Uptake and accessibility of surgical robotics in England

Kyle Lam¹ | Jonathan Clarke² | Sanjay Purkayastha¹ | James M. Kinross¹

¹Department of Surgery and Cancer, Imperial College London, London, UK
²Centre for Mathematics of Precision Healthcare, Department of Mathematics, Imperial College London, London, UK

Correspondence
Jonathan Clarke, Centre for Mathematics of Precision Healthcare, Department of Mathematics, Imperial College London, London, UK.
Email: j.clarke@imperial.ac.uk

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Abstract
Background: The distribution, utilisation and accessibility of surgical robotics in England is unknown.

Methods: A nationwide Freedom of Information (FOI) request was sent to all acute National Health Service (NHS) trusts. Accessibility was assessed for 32 843 Lower Super Output Areas in England.

Results: All 149 acute NHS trusts responded to the FOI request. Sixty-one robots are distributed between 48 trusts. The number of robots and robotic procedures has increased annually. Urological procedures comprise 84.2% of robotic procedures. Procedure volume varies between robotic centres ranging from 1 to 683 in 2018. Over 2.4 million people have a travel time of over 1 hour to their nearest robotic centre.

Discussion: National accessibility to robotic services and case volumes are variable and does not represent good value for the NHS. A national robotic surgery registry could improve the quality of robotic surgery and is needed to dynamically assess national provision of this technology.

Keywords
accessibility, distribution, surgical robotics, utility

1 INTRODUCTION

The first DaVinci® robot (Intuitive Surgical Inc) in the United Kingdom was installed in St Mary’s Hospital, London in 2001.¹ Nearly 20 years later, robotic surgery has evolved into a global industry, that continues to grow. Thousand hundred and nineteen Da Vinci robots were sold worldwide in 2019, an increase of over 20% from 2018.²³ Despite the cost of these robots often exceeding £1 million, there is currently no national registry to record the location and utilisation of surgical robots in the National Health Service (NHS) and private providers. This absence impedes precise mapping of the clinical utility of these robots and has led to an over-reliance on commercial data.

Observational data from large retrospective studies have demonstrated the safety and feasibility of robotic surgery across multiple procedures.⁴–⁶ The greater manoeuvrability and enhanced visibility are commonly cited as the advantages of the robotic approach and this is especially highlighted in technically challenging anatomical areas such as the pelvis.⁷ Moreover, increased uptake of robotic surgery may be, in part, attributable to surgeon preference. Ergonomic advantages of the robotic approach have been found to decrease physical workload and mental stress when compared to the laparoscopic approach.⁸⁹ However, this growth has occurred in the absence of compelling evidence from multiple randomised controlled trials, which have to date failed to convincingly show any advantage for robotics over open or laparoscopic approaches.¹⁰–¹³ Part of the
reason for this failure has been the challenge of robustly assessing complex robotic interventions in heterogeneous patient and clinical cohorts, and the rapid evolution of the technology itself. Thus, new methodologies are urgently required for assessing the clinical utility and safety of these systems.

Acquisition of surgical robots has been managed in England by individual trusts with no centralised strategy defined. We hypothesise that this has led to unequal distribution of robots nationally. As a result, an individual’s access to surgical robotics will vary according to where they live potentially leading to a ‘postcode lottery’. Decentralised adoption of an expensive resource may produce inequitable accessibility which is contrary to the NHS constitution.16

The primary aim of this study is to examine the adoption of surgical robotics through a nationwide Freedom of Information (FOI) request to all acute NHS trusts in England.

The secondary aims are to determine procedure volume and nationwide accessibility to robotic surgery and to establish robust data on clinical utility.

2 MATERIALS AND METHODS

2.1 FOI Act requests

One hundred and forty-nine acute hospital trusts were identified from Estates Returns Information Collection data, publicly available from NHS Digital.15 FOI Act requests were sent to all 149 acute NHS trusts on the 14th November 2019 in accordance with the FOI Act 2000.16 The FOI Act gives the public the right of access to information held by public authorities. Members of the public are entitled to request information from public authorities and should be responded to within 20 working days. Trusts were asked to provide information concerning three broad areas: first, the number of robots in use; second, the number of procedures performed annually between 2013 and the date of the request and finally, the cost of the robot, disposables and maintenance. Whilst public authorities are obliged to respond to FOI requests, they are able to refuse requests should the request be deemed to take too much staff time to complete.16 We therefore chose to limit our request to the specialties in which the most robotic procedures are performed.17 We acknowledge the use of robotic approaches in other specialties including ENT,18 cardiothoracic19 and orthopaedic surgery.20 The full FOI request is available in the Data S1.

2.2 Spatial accessibility to surgical robotics

The locations of hospitals with surgical robots and travel time to nearest robot for England are mapped. Accessibility to surgical robots is calculated using the Enhanced Two-Step Floating Catchment Area (E2SFCA) Method. All results are described and represented spatially using choropleth maps.

2.2.1 Geographic unit of aggregation

Smaller geographic units of analysis allow more precise estimates of the time to travel between a patient’s home and surgical robotic centre. The Lower Layer Super Output Area (LSOA) is a mutually exclusive, collectively exhaustive census geography, of which there are 32 843 in England excluding the Isles of Scilly, with an average population of around 1700 individuals.21

2.2.2 Travel time data

The traffic-free road travel times between all trusts with surgical robotics and the population-weighted centroids of all LSOAs in England were obtained from https://pythonhealthcare.org/ and supplemented with additional Open Street Map queries (openstreetmap.org) using the MapBox REST API (mapbox.com). Where trusts were composed of more than one site, the site of the surgical robot was further clarified by amendment to the original FOI request.

2.2.3 Enhanced Two-Step Floating Catchment Area

Accessibility to surgical robotics was calculated for each LSOA in England using the E2SFCA method,22 as follows:

Step 1: In the first step, the supply: demand ratio ($R_j$) is calculated as the ratio of the number of surgical robots to the expected demand from the nearby population:

$$R_j = \frac{S_j}{\sum_{k} (D_k G(t_{kj}, t_m))}$$

- $S_j$ is the number of robots in the site.
- $D_k$ is the demand of the location - in this case is the crude LSOA population in 2018.
- $G(t_{kj}, t_m)$ is the Gaussian distance decay function for the travel time between LSOA k and Hospital j (see below).

A Gaussian decay function was defined to preferentially weight populations closer to a hospital than those further away, as described in,22 as follows:

$$G(t_{kj}, t_m) = \begin{cases} \frac{e^{-0.5(t_{kj} - t_m)^2}}{1 - e^{-0.5(t_{kj} - t_m)^2}} & t_{kj} \leq t_m \\ 0 & t_{kj} > t_m \end{cases}$$

- $t_{kj}$ is the travel time between hospital j and LSOA k.
- $t_m$ is the outer limit of the region of LSOAs contributing cases to the hospital j.

In this study, an upper limit ($t_m$) of 60 min travel by road was taken as an appropriate maximal threshold. At 40 min a weight of 0.5
is applied. Outside of the 60 min catchment radius, all LSOAs receive a weighting of 0.

Step 2: In the second step, the accessibility of LSOA \( k \) \( (A_k) \) is calculated as the sum of the capacity: demand ratio \( (R_j) \) of all hospitals within 60 min road travel after weighting by the same Gaussian decay function as Equation (2).

\[
A_k = \sum_j R_j G(t_{kj}, t_m)
\]

- \( A_k \) is the accessibility of surgical robots for LSOA \( k \).
- \( R_j \) is the capacity: demand ratio of hospital \( j \), from the set of \( J \) hospital trusts with surgical robots.
- \( G(t_{kj}, t_m) \) is the Gaussian distance decay function for the travel time between LSOA \( k \) and hospital \( j \).

3 | RESULTS

All 149 NHS trusts responded to the FOI request. Forty-eight of these trusts (25.9%) had a surgical robot. Forty-one of these 48 trusts provided procedural data. The seven trusts unable to supply procedural data were unable to dedicate resources to supply this data following the outbreak of Covid-19, and a decision was made to cease data collection at the end of March 2020. Ten out of 48 trusts responded with full financial data with the majority of non-respondents exempting due to Commercial Interests under Section 43(2) of the FOI Act 2000.

3.1 | Mapping of robotic centres

The geographic location of robotic centres in England are shown in Figure 1. Robotic centres were generally located in large hospitals located within cities and large towns. Seven robotic centres were located within London alone. The uptake of robotic surgery continues to rise with trusts continuing to buy robots (Figure 2) and five NHS trusts expressed plans for further purchase of a surgical robot within the next 18 months. Five trusts lease their robots. The market for surgical robotic platforms in the NHS is dominated exclusively by Intuitive’s Da Vinci with all 48 trusts using a Da Vinci robot. The Da Vinci Si was the most common model 41 (67.2%), with the Da Vinci Xi 17 (27.9%) and the Da Vinci X 3 (4.9%) the other models.

3.2 | Procedure data

Procedure data supplied by the 41 responding robotic centres are detailed in Table 1. The median number of procedures performed per trust in 2018 was 295 (208.5–403.25; 2018 was used as trusts only supplied data up to November for 2019). The number of procedures annually varied between a single procedure in one NHS trust to 683 procedures in another. Four trusts performed more than 500 procedures in 2018. Robotic procedures in England are dominated by urological procedures (84.2%), with gynaecological procedures making up 9.9%, colorectal 4.2% and general surgery the remaining procedures (1.7%). Trusts reported 190 (56.5%) robotic urological consultant surgeons, 62 (18.5%) colorectal consultant surgeons, 45 (13.4%) gynaecological consultant surgeons and 39 (11.6%) general consultant surgeons.

3.3 | Spatial accessibility to robotic surgery

Travel time to robotic centres were determined and mapped in Figure 3. Thirty one thousand three hundred and ninety-four LSOAs are within a 60-min drive of a robotic surgical centre, representing 53 362 928 people (95.7% of the population of England). 69.4% of the population live within a 30-min drive of a robotic surgical centre. The enhanced two-step floating catchment area method provides a single quantifiable measure of accessibility. Rural areas in the counties of Cumbria and Lincolnshire are particularly poorly served (Figures 3 and 4).
Accessibility to robotic centres calculated using the E2SFCA method varied across England and was highest in the North East of England, the South West of England and in Greater London (Figure 5). With the exception of Greater London, areas with high spatial accessibility to robotic surgical services were located in large towns or small cities with surrounding rural communities. In these cases, high accessibility is conferred by the presence of one or two robots in relatively sparsely populated areas, rather than many robots in a conurbation. The West Midlands, despite being near to many robotic surgical centres has lower spatial accessibility due to its larger constituent populations. 4.3% of the population of England (2,412,008 people) have zero accessibility to robotic surgical services, owing to the travel time to their nearest robotic centre exceeding 60 min.

### 3.4 Economic data

Economic data received were limited by the fact that many trusts exempted response due to commercial interests. Of those who did respond, the median cost of a robot was £1,350,000 (1,000,000–1,679,377). The median cost of disposables per trust per annum was £352,000 (220,000–522,583). The median cost of maintenance per trust per annum was £140,000 (120,000–150,000). Fourteen trusts provided full positive responses to the FOI request supplying procedure and cost data for disposables and maintenance allowing calculation of per procedure costs by dividing the sum of annual expenditure on disposables and maintenance by the annual number of procedures in 2018. These values ranged from £1,587 per procedure for a centre performing 446 procedures a year to £8,679 per procedure for a centre performing only 53 cases a year. All centres with costs of greater than £3,000 per procedure were performing fewer than 200 procedures per year.
4 | DISCUSSION

This is the first published nationwide study to map out the extent of robotic surgery in England. We have successfully surveyed all acute NHS trusts within England. In keeping with worldwide data, the number of robots has risen annually since 2013. This trend is likely to continue as five further trusts reported plans to purchase a robot in the next 18 months. In addition, the distribution of 61 robots across English NHS trusts is almost certainly an underestimate of the nationwide number, given the likely use of robotic surgery within private non-NHS hospitals, those used with a research capacity and alternative robotic platforms such as the Mako SmartRobotics™ (Stryker Ltd) used in orthopaedic surgery. The increase in number of robots across the NHS has occurred despite the lack of convincing evidence to support robotic surgery from randomised control trials calling into question the value of robotics for surgeons and the NHS. Surgeons do, however, report better ergonomics with robotic approaches compared to laparoscopic approaches but does this alone justify the use of robotic surgery in the NHS?

The Da Vinci robot is the only model of robot in routine use at the time of our survey, confirming Intuitive Surgical’s current monopoly of the surgical robotics health market. We note, however, since the completion of our FOI request the commencement of the use of CMR Surgical’s Versius robot in NHS trusts. Moreover, further creations from Verb Surgical, TransEnterix and Medtronic means hospital providers will, for the first time, be able to choose between manufacturers. Due to this competition, it is likely we will see innovation in business models and a move towards cheaper licencing and subscription models permitting access to the machine and disposable instruments. To date, five of the 22 trusts who reported robot cost data have opted to lease their robot rather than own them outright.

In keeping with the increasing number of surgical robots, there has been a rise in robotic surgical procedures performed in England. However, there is significant variation in the volume of robotic procedures being performed between centres. In 2018, the total procedure volume per hospital provider ranged from 1 to 683 cases. In centres performing robotic urological surgery the median number of procedures was 263 (170-372). However, robotic colorectal surgery is in its infancy by comparison, with the median number of procedures only 29 (8-38). Low volume use of robotic surgery is a major impediment to both its safe use, but also to demonstrating its benefit and clinical impact. This data suggests that the distributed adoption of surgical technologies across geographical regions and specialities leads to a heterogeneous uptake and a failure of translation into standard of care.

A possible solution to this challenge is the centralisation of robotic centres into ‘innovation hubs’ than can establish best practice, clinical evidence and patient volumes. The data presented here has demonstrated that accessibility to robotic centres in England is variable. The majority of the country is within a 60-min radius to a surgical robotic centre, but there are areas of the country such as the East Midlands and the North West which appear to be underserved. Unsurprisingly, large cities which are typically home to teaching hospitals have good accessibility to robotic surgery, but less urban centres such as Kent also have good accessibility. However, this also presents challenges around the value proposition of robotic systems for the NHS and the UK’s tax-payers because the two main hospitals in this region, Medway NHS Foundation Trust and East Kent Hospitals NHS trust are less than 30 miles apart. Yet they both have surgical robots, costing on average over £1.3 million. This is in part a consequence of NHS trusts operating independently and local variation in elective cancer work. However, a national centralisation strategy would allow robotic centres to be distributed efficiently and prevent the emergence of new low volume robotic centres which are
unlikely to be safe or cost effective. A centralised approach can also deliver economies of scale. The range in the prices paid for robots, disposables and maintenance, and the number of trusts exempting to disclose financial data for commercial reasons, suggest that handling these purchases at a national level may be able to secure a better deal for the NHS as a whole. NHS strategy states that there is a desire to move to a more centralised procurement model, and there is a precedent for doing so. Centralisation of procurement strategy for robotics is likely to represent better value for the NHS. Moreover, these centres will be properly assessed and compare the merits of novel and competing robotic systems as they enter the market in the NHS. Implementation of a centralised robotic surgery however, will not be without challenge. Trusts currently have licence to operate independently and funding is variable between trusts with many receiving charitable support. Centralisation will therefore require a national strategy. Encouragingly, there is precedent in the centralisation of specialist cancer surgery and specialist vascular surgery services; work would need to be undertaken to understand lessons learned from these projects and to apply them to centralisation of robotic surgery.

This strategy would also address the issue of learning curves in the adoption of robotics. Present learning curve estimates cannot be relied upon due to poor reporting standards and the significant degree of heterogeneity in methodology. Minimum oncological resection standards exist in laparoscopic surgery for resections, but this has been much harder to properly assess in robotic surgery. National robotic learning curve standards must now be urgently defined and this cannot be achieved without national coordination. Covid-19 has fragmented surgical services and caused significant disruption to surgical volumes and education. The current robotic framework has little resilience and it is unlikely to maintain robotic surgical learning curves for the foreseeable future.

The National Bowel Cancer Audit in 2019 have reported for the first time on the uptake of robotic surgery by NHS trust and by surgeon, including what proportion of their cases are recorded as robotic. Given the nationwide uptake of robotic surgery, the second solution must be to extend this into a centralised database for all robotic surgery. This will allow dynamic assessment of distribution and use of surgical robotics allowing future national robotic strategy to be continually assessed. Databases consisting of spreadsheets of costs and procedure volumes will soon be surpassed by the modern robotic database which will include an eclectic mixture of video, kinematic and sensor data in addition to outcome data. The true value in new robotic platforms currently entering the market is likely not to be in the robots themselves but the data that comes from them. This data and its sharing will serve as the platform which may deliver the leap in clinical outcomes which robotic surgery has promised for so long but failed to deliver.

Whilst we have received a response from all acute NHS trusts surveyed, our study is limited by a fragmented data set with incomplete procedural and financial data. We are unable to make any economic conclusions with our data beyond descriptive statistics given fewer than 25% of respondents replied with full economic data. This may be due to the fact that individual trusts are able to negotiate rates for purchase of robots, disposables and maintenance, and therefore feel that disclosing this commercial sensitive information could disadvantage them. Conclusions regarding high volume centres were also unable to be made as procedural data could not be fully collected following the outbreak of Covid-19. Procedural data are also highly dependent upon accurate coding at the trust level. Finally, we have not included data from private healthcare providers which are not required to respond to FOI requests, and we have not included new systems that are being assessed as part of research activities or pilot testing of new commercial systems.

This study has mapped the real-world uptake of robotic systems in a public healthcare system. The lack of a national robotic strategy has led to variable accessibility to surgical robotics with decisions made only at a trust level. The issues caused by the absence of a national robotic registry have been demonstrated by the necessity to send individual FOI requests to every NHS trust. However, this study has also shown the use of FOI requests as a powerful means of collecting data that can be used to inform health policy and national surgical strategy.

5 CONCLUSIONS

This is the first nationwide study to map out the extent of adoption of robotic surgery in a large public healthcare system and has demonstrated that the number of robots and robotic procedures continue to rise. Accessibility to robotic services is generally good, but certain areas of England such as the North West and the East Midlands are relatively underserved. The future of robotic surgery across England may lie in further one-off acquisitions of robots by individual trusts, where the number of procedures may be relatively low, but in high volume robotic centres. However, further safety and economic analysis is required to determine whether this strategy is indeed the future for robotic surgery in the NHS. To allow this analysis to be carried out in the future, we should ensure that data from all robots within the NHS are tracked at trust level and shared at a national level. This will allow evaluation of the value of robotic surgery to the NHS and to English surgeons beyond observational data. National data will be crucial in order to define our future national robotics strategy.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Kyle Lam, Jonathan Clarke and James M. Kinross substantially contributed to discussion of content, wrote the article and reviewed and edited the manuscript before submission. Sanjay Purkayastha substantially contributed to discussion of content and reviewed and edited the manuscript before submission.
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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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