** Model estimates of mean baseline acute hospital length of stay (AHLOS) per hospital (in days) and mean Index of Multiple Deprivation (IMD) score of the counties in which the hospital serves with 95% confidence intervals. Multiple regression model was adjusted for patient covariates that had a p-value<0.3 in univariable analysis.

**STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies***

| Section/Topic | Item # | Recommendation | Reported on page # |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 & 2 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2-3 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 6 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 7 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 7-8 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 7 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 8-10 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 8 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 10-12 |
| Study size | 10 | Explain how the study size was arrived at | 7 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 8-10 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 11 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | NA |
| | | (*c*) Explain how missing data were addressed | 12 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | NA |
| | | (*e*) Describe any sensitivity analyses | 11-12 |
| **Results** | | | |

| | | | |
|---|---|---|---|
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 14 |
| | | (b) Give reasons for non-participation at each stage | 14 |
| | | (c) Consider use of a flow diagram | Fig 1 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 14 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 14 &15 |
| | | (c) Summarise follow-up time (eg, average and total amount) | NA |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | 16 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 19-21 (and Table S4) |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | NA |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 22 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 23 |
| **Limitations** | | | |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 23-27 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 27 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 28 |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.