Implementing the NHS England Long Term Plan for stroke: how should reperfusion services be configured? A modelling study

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Abstract

Objectives: To guide policy when planning reperfusion thrombolysis (IVT) and thrombectomy (MT) services for acute stroke in England, focussing on the choice between 'mothership' (direct conveyance to an MT centre) and 'drip-and-ship' (secondary transfer for MT after local IVT) provision and the impact of bypassing local acute stroke centres.

Methods: Computer modelling was used to estimate the likely outcomes from reperfusion therapies, along with admission numbers to units, based on expected times to IVT and MT.

Results: Without pre-hospital selection for LAO, 94% of the population of England live in areas where the greatest clinical benefit accrues from direct conveyance to an IVT/MT centre. If this model was followed then net benefit from reperfusion is predicted to be increased from 31 to 34 additional disability-free outcomes / 1,000 admissions. However, this policy produces unsustainable admission numbers at these centres, and depletes all but 19 IVT-only units of all stroke admissions. Implementing a maximum permitted additional travel time to bypass an IVT-only unit, or using a pre-hospital test for LAO, both increase net benefit over the current drip-and-ship model, but produce a similar destabilising effect on acute systems of care. Use of IVT-only units manage admission numbers to IVT/MT centres.

Conclusions: The mothership model reduces time to MT at the cost of increased time to IVT, but the benefit of faster MT is predicted to lead to a modest improvement in overall outcomes. Providing a sustainable national system of acute stroke care requires a hybrid of mothership and drip-and-ship provision.

Introduction

In the UK, about 95,000 people are hospitalised each year with acute stroke [1,2], and over half of these people are left with long-term disability at great cost to individuals and society [3]. Disability and institutionalisation after ischaemic stroke are significantly reduced by reperfusion treatments – intravenous thrombolysis (IVT) [4] and mechanical thrombectomy (MT) [5]. IVT is a treatment that may be considered for all potentially disabling ischaemic strokes (which are about 88% of all strokes [6]) presenting in a treatable time window, whereas MT may be considered for all large artery occlusions (LAO), which are present in about 40% of all acute ischaemic strokes [7].

In 2019-20 in the UK these treatments were given to 11.7% and 1.8% of patients with acute stroke respectively [2]. The 2019 NHS England Long Term Plan [3] set out the ambition that, by 2025, acute stroke units will deliver IVT to about 20% of patients, and MT to about 10% [8]. To achieve such increases in reperfusion, the NHS England Long Term Plan acknowledges the need for the centralisation of hyperacute stroke care into fewer well-equipped and staffed hospitals [9], noting that metropolitan areas that have recently centralised stroke care have achieved improved outcomes [10,11].

Two principal models for the provision of reperfusion are generally considered: the so-called mothership, where regional centres (sometimes referred to as comprehensive stroke centres) provide IVT and MT for all eligible suspected stroke patients, with ambulances bypassing local acute services; and drip-and-ship, where IVT is provided at smaller local units (sometimes referred to as acute stroke centres), followed by secondary transfer of selected patients to regional centres for MT. Currently, drip-and-ship is the predominant and commissioned model of provision in the UK. Reconfiguring hyperacute stroke services to a more centralised mothership model could increase direct access to MT for the eligible minority, but at the expense of increased travel times and delayed IVT for many patients; it could also substantially increase admissions to the regional MT centres, many of whom would be ineligible for reperfusion. Modelling and simulation has been suggested as being particularly useful in planning of stroke care for being able to generalise outside of local clinical studies [12]. We therefore set out to examine the impact of the reperfusion ambitions in the NHS England Long Term Plan for stroke on population disability, and to model the optimal organisation of hyperacute stroke provision necessary to achieve these ambitions in a sustainable way.

Method

Location of thrombolysis and thrombectomy centres

The location of thrombolysis centres was taken as the 107 hyperacute stroke units in England providing thrombolysis in 2019 [2]. Within this number, the location of IVT/MT centres, in our base case model, was taken as the 24 neuroscience centres in England which are either providing or planning to provide MT [2].

Admission numbers and travel times for patients

Patients are located to one of 32,833 Lower Super Output Areas (LSOA) in England. Admissions for stroke per LSOA for three years 2015-2017 were obtained from NHS Hospital Episodes Statistics, including 242,874 patients coded with an emergency admission of ischaemic or haemorrhagic stroke (primary diagnosis ICD-10 I61, I63, I64). When predicting the number of MT

procedures, we have assumed that the proportion of confirmed stroke patients eligible for MT in the UK is 10%, as previously estimated [13].

Travel times were estimated from all LSOA to all hospitals using Microsoft MapPoint. In a ‘drip and ship’ model, where an inter-hospital transfer may be required for MT, we assumed a net delay in MT of 60 minutes + inter-hospital transfer time (obtained from MapPoint).

Clinical outcome

Clinical outcome from reperfusion is quantified in terms of a disability-free outcome three months after stroke (a modified Rankin Scale score of 0-1/6 describes either no or only minor non-disabling symptoms [14]). We have published the detailed method and code used to estimate outcomes [15]. This method is a development of the method of Holodinsky *et al.* [16], and incorporates the known decay of effectiveness of IVT [4] and MT [17] over time.

For those patients with the prospect of treatment we assume it takes 60 minutes from stroke onset to the ambulance leaving the scene. Time to IVT is therefore 60 minutes + ambulance travel time + door-to-needle time (D2N). D2N times for IVT in the model are set to a standardised 40 minutes across all hospitals. For patients who attend an IVT/MT centre as their first admitting hospital, time to MT is given by 60 minutes + ambulance travel time + door-to-puncture time (D2P), where D2P for MT in the model are set to a standardised 90 minutes across all hospitals.

If a patient first attends a unit which does not provide MT, the time to MT incurs a further net delay and added inter-hospital travel time. The net delay used may be shorter than the actual door-in to door-out time at the first admitting hospital, as some process steps have already been completed on arrival at the MT centre. Previously, in a large clinical trial it was shown that patients receiving MT after transfer were treated 110 minutes later than patients admitted directly, 35 minutes of which was attributable to inter-hospital travel time, suggesting a net delay of 75 minutes + travel time [18]. In our modelling we have anticipated some improvement over these historical results and have assumed a 60 minute net delay in addition to the inter-hospital transfer travel time.

Pre-hospital selection

In recent years several methods for ambulance paramedics to select patients with LAO as potential candidates for MT have been developed [19]. We have used the performance of one of the most widely studied, the RACE pre-hospital diagnostic for LAO [20], to assess the potential impact of selection of patients most likely to benefit from direct transport to an IVT/MT centre, bypassing any nearer IVT-only centre.

Varying number and location of thrombectomy centres

For selecting locations of IVT/MT centres (in addition to the current 24 neuroscience centres) we have used a genetic algorithm as previously described [21]. The algorithm optimises choice of stroke units based on maximising access to stroke units and on achieving the minimum guideline admissions to as many hospitals as possible, while also keeping the number of admissions to the largest unit to as low as possible. National guidelines recommend a minimum number of admissions to an acute stroke unit, providing thrombolysis, of 600 patients per year [22], coupled to the recommendation that travel time to hyperacute stroke care should be ideally 30 minutes or less, and no more than 60 minutes [23]. A further competing priority is the minimum number of MT procedures to be performed by any given unit to maintain institutional expertise. In order to

maintain the procedural skills of interventional teams and yet have sufficient specialists to staff a rota, we have used a minimum threshold of 150 MT procedures per year for an IVT/MT centre [24].

Results

Benefit of IVT and MT – Drip and ship

We estimated net clinical benefit of a drip-and-ship model of care, where all patients are assumed to travel to their closest acute stroke unit (providing at least IVT) first, and travel onwards to their nearest IVT/MT centre if necessary. If current IVT rates (which range from 4 to 22% [6]) are used then the clinical benefit without and with 24/7 MT at 24 current neuroscience centres would be 10.9 and 18.0 additional disability-free outcomes / 1,000 admissions. If a uniform 20% IVT rate was achieved then clinical benefit without and with 24/7 MT at 24 neuroscience centres would be 18.9 and 31.1 additional disability-free outcomes / 1,000 admissions. Figure 1 shows the geographical variation in clinical benefit with these scenarios. First hospital admissions in this model range from 259 to 1,964. If patients attend their closest unit first, 27% directly attend an IVT/MT centre first.

The rest of the analysis presented assumes uniform 20% IVT and 10% MT rates.

Benefit of IVT and MT – Mothership

If all patients travelled to their nearest IVT/MT centres and bypassed a more local IVT-only unit, the delay in IVT and the effect on clinical outcome is shown in figure 2. The net clinical benefit would be an additional 33.5 disability-free outcomes / 1,000 admissions. The mothership model therefore gives a modest net improvement in outcome over drip-and-ship; though importantly individual regions may have a poorer or better predicted outcome with a mothership model (ranging from a reduction of 6.0, to an increase of 13.8 additional disability-free outcomes / 1,000 admissions). First hospital admissions in this model range from 1,228 to 6,183, with 22 out of 24 IVT/MT centres receiving more than 2,000 patients per year.

Destination based on most likely good outcome

Instead of all patients being conveyed to their closest acute stroke unit as in the drip-and-ship model, or all patients travelling directly to their nearest IVT/MT centre as in the mothership model, it is possible to make a patient-specific decision by using a prediction, in the absence of any diagnostic test for LAO, as to whether disability outcome is improved by bypassing a more local IVT-only unit and travelling further to directly attend an IVT/MT centre. Overall clinical benefit is predicted to increase to 33.6 additional disability-free outcomes / 1,000 admissions, a marginal improvement over an exclusive mothership model. Figure 3 shows the effect that this has on the catchment area of IVT-only units and IVT/MT centres. Compared to the drip-and-ship model, the travel time to the first admitting stroke unit is, on average, increased from 19 to 34 minutes, but travel time to an IVT/MT centre is reduced from 94 to 42 minutes. Such a strategy causes significant disruption to admission numbers. Compared with the drip-and-ship model, the proportion of patients directly attending an IVT/MT centre rises from 27% to 94%, and average first admissions to an IVT/MT centre rises from 918 to 3,187, with the largest centre increasing from 1,964 to 5,578. Average first admissions to IVT-only units fall from 572 to 43, with 64 out of 83 IVT-only units depleted of all their stroke admissions.

Destination based on maximum additional travel time

So far we have examined the effect of bypassing a nearer IVT-only centre in order to directly attend an IVT/MT centre for all patients (mothership model), and just for those for whom it is expected that bypass will confer a better clinical outcome. Alternatively we can assess the impact of allowing a maximum additional travel time in order for a patient to travel directly to an IVT/MT centre. In previous studies we have used the concept of *ambulance bias*, defined as the additional time that an ambulance crew is willing to travel in order to convey a patient directly to an IVT/MT centre. As ambulance bias increases, a number of effects are observed (figure 4): average time to IVT is increased, average time to MT is reduced, net clinical outcome is improved, admissions to IVT-only units fall, and admissions to IVT/MT centres increase. For example, if ambulance crews are willing to travel 15 minutes further in order to directly attend an IVT/MT centre, the net benefit of reperfusion treatment increases from 31.1 to 32.3 additional good outcomes per 1,000 admissions. However, the proportion of all stroke patients admitted directly to an IVT/MT centre would increase from 27% to 52%. The number of units with fewer than 300 first admissions per year increases from three to 18, while the number of units with fewer than 600 first admissions per year increases from 39 to 64 (out of 83 IVT-only units in total). At the same time, the number of units with more than 2,000 first admissions increase from zero to eight.

Pre-hospital selection for large artery occlusion

Applying the RACE pre-hospital diagnostic test for LVO, with all 'RACE-positive' patients taken directly to an IVT/MT centre, increases the number of additional disability-free outcomes from 31.1 to 33.4 per 1,000 admissions. However, the proportion of all stroke patients admitted directly to an IVT/MT centre would increase from 27% to 62%. The number of units with fewer than 300 first admissions per year increases from three to 30, while the number of units with fewer than 600 first admissions per year increases from 39 to 74 (out of 83 IVT-only units in total). At the same time, the number of units with more than 2,000 admissions increases from zero to eleven.

Increasing the number of thrombectomy units

Our genetic algorithm identified the optimal locations of additional IVT/MT centres, in order to maximise access to MT while also limiting maximum admission numbers to all units (figure 5). As the number of units providing both IVT and MT increases, time to MT reduces and the net clinical benefit of reperfusion treatment increases from 31.1 to 36.2 additional good outcomes per 1,000 admissions with all 107 units providing both IVT and MT. However, beyond about 30 IVT/MT centres, the capacity to maintain 150 procedures per year at each centre markedly reduces. If all IVT/MT centres are required to perform at least 150 MT procedures per year the maximum clinical benefit, achieved with 29 IVT/MT centres, is 31.5 additional disability-free outcomes per 1,000 admissions.

Discussion

Our modelling study of acute stroke provision in England, and our comparative analysis of the differing configurations of IVT-only units and IVT/MT centres, has produced several key findings of direct relevance to the implementation of reperfusion treatment to maximise the benefits for the population from this highly effective but disruptive innovation. First, we have shown that the population benefit from reperfusion is maximised when the proportion of units that are MT-capable is highest. Put another way, the closer the ultimate national configuration of acute stroke units is to

a full mothership model, the greater the benefits achievable from reperfusion as a whole. This can be achieved either by reducing the number of IVT-only units, or by increasing the number of IVT/MT centres, or more pragmatically by undertaking a mixture of both. Other considerations will determine which of these is the most deliverable – for the additional IVT/MT centres, significant barriers to the prompt development of new units are capital cost, workforce and time taken. We have also shown that a full mothership model, or any system heavily biased towards a mothership model, produces unsustainably large admission numbers to a relatively small number of IVT/MT centres. The conclusion from these observations is that the principal purpose of retaining IVT-only units, at least from the point of view of reperfusion, is not so much to confer additional benefit from the earlier, more local provision of IVT, but instead to mitigate unsustainable pressures on the IVT/MT centres, some of which would otherwise be several times larger than the current largest stroke unit in England. This illustrates the balance that has to be struck between the benefits to the individual from earlier reperfusion and the dis-benefits to the population from destabilising the acute stroke care system as a whole.

Second, although we have identified that a hybrid model is essential to create a sustainable system, we have also identified some important factors that would destabilise any hybrid system. Principal among these is the natural inclination for ambulance paramedics to travel a little further in order to improve the chances of reperfusion treatment for the individual patient under their care, which we have called ‘ambulance bias’. This phenomenon is well recognised anecdotally, with some IVT/MT centres reporting ambulances travelling up to 30 minutes further to deliver their patient to a MT-capable site (C Roffe, personal communication). This has the net effect of converting any hybrid system towards a de facto mothership model, with a pronounced increase in the proportion of patients conveyed directly to an IVT/MT centre, and a corresponding large reduction in admissions to IVT-only units, effectively negating the mitigating effect of having IVT-only units at all. These considerations of institutional viability (at either end of the scale for stroke admissions) have not featured in the reasoning behind other configuration analyses based on additional transport time [25]. In its most extreme form, a model based on ambulances taking the patient directly to the site that offers the patient the best chance of a good outcome would result in 94% of patients being conveyed directly to IVT/MT centres, and deplete all but 19 IVT-only units in England of any admissions at all.

Third, we have highlighted the limitations of current pre-hospital diagnostics in appropriately selecting patients for conveyance directly to an IVT/MT centre – as in the example of the low specificity of the RACE pre-hospital clinical assessment screening test for LAO [20]. This low specificity has a predictably similar effect to ambulance bias in effectively converting a hybrid model towards a mothership system. The RACE test has been proposed as a means of concentrating the resources of IVT/MT centres on those most likely to benefit, based on pilot data in Catalonia, an area with a population of 7.5M served by 5 MT-capable sites [26]. However, recent unpublished data from the follow-up randomised trial in Catalonia of the use of the RACE test in determining the initial destination of an ambulance conveying a patient with suspected stroke has not shown any disability benefit from such a policy [25]. This finding should therefore prompt caution in the interpretation of studies of pre-hospital diagnostics and in how they might be applied to the NHS in England, with its much lower proportion of patients (27%) for whom an IVT/MT centre is their nearest acute stroke unit. It is also noteworthy that most diagnostic tests being developed are for LAO, rather than suitability for MT, and so some further selection is required to filter out those

LAO patients who would benefit from MT. For the time being at least, until other pre-hospital diagnostic tests with superior specificity are developed (whether they be clinical assessment scales, biomarkers or teleconsultation [27]), prehospital selection does not offer the prospect of improving the population benefit from reperfusion without jeopardising the stability of a hybrid system. This is a key area for further service development and research.

Our study does have some limitations. We have based our model on assumptions regarding a reasonably achievable level of both IVT and MT, at 20% and 10% of total admitted stroke cases respectively [8]. For MT, the main limitations include initial diagnosis of LAO, angiographic theatre and MT centre capacity, and workforce. For IVT, these levels of treatment have been achieved in many regions and countries elsewhere in Europe [28,29] but there is persisting doubt about whether such levels can be consistently achieved in the UK, and, despite many quality improvement initiatives, the proportion of total patients with a stroke receiving IVT treatment has remained unchanged at 11-12% over the last 7 years [2]. Not only this, but a five-fold variation between sites in IVT rates persists, an observation that is only partly explained by casemix. The eradication of such a wide degree of variation would be a substantial challenge in any healthcare system and the evidence base for methods for doing so on such a scale is not strong. Nonetheless, any reduction in variation, coupled with any increase in the overall rate of both IVT and MT, would confer a very substantial population benefit even if it falls short of the ambitions of the NHS England Long Term Plan which are used as a basis for the modelling in this study. Furthermore, the observations in our study regarding the relative effects of the different policies are independent of the overall level of reperfusion treatment applied. The twin objectives of increasing reperfusion use and reducing geographical variation both contribute to the overarching aim of significantly increasing the number of patients left disability-free from acute stroke treatments.

The second limitation is that the model has been limited both to the acute aspect of the stroke pathway and to the measurable benefits from reperfusion therapy only. We have not had data on which to base any assumptions about the unintended consequences of the sort of service transformation modelled in this study. In particular, in a mothership or predominantly mothership model, such a policy inevitably involves large numbers of patients being conveyed to an IVT/MT centre for whom MT is either not indicated (e.g. lacunar stroke, cerebral haemorrhage) or inappropriate, for example because of significant co-morbidities. Such patients stand to benefit not at all from being redirected to an IVT/MT centre rather than their local IVT-only unit, and could quite plausibly suffer harm, if only through being displaced from their local health and social services. Relatively small disbenefits, although unmeasured but applied to the large proportion of stroke patients for whom reperfusion is not a viable treatment option (80%), could quite readily negate much of the more easily recognised benefits from improved access to reperfusion for the minority of patients. Bearing in mind that some of the differences in population benefit between respective configurations can be numerically quite small, these disbenefits could be decisive, but substantiating them has not been feasible in this study.

A further limitation is the extent to which we have been able to model stroke mimic activity. The meaning of a 'stroke mimic' differs according to where the patient is along the pathway of care – it may reflect FAST-positive patients conveyed to hospital by ambulance services on suspicion of stroke, or patients selected in Emergency Departments for admission to a stroke unit [30]. Published data for this latter category would suggest a rule of up to 'one third again' for mimics [31,32], which would substantially inflate the figures we have used for admissions to all sites in our

modelling. However defined, stroke mimics would consistently increase conveyances and admissions across the board, but they would not affect the relative differences between the various policies if uniformly applied. Thus, they need to be considered when planning for overall levels of emergency activity for ambulance services and acute sites, but they do not influence the discrimination between the various scenarios we have considered.

Another limiting factor to consider is that we have modelled and presented clinical benefit purely in terms of disability-free survival, rather than reductions in other disability states. For instance, converting a patient from severe disability (mRS 4-5) to mild disability (mRS 2) is a significant gain and even reduction from severe to moderate disability (mRS 3) is advantageous to individuals and society. We have defined mRS 0-1 rather than 0-2 as a good outcome, whereas mRS 0-1 is in reality an excellent outcome; our modelling therefore presents a conservative picture of the population benefit from the widespread application of reperfusion treatments.

Our estimates of the time-dependent benefits of MT are based on the largest completed study of the effectiveness of MT in a national acute stroke system, the Dutch MR CLEAN randomised controlled trial [33]. We used these data, in preference to the HERMES individual patient meta-analysis [34], on the understanding that MR CLEAN most closely represents the implementation of MT within the English NHS. The HERMES meta-analysis included several studies which used imaging-based selection of later-presenting patients, which has the effect of flattening the curve representing the decay of absolute benefit from MT over time [35]. Currently this category of late-presenting patients represents very few patients treated in England, a situation that is likely to prevail for some time. However, as clinical practice develops with late-presenting and other patients [36,37], this is likely to involve more MT-eligible, IVT-ineligible patients, and thus strengthen the case for a predominantly mothership model. The HERMES meta-analysis reported that 87% of patients who received MT had first received IVT [34]. However, national stroke audit data for the last three years shows this proportion to be much lower in real-life UK practice at 54% [2], presumably reflecting the greater use of MT for patients deemed ineligible for IVT who tended to be excluded from the trials. If MT is given to more patients who are ineligible for IVT then the benefit of bypassing an IVT-only unit to be taken directly to an IVT/MT centre will be greater than predicted in our study and further strengthen the case for centralisation.

Conclusions

Our modelling study of the impact of the implementation of 24/7 MT services across England has identified three key components that should influence policy as the NHS seeks to promote the uptake of this highly effective but disruptive innovation in stroke treatment:

- we have provided reliable estimates of the magnitude of the population benefit from the widespread implementation of reperfusion to the extent anticipated in the NHS England Long Term Plan, with the potential to approximately treble the additional benefit in terms of people with stroke surviving free of disability;
- we have demonstrated how closely linked the full implementation of IVT and MT needs to be if the full extent of the population benefit from reperfusion is to be realised, including the eradication of substantial persisting inter-hospital variation in IVT rates;
- we have modelled several key aspects of pre-hospital management which could destabilise a hybrid system of IVT-only units and IVT/MT centres, along with the areas that require further

research to advance our understanding of how systems will perform in real-world implementation.

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Figures

Figure 1: Geographical variation in clinical benefit (additional good outcomes / 1,000 admissions). A) IVT provided at 107 stroke units, with IVT rates for units taken from 2018-19 SSNAP report. B) IVT provided at 107 stroke units, with 20% IVT at all units. C) IVT provided at 107 stroke units, and MT also provided at the 24 neuroscience centres, with IVT rates for units taken from 2018-19 SSNAP report. D) IVT provided at 107 stroke units, and MT also provided at the 24 neuroscience centres, with 20% IVT at all units. Circles show IVT-only units, stars show IVT/MT centres, with 10% patients receiving MT.

Figure 2: The effect of implementing the mothership model, where all patients bypass their more local IVT-only unit (circles) to directly attend one of the 24 IVT/MT centres (stars). Maps show delay in receiving IVT (left panel) and net change in the clinical benefit of reperfusion (right panel).

Figure 3: Catchment areas for either IVT/MT centres (stars) or IVT-only units (circles) if decision on conveyance to first stroke unit is made by either closest unit (left panel) or the destination that gives the highest probability of a good outcome (without any pre-hospital diagnostic; right panel). The model has 24 IVT/MT centres at the current neuroscience centres and 83 IVT-only units at the remaining current acute stroke centres.

Figure 4: The effect of ambulance bias on travel time to IVT and MT (top left panel), clinical outcome (top right panel), admission numbers to IVT-only units (bottom left panel) and admission numbers to combined IVT/MT centres (bottom left panel). Ambulance bias is measured as the additional travel time an ambulance crew will allow to go directly to an IVT/MT centre instead of a closer IVT-only unit. Boxplots show median (mid-way line), interquartile range (box), range (whiskers) for individual units. If a patient first attends an IVT-only unit, time to the IVT/MT centre will include road transfer time and process related delays. The model has 24 IVT/MT centres at the current neuroscience centres and 83 IVT-only units at the remaining current acute stroke centres.

Figure 5: The effect of converting IVT-only units to IVT/MT centres. The charts show effect on travel time to an IVT/MT centre (left panel), the percentage of patients meeting MT admission targets (middle panel), and the clinical benefit of reperfusion (right panel). The base case model has 24 IVT/MT centres at the current neuroscience centres and 83 IVT-only units at the remaining current acute stroke centres.

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Contribution

All authors were involved in the design and planning of the work. MA & KP performed the required coding for the work; all authors reviewed outputs from the work and suggested next steps. All authors have been involved in the writing of the paper.

Ken Stein is the guarantor of the work.

Competing interests

We have read and understood BMJ policy on declaration of interests and declare the following interests:

Prof. White reports grants from Microvention Terumo, grants from Stryker, grants from Codman, grants from Medtronic, grants from Penumbra, personal fees from Microvention Terumo, outside the submitted work.

GFs organisation has received an unrestricted medical education grant from Medtronic to support development of an implementation guide for mechanical thrombectomy. GF has received personal remuneration from Medtronic and Stryker for advisory board and educational meeting lectures.

Ethics approval

As this modelling study uses Hospital Episodes Statistics aggregate patient counts by geographical area, no ethical approval is required.

Transparency

Prof. Martin James affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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Disclaimer

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Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Data sharing

Admissions per lower super output area (LSOA), travel times from all LSOAs to all acute stroke units, and base code used for this model may be found at:
https://github.com/MichaelAllen1966/stroke_unit_location