PATTERNS AND OUTCOMES OF NEUROSURGERY IN ENGLAND OVER A FIVE-YEAR PERIOD: A NATIONAL RETROSPECTIVE COHORT STUDY

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ABSTRACT

Background

Neurosurgical practice has seen major changes over several decades. There are no recent evaluations of national neurosurgical practice. The aim of this observational study was to describe neurosurgical practice in England and to use outcomes to assess and benchmark the quality of care in neurosurgery.

Material and Methods

This national retrospective cohort study analysed Hospital Episode Statistics (HES) data from April 2013 to March 2018 for all adult admissions with a specialty code for neurosurgery. The epidemiology of patients and RCS Charlson comorbidities were derived and procedure incidence rates per 100,000 person-years calculated. Postoperative outcomes for elective and non-elective patients included: median length of stay, the proportion of patients requiring additional inpatient neurosurgical procedures, the proportion of patients discharged to their usual address, and in-hospital mortality rates.

Results

During the 5-year study period, there were 371,418 admissions to neurosurgery. The proportion of admissions involving a neurosurgical procedure was 77.3% (n=287,077). Of these, 45% were for cranial surgery and 37% for spinal. Overall, 68.3% were elective procedures. The incidence rates of most procedures were low (<20 per 100,000 person-years). Following elective neurosurgical procedures, in-hospital mortality rates for cranial and spinal surgery were 0.5% (95% CI, 0.5-0.6) and 0.1% (95% CI, 0.04-0.1), respectively. After non-elective neurosurgery, mortality rates were 7.4% (95% CI, 7.2-7.6) and 1.3% (95% CI, 1.2-1.5) for cranial and spinal surgery, respectively. Approximately 1 in 4 patients had additional procedures following non-elective cranial surgery (24%; 95% CI, 23.6-24.3). Outcomes were highly variable across different subspecialty areas.

Conclusions

The incidence rates of neurological procedures is low within England, and neurosurgical units have a high volume of non-surgical admissions. In-hospital mortality rates after elective neurosurgery are low but there may be opportunities for quality improvement programmes to improve outcomes for non-elective surgery as well as ensuring equitable access to treatment.

ABBREVIATIONS

GIRFT – Getting It Right First Time, HES – Hospital Episode Statistics, LOS – Length of stay, NHS – National Health Service, NNAP –National Neurosurgical Audit Programme, OPCS - Office of Population Censuses and Surveys, RCS – Royal College of Surgeons, SRS – Stereotactic radiosurgery.

KEYWORDS

Neurosurgery, Hospital Episode Statistics, admissions, outcomes, mortality, quality of care.

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INTRODUCTION

Neurosurgical practice has seen many important changes over several decades, such as the shift toward endovascular treatment of intracranial aneurysms [1], and the introduction of advanced molecular testing and surgical technology in the treatment of brain tumours.[2] Technological innovation and greater use of medical devices have been major drivers of these changes.[3] Neurosurgical procedures have evolved, and as outcomes have improved the number of patients being treated has increased.[4]

There are no recent evaluations of national neurosurgical practice in the UK, with the last prospective cohort studies being Safe Neurosurgery 1993 and Safe Neurosurgery 2000.[5] More recent studies of neurosurgical services have been based on data from single institutions or surgeons [6,7] and these may not give a representative picture of practice nationally. This partly reflects the cost and data burden of running national surgical registries. Although there are now several national neurosurgical registries, they record data on specific conditions or surgical procedures for primary neurosurgical research. They are not orientated to support service evaluation and provide only a partial picture of national neurosurgical practice. Consequently, recent national quality improvement programmes for neurosurgery in England (such as the National Neurosurgical Audit Programme (NNAP) and Cranial Neurosurgery and Spinal Surgery Getting It Right First Time (GIRFT) Programmes[8–10]) have focused on using national hospital administrative datasets. To be effective, quality improvement initiatives require robust outcome measures and quality (process) indicators. Currently, there is a lack of validated quality indicators for neurosurgery, with practice often being described using generic measures such as readmission and reoperation rates and length of stay.[11] Many studies have been able to derive these common outcome measures, but it may also be possible to produce indicators specific to neurosurgery.

The aim of this observational study was firstly to describe the current pattern of neurosurgical admissions and procedures in England, and thereby give an overview of the epidemiology of neurosurgical patients. Secondly, it aims to investigate the range of outcome measures that might be produced from hospital administrative data and use these to assess and benchmark the quality of care in neurosurgery.

METHODS

Data

All admissions of adults (≥18 years) involving neurosurgical care to one of the 24 NHS neurosurgical units in England from 1st April 2013 to 31st March 2018 (five years) were identified in Hospital Episode Statistics (HES) data.[8] HES is the hospital administrative database for NHS hospitals in England. Its primary purpose is for financial reimbursement of hospitals, but it is also used for clinical research and audit.[12] It contains information on the type and timing of admissions, diagnosed conditions and the procedures performed.

Procedures are recorded using the UK Office of Population Censuses and Surveys classification (OPCS, version 4). Each episode of care contains one primary procedure (the most resource intensive) and 23 secondary procedure fields.[13] This study defined neurosurgical procedures using the NNAP Coding Framework which classifies 870 OPCS codes into three types (cranial, spinal or other) and 16 clinical categories which broadly reflect neurosurgical subspecialty practice.[8]

Neurosurgical admissions were defined as admissions involving at least one episode of care under a consultant neurosurgeon. Admissions were split into three types based on the primary procedure: a '*neurosurgical procedure*' group, a '*non-neurosurgical procedure*' group (procedures not in the NNAP Coding Framework), and a '*no procedure*' group. Admissions were categorised as either elective or non-elective (emergency admissions and inter-hospital transfers).

The outcome measures include length of stay (LOS), additional neurosurgical procedure rates during the hospital admission, the proportion of patients discharged to their usual address, and in-hospital mortality rates. In addition, the number of day-of-surgery cancellations in the *no procedure* group was identified using Health Resource Group (HRG) codes which are used by hospitals as a common standard of reporting activity.[14] The day-of-surgery cancellation rate was estimated by dividing the average annual number of cancellations by the number of procedures.

The additional procedures metric counted those performed on a different day to the primary procedure. It included both planned and unplanned surgery because these two types cannot be distinguished in HES.

Diagnoses are recorded in HES using the International Classification of Diseases (ICD, version 10).[13] Each episode of care has a primary diagnosis and up to 19 secondary diagnoses. The prevalence of comorbid disease was estimated using the Royal College of Surgeons (RCS) Charlson Score which was developed and validated with HES data.[15]

Analysis

An initial analysis described the types of admissions and procedures in neurosurgical practice, focussing on annual volumes of admissions, the proportion of admissions of each type (cranial, spinal, other) and the subspecialty. The total volume included both the number of primary and secondary neurosurgical procedures. The study determined the variation in overall volumes of procedures performed in the 24 neurosurgical units. Stereotactic radiosurgery (SRS) was excluded from the analysis of subspecialty practice because it is not mandatory to report this activity to HES and most trusts do not.[9] It was, however, included in analysis of the overall number of admissions. Admissions in the *non-neurosurgical procedure* and *no procedure* groups were explored by primary diagnosis (± primary procedure). Records with poor quality data – such as no diagnosis codes or date errors – were excluded.

Basic demographic information including age, sex, and comorbidity were summarised using descriptive statistics (mean, median, proportion, standard deviation (SD), interquartile range). The prevalence of comorbidity was described in addition to overall RCS Charlson Scores. The incidence rates of neurosurgical procedures were calculated per 100,000 person-years, stratified by age and sex. Mid-year population estimates from the Office for National Statistics were used to estimate the adult population of England during the study period.[16]

The four outcome measures were calculated for the type of admission, type of procedure (cranial, spinal, other) and the subspecialties. Each outcome measure was reported with the 95% confidence interval (CI).

Data analysis was performed using Stata (version 15) and Microsoft Excel 365 (version 2020). The work has been reported in line with the STROCSS criteria.[17]. The study is registered at https://register.clinicaltrials.gov with the unique identifier NCT05097066

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RESULTS

Admissions and procedures

From 1st April 2013 to 31st March 2018, the basic extract contained 373,682 admissions. Excluding 2,264 (0.6%) records with poor quality data left a total of 371,418 admissions – approximately 74,284 per annum. Figure 1 shows the annual volume of admissions and proportions in each of the admission groups. There were 287,077 admissions that involved a primary neurosurgical procedure (Table 1). Among these, 57,224 patients also had a secondary procedure, resulting in a total of 344,301 procedures– approximately 68,860 per annum. Most neurosurgical procedures were elective (68.3%, n=196,166). The median annual volume of neurosurgical procedures per neurosurgical unit was 2,301, with a range of 1,088 in the lowest volume unit and 4,795 in the highest.

The proportions of admissions in the *neurosurgical procedure* group by type (cranial, spinal, and other) and subspecialty are shown in Figures 2a-b. Cranial surgery comprised 45% of all activity, spinal surgery 37% and other procedures 18%. SRS is not included in these figures because it is not routinely reported to HES.[9]

Of the remaining admissions, 14.2% (n=52,913) and 8.5% (n=31,428) were in the *non-neurosurgical procedure* and *no procedure* groups, respectively. There were 15,576 cancellations making up half (49.6%) of the *no procedure* group, which is approximately 3,115 admissions per annum or 4% of all admissions. The day-of-surgery cancellation rate was 7.4%. There was an increase in the number of cancellations from 7.0% in year 1 to 7.9% in year 5 (p<0.001).

The primary diagnoses in the *non-neurosurgical procedure* and *no procedure* admission groups (n=84,341) are shown in Figure S1a (supplementary material). Spinal disorders (excluding spinal trauma) accounted for 21.2% (n=17,891) of these admissions. Cranial trauma (16.2%, n=13,638)), central nervous system neoplasms (7.3%, n=6,117), spinal trauma (6.4%, n=5,385) and post-operative complications (6.3%, n=5,281) were the next largest groups. The primary procedures in the *non-neurosurgical procedure* group (n=52,913) were mostly diagnostic imaging (62.7%, n=33,176), minor surgical procedures (5%, n=2,646) and ventilator support (4.2%, n=2,222) (Figure S1b, supplementary material).

Neurosurgical patients

Descriptive statistics for age and sex of patients grouped by type of admission and procedure are shown in Table S1 (supplementary material). The mean age of patients admitted for neurosurgical care was 54.2 (SD 16.8 years). Most patients had no RCS Charlson comorbidities; 62.5% scored 0, 27.8% scored 1 and 9.7% scored 2 or more comorbidities on the RCS Charlson Score (Figure S2, supplementary material).

Incidence rates for most neurosurgical procedures increase with age before tailing off in the oldest age groups (Figure 3a-f). The incidence of most neurosurgical subspecialty procedures is low in all age groups, generally being less than 20 procedures per 100,000 patient-years; exceptions were: neuro-oncology surgery in older men, lumbar and cervical spine surgery, and general and trauma neurosurgery in the oldest age groups. General neurosurgery includes common procedures to treat infections, intracerebral haemorrhage, repair of dura and others.

Outcomes – elective neurosurgery

There were large differences in the four reported outcome measures across neurosurgical practice, with distinct patterns among elective and non-elective admissions. The results of the four outcome measures for elective neurosurgery are shown in Table 2. The median LOS was three days for cranial procedures and two days for spinal procedures. LOS is subspecialty practice varied between zero (day cases) and six days. The median LOS for all elective neurosurgical procedures decreased from two days to one day ($p<0.0001$) over the study period. This reflected an overall increase in the volume of day cases. Additional neurosurgical procedures were performed following 7% of cranial procedures and 1.7% of spinal procedures. The highest rates of additional procedures followed surgery for CSF disorders (10.1%), general neurosurgery (9.8%) and skull base surgery (8.4%). Over 90% of patients were discharged to their usual address following elective neurosurgery, expect after intradural spine surgery (88.5%). In-hospital mortality rates for elective procedures were generally low, with rates of 0.5% and 0.1% after cranial and spinal surgery, respectively. Patients with neuro-oncology conditions had the highest elective mortality rate at 1%.

Outcomes – non-elective neurosurgery

The outcomes for non-elective neurosurgery are shown in Table 3. The median LOS was 11 days for cranial procedures and seven days for spinal procedures and ranged from four to 15 days in subspecialty practice. Additional procedures were frequently required in non-elective cranial surgery (24%) and spinal surgery (6.8%). Further surgery was most commonly required following dysraphism procedures (41.7%), CSF disorder procedures (38.6%) and neurovascular surgery (36.9%). Overall, only 66.5% of all neurosurgical admissions were discharged to their usual address. Of the remaining 33.5%, 24.7% had on-going in-hospital care, 5.4% died in hospital, 1.9% were discharged to care facilities and 1.5% were discharged to other destinations. Post-operative in-hospital mortality was highly variable after non-elective surgery, being highest following cranial procedures (7.4%), CSF disorder procedures, general & trauma neurosurgery (8%) and neurovascular surgery (6.2%).

DISCUSSION

Neurosurgery is a broad surgical discipline with many subspecialty areas and the delivery of neurosurgical services is complex. The aim of this study was to provide an up-to-date description of neurosurgical practice in England in terms of patterns of neurosurgical admissions, epidemiological data, and differences in outcomes across neurosurgical practice. Our study aimed to examine how these outcome measures can be used to assess the quality of care in neurosurgery.

Trends in epidemiology and outcomes in HES data

Incidence rates for cranial surgery are similar in men and women up to the fifth decade, after which incidence is higher in men. A similar pattern of sex differences was apparent in spinal surgery, with a higher incidence of lumbar and cervical spine procedures in men from the sixth decade upwards. These age and sex differences broadly reflect the epidemiology of the underlying diseases. For example, glioblastoma is significantly more common in males in England overall and the differences get larger with age.[18,19] Traumatic brain injury in England and Wales has a peak incidence in the 80+ years age group and severe injures requiring surgery are significantly more common in males.[20,21] Female sex is a known risk factor for aneurysm formation and subarachnoid haemorrhage.[22]

The study observed a decrease in the rates of many procedures in older patients, particularly in the 80+ age group (Figure 3). Age is known to be associated with worse outcomes for many neurosurgical procedures[23] and frailty has been shown to be a strong predictor of post-operative mortality in neurosurgery.[24] The perceived risk of poor outcomes in older patients may discourage surgeons from offering neurosurgical intervention and patients from consenting to treatment. It is vital to ensure that access to neurosurgery is equitable for older patients and appropriate to each individual's state of health.[25] Further research using HES could examine the relative rates of neurosurgical and conservative treatment in older fit patients, but prospective studies would be required to determine whether neurosurgical treatment is actually being offered to these patients.

The outcomes of subspecialty procedures serve as a useful baseline for neurosurgical units to compare their performance. Variation in LOS may relate to service configuration as much as variations in clinical practice, and this may help units to identify barriers to discharge that prolong LOS.[9] In-hospital mortality rates are low following elective neurosurgery, and mortality is particularly uncommon following elective spinal surgery. This is consistent with other studies on early post-operative mortality after neurosurgery [26–28], but it has not previously been described in general neurosurgical practice in England. The relatively high rates of in-hospital mortality – as well as additional procedures, lower rates of discharge home, and longer LOS – in non-elective admissions generally reflect the debilitating nature of acute neurological conditions that are treated by neurosurgery. Initiatives intended to improve quality and efficiency should be targeted toward areas with worse outcomes.

Changes in neurosurgical practice

Overall, 24.5% of neurosurgical procedures were non-elective but historically this figure has been much higher. A review of UK neurosurgical practice from 1993 to 1999 found that approximately 59% of all operations were performed as an emergency.[5] Spinal surgery has increased in proportion from approximately 24% in the 1990's to 37% in this study, most of which is elective activity.[5] The definition of an emergency and the spectrum of procedures included in that analysis may have differed from this study. Even so, it is likely that this change is largely due advances in neurosurgical practice and changes in demography and disease prevalence. The rate of traumatic brain injury, for example, has decreased over time, driven by public health interventions such as improvements in road safety.[29] Better diagnostic techniques, improvements and innovations in treatment of neurosurgical diseases and increasing treatment rates in older patients may also have increased the proportion of elective neurosurgical procedures.[4]

The proportion of admissions in which no neurosurgical procedure was performed (the *non-neurosurgical procedure* and *no procedure* groups) was 22.7%. Interestingly, this has not changed a great deal compared to the 1990's when 24% of all admissions involved no operation.[5] Some conditions warrant a neurosurgical admission for clinical assessment, a period of observation or non-surgical management. Analysis of the primary diagnoses in these admissions showed that the largest proportion were for non-traumatic spinal conditions – commonly lower back pain or radiculopathy (Figure S1a, supplementary material). The GIRFT Programme for Spinal Services (2019) reported that large numbers of patients were admitted acutely with spinal conditions and had no procedure, and many stayed in hospital for four or more days.[10] There was some evidence that alternative care pathways – such as an on-call spinal clinic for urgent referrals or the provision of physiotherapy services in the emergency department – reduced unnecessary admissions.[10] Greater access to magnetic resonance imaging (MRI) in referring hospitals has been identified as one way to reduce unnecessary inter-hospital transfers and non-surgical admissions.[10] It may be possible to develop alternative care pathways to prevent unnecessary or prolonged admissions for other conditions.

Reducing day-of-surgery cancellation rates would avoid unnecessary hospital attendances. Cancellations are frequently due to a lack of capacity or issues with the organisation of services. A recent, large, nationwide cohort study showed that the day of surgery cancellation rate in the NHS is about 13.9%.[30] This study found that the situation is less problematic in neurosurgery with a cancellation rate of 7.4%, but this is not insignificant.

Quality assurance

One of the major challenges for neurosurgery is how to assess, benchmark and improve quality of care in a complex area of healthcare. The challenge is compounded by differences between units in the type and volume of procedures performed, use of surgical technology and treatment philosophy. The findings described in this study have several implications for quality improvement initiatives.

Firstly, a clear distinction should be maintained between elective and non-elective cases when outcomes are reported and compared. This can be challenging in some areas depending on the way services are organised. Some neurosurgery departments have an expedited elective pathway to treat patients who present acutely with a brain tumour, whereas others provide surgical treatment during the initial non-elective admission, for example.[9] Outcome measures should be reported with the relative rates of elective and non-elective procedures, where this provides relevant context for interpreting comparative outcomes between units.

Secondly, comparisons must be risk-adjusted for differences in both epidemiological factors – such as age, sex and comorbidity – and procedural case-mix.[31,32] HES has several limitations in this area. It is not possible, for example, to account for the severity of the presenting illness or functional status of patients. It does not contain clinical data such as histopathology or radiological test results that could be relevant to risk-adjustment. However, HES can be linked to other datasets – such as the National Cancer

Registry and Analysis Service dataset [33] or neurosurgical registries – to enrich the data and overcome these problems.

Thirdly, most neurosurgical procedures are performed in low volumes, and some in very low volumes. This can impact on the statistical validity of comparisons, and therefore outcome measures need to be validated for use in low volume surgery.[34]

The delivery of neurosurgical care involves substantial input from the clinical neurosciences, other surgical specialties, general neurosurgical and specialist nursing, neurorehabilitation, and allied health professionals.[35] Neurosurgical outcomes reflect a complex interaction between individual and team skills, organisational processes and patient factors; not just the performance of individual neurosurgeons or neurosurgical teams.[36] It is important to be mindful of this when interpreting neurosurgical outcomes and these are important considerations for quality improvement programmes.

Limitations

This study had several limitations. The volume of neurosurgical activity was under-estimated for several reasons. SRS data are not routinely reported in HES, although most neurosurgical units provide it. The number of additional procedures was under-estimated because the method used would not have detected same day returns to theatre for surgical complications, for example. Some patients may have had neurosurgical procedures but remained under the care of a different specialty and this activity may not have been included in the study. The study also did not consider neurosurgical procedures performed outside of the 24 neurosurgical units in England, such as NHS patients treated in private healthcare facilities. Lastly, administrative datasets are subject to coding errors in the form of missing or incorrect clinical data, although only 0.6% of records were excluded because no diagnosis codes were recorded.

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CONCLUSIONS

This study has provided a detailed description of neurosurgical practice in England, highlighting several important trends such as the low incidence rates of procedures in older age groups and a high volume of non-surgical admissions. We have provided some baseline measures of the quality of care provided by neurosurgical units, such as the low in-hospital mortality rates after elective neurosurgery. Quality improvement programmes should focus on ensuring equity of access to treatment for all patients, supporting efficient use of neurosurgical resources, improving care in areas with worse outcomes and on producing robust quality indicators. The end of the study period was exactly two years prior to the first UK lockdown due to the COVID-19 pandemic. The data may serve as a useful baseline for assessing the impact on neurosurgical activity and any deterioration in outcomes.

REFERENCES

1 Lee KS, Zhang JJY, Nguyen V, *et al.* The evolution of intracranial aneurysm treatment techniques and future directions. *Neurosurg Rev* Published Online First: 2021.

2 Magge RS, Barbaro M, Fine HA. Innovations in Neuro-Oncology. *World Neurosurg* 2021;**151**:386–91.

3 Marcus HJ, Hughes-hallett A, Kwasnicki RM, *et al.* Technological innovation in neurosurgery: a quantitative study. *J Neurosurg* 2015;**123**:1–8.

4 Kamat AS, Parker A. The evolution of neurosurgery: How has our practice changed? *Br J Neurosurg* 2013;**27**:747–51.

5 Nelson M. Safe Neurosurgery 2000. 1999. https://www.sbns.org.uk/index.php/policies-and-publications/archive-documents/ (accessed 20 Feb 2021).

6 Tarnaris A, Arvin B, Ashkan K. Evolution in practice: How has British neurosurgery changed in the last 10 years? *Ann R Coll Surg Engl* 2008;**90**:508–12.

7 Sandeman DR. 15-Year Longitudinal Study of Mortality in a General Neurosurgical Practice. *Br J Neurosurg* 2015;**29**:500–4.

8 Society of British Neurological Surgeons (SBNS). The Neurosurgical National Audit Programme (NNAP). 2021.https://www.nnap.org.uk/ (accessed 17 Jun 2021).

9 Phillips N. Cranial Neurosurgery - GIRFT Programme National Specialty Report. 2018. https://www.gettingitrightfirsttime.co.uk/surgical-specialty/cranial-neurosurgery/

10 Hutton M. Spinal Services - GIRFT Programme National Specialty Report. 2019. http://gettingitrightfirsttime.co.uk

11 Schipmann S, Schwake M, Suero Molina E, *et al.* Quality Indicators in Cranial Neurosurgery: Which Are Presently Substantiated? A Systematic Review. *World Neurosurg* 2017;**104**:104–12.

12 Herbert A, Wijlaars L, Zylbersztejn A, *et al.* Data Resource Profile: Hospital Episode Statistics Admitted Patient Care (HES APC). *Int J Epidemiol* 2017;**46**:1093-1093i.

13 NHS Digital. Clinical Classifications. https://digital.nhs.uk/services/terminology-and-classifications/clinical-classifications (accessed 16 Jun 2021).

14 NHS Digital. Healthcare Resource Groups (HRGs). https://digital.nhs.uk/data-and-information/information-standards/information-standards-and-data-collections-including-extractions/publications-and-notifications/standards-and-collections/isb-0070-healthcare-resource-groups-hrgs#current-release (accessed 10 Dec 2020).

15 Armitage JN, Van Der Meulen JH. Identifying co-morbidity in surgical patients using administrative data with the Royal College of Surgeons Charlson Score. *Br J Surg* 2010;**97**:772–81.

16 Office for National Statistics. Population estimates. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates (accessed 20 Feb 2021).

17 Mathew G, Agha R. STROCSS 2021: Strengthening the reporting of cohort, cross-sectional and case-control studies in surgery. *Int J Surg* 2021;**96**:106165.

18 Ostrom QT, Gittleman H, Stetson L, *et al.* Epidemiology of Gliomas. *Cancer Treat Res* 2015;**163**:1–14.

19 Brodbelt A, Greenberg D, Winters T, *et al.* Glioblastoma in England: 2007-2011. *Eur J Cancer* 2015;**51**:533–42.

20 Lawrence T, Helmy A, Bouamra O, *et al.* Traumatic brain injury in England and Wales: Prospective audit of epidemiology, complications and standardised mortality. *BMJ Open* 2016;**6**:1–9.

21 Hutchinson PJ, Kolias AG, Timofeev IS, *et al.* Trial of Decompressive Craniectomy for Traumatic Intracranial Hypertension. *N Engl J Med* 2016;**375**:1119–30.

22 Turan N, Heider RA-J, Zaharieva D, *et al.* Sex Differences in the Formation of Intracranial Aneurysms and Incidence and Outcome of Subarachnoid Hemorrhage: Review of Experimental and Human Studies. *Transl Stroke Res* 2016;**7**:12–9.

23 Stovell MG, Jenkinson MD. Neurosurgery in octogenarians. *Br J Neurosurg* 2014;**28**:611–5.

24 George EL, Hall DE, Youk A, *et al.* Association between Patient Frailty and Postoperative Mortality across Multiple Noncardiac Surgical Specialties. *JAMA Surg* 2021;**156**.

25 Edlmann E, Whitfield PC. The changing face of neurosurgery for the older person. *J Neurol* 2020;**267**:2469–74.

26 Schär RT, Tashi S, Branca M, *et al.* How safe are elective craniotomies in elderly patients in

neurosurgery today? A prospective cohort study of 1452 consecutive cases. *J Neurosurg* 2020;:1–9.

27 Reponen E, Korja M, Niemi T, *et al.* Preoperative identification of neurosurgery patients with a high risk of in-hospital complications: a prospective cohort of 418 consecutive elective craniotomy patients. *J Neurosurg* 2015;**123**:594–604.

28 Lukasiewicz AM, Basques BA, Bohl DD, *et al.* Myelopathy Is Associated with Increased All-Cause Morbidity and Mortality Following Anterior Cervical Discectomy and Fusion: A Study of 5256 Patients in American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP). *Spine (Phila Pa 1976)* 2015;**40**:443–9.

29 Khellaf A, Khan DZ, Helmy A. Recent advances in traumatic brain injury. *J Neurol* 2019;**266**:2878–89.

30 Wong DJN, Harris SK, Moonesinghe SR, *et al.* Cancelled operations: a 7-day cohort study of planned adult inpatient surgery in 245 UK National Health Service hospitals. *Br J Anaesth* 2018;**121**:730–8.

31 Moonesinghe SR. Individualised surgical outcomes: Please look the other way. *Postgrad Med J* 2013;**89**:677–8.

32 Alderson D, Cromwell D. Publication of surgeon-specific outcomes. *Br J Surg* 2014;**101**:1335–7.

33 Henson KE, Elliss-Brookes L, Coupland VH, *et al.* Data Resource Profile: National Cancer Registration Dataset in England. *Int J Epidemiol* 2020;**49**:16-16H.

34 Dimick JB, Welch HG, Birkmeyer JD. Surgical Mortality as an Indicator of Hospital Quality. *JAMA - J Am Med Assoc* 2004;**292**:847.

35 Somma T, Ius T, Certo F, *et al.* From the Champion to the Team: New Treatment Paradigms in Contemporary Neurosurgery. *World Neurosurg* 2019;**131**:141–8.

36 Vincent C, Moorthy K, Sarker SK, *et al.* Systems Approaches to Surgical Quality and Safety: From Concept to Measurement. *Ann Surg* 2004;**239**:475–82.

Type of clinical activity	Volume	Average annual volume	Average annual change in volume (% ± SD)	Proportion of all admissions (%)	Proportion of category (%)
All admissions involving neurosurgical care	371,418	74,284	0.6 ± 0.9	100	100
Elective	226,739	45,348	1.2 ± 2.0	61.0	61.0
Non-elective	144,679	28,936	-0.3 ± 1.5	39.0	39.0
Admissions with a primary neurosurgical procedure	287,077	57,415	0.3 ± 1.3	77.3	100
Elective	196,166	39,233	1.2 ±2.0	52.8	68.3
Non-elective	90,911	18,182	-1.7 ± 1.1	24.5	31.7
Admissions with a non-neurosurgical procedure	52,913	10,583	1.4 ± 3.3	14.2	100
Elective	11,674	2,335	-1.7 ± 4.9	3.1	22.1
Non-elective	41,239	8,248	2.3 ± 2.9	11.1	77.9
Admissions with no recorded procedure	31,428	6,286	2.6 ± 3.8	8.5	100
Elective	18,899	3,780	3.7 ± 5.8	5.1	60.1
Non-elective	12,529	2,506	1.1 ± 2.9	3.4	39.9

Table 1: Volume of admissions involving neurosurgical care to the 24 neurosurgical units in England from 31st March 2013 to 1st April 2018.

Type of clinical activity	Length of stay median (IQR)	95% CI	Additional neurosurgical procedure %	95% CI	Discharged to usual address %	95% CI	Post-operative in-hospital mortality %	95% CI
All admissions involving neurosurgical care	1 (0 - 3)	1 - 1	–	–	96.1	96 - 96.2	–	–
Neurosurgical procedure	2 (0 - 4)	2 - 2	–	–	95.9	95.8 - 96	–	–
Non-neurosurgical procedure	0 (0 - 2)	0 - 0	–	–	95.9	95.5 - 96.3	–	–
No procedure	0 (0 - 1)	0 - 0	–	–	98.3	98.1 - 98.4	–	–
Type of procedure								
Cranial	3 (2 - 6)	3 - 4	7.0	6.8 - 7.2	91.8	92.5 - 92.9	0.5	0.5 - 0.6
Spinal	2 (1 - 3)	2 - 2	1.7	1.6 - 1.8	97.8	97.0 - 97.2	0.1	0.04 - 0.1
Other	0 (0)	-	0.9	0.8 - 1	90.4	98.2 - 98.4	0.02	0.01 - 0.04
Clinical category								
General neurosurgery	3 (2 - 5)	3 - 3	9.8	9.1 - 10.5	91.8	91.2 - 92.4	0.5	0.4 - 0.7
Functional	1 (0 - 3)	1 - 1	5.4	5.1 - 5.7	97.8	97.6 – 98.0	0.1	0.05 - 0.1
Neuro-oncology	4 (2 - 7)	4 - 4	3.7	3.5 - 4	90.4	89.9 - 90.8	1.0	0.8 - 1.1
CSF disorders	3 (2 - 6)	3 - 3	10.1	9.4 - 10.8	92.3	91.7 - 92.9	0.3	0.2 - 0.4
Skull base	5 (3 - 8)	5 - 5	8.4	8 - 8.9	90.8	90.3 - 91.3	0.5	0.4 - 0.7
Neurovascular	3 (2 - 6)	3 - 3	7.5	6.9 - 8.2	94.0	93.4 - 94.6	0.5	0.4 - 0.7
Intradural spine	6 (4 - 10)	6 - 6	4.5	3.8 - 5.3	88.5	87.3 - 89.5	0.3	0.1 - 0.5
Dysraphism	6 (5 - 10)	6 - 7	5.1	3.1 - 8.3	92.5	88.9 – 95.0	0	–
Cervical spine	2 (1 - 3)	2 - 2	0.7	0.6 - 0.8	96.7	96.5 - 96.9	0.1	0.03 - 0.1
Lumbar spine	1 (1 - 2)	1 - 1	0.9	0.8 - 1	98.3	98.2 - 98.4	0.03	0.02 - 0.1
Complex spine	4 (2 - 7)	4 - 4	3.6	3.2 - 4	95.4	94.9 - 95.8	0.1	0.1 - 0.2
Spine - other	2 (1 - 5)	2 - 2	2.4	1.9 - 3	94.3	93.3 - 95.1	0.1	0.1 - 0.4
Peripheral	0 (0)	-	0.3	0.2 - 0.5	99.2	98.9 - 99.4	0.04	0.01 - 0.2
Diagnostic	0 (0)	-	2.3	2.1 - 2.6	98.1	97.8 - 98.3	0.05	0.02 - 0.1
Non-classified	0 (0)	-	0.4	0.3 - 0.5	97.9	97.7 - 98.1	0	–

Table 2: Patient outcomes following elective neurosurgical admissions including average length of stay, proportion having secondary neurosurgical procedures, proportion discharged to usual address and post-operative in-hospital mortality rate. **Note:** The *CSF disorder* category includes patients with conditions where an external ventricular drain (EVD) insertion was the primary procedure.

	Length of stay		Additional neurosurgical procedure		Discharged to usual address		Post-operative in-hospital mortality	
Type of clinical activity	**median (IQR)**	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**%**	**95% CI**
All admissions involving neurosurgical care	8 (3 - 16)	8 - 8	–	–	66.5	66.2 - 66.7	5.4	5.3 - 5.5
Neurosurgical procedure	10 (5 - 20)	10 - 10	–	–	63.6	63.3 - 63.9	5.3	5.2 - 5.5
Non-neurosurgical procedure	5 (2 - 12)	5 - 5	–	–	69.5	69.0 - 69.9	6.1	5.9 - 6.4
No procedure	2 (1 - 5)	2 - 2	–	–	77.8	77.1 - 78.5	3.7	3.3 – 4.0
Type of procedure								
Cranial	11 (6 - 21)	11 - 11	24.0	23.6 - 24.3	57.9	57.5 - 58.3	7.4	7.2 - 7.6
Spinal	7 (3 - 14)	7 - 8	6.8	6.5 - 7.2	72.2	71.6 - 72.8	1.3	1.2 - 1.5
Other	7 (3 - 12)	7 - 7	27.5	26.7 - 28.4	77.1	76.3 - 77.9	1.9	1.7 - 2.2
Clinical category								
General & Trauma neurosurgery	11 (5 - 22)	10 - 11	17.6	17.1 - 18	50.2	49.6 - 50.8	8.0	7.7 - 8.4
Functional	7 (3 - 15)	7 - 8	11.2	9.5 - 13.2	80.1	77.7 - 82.3	3.3	2.4 - 4.5
Neuro-oncology	10 (6 - 17)	9 - 10	10.1	9.4 - 10.8	73.0	72.0 - 73.9	3.4	3 - 3.8
CSF disorders	10 (4 - 23)	9 - 10	38.6	37.7 - 39.5	58.9	58.0 - 59.8	11.1	10.5 - 11.6
Skull base	12 (7 - 21)	11 - 12	17.0	15.5 - 18.7	69.6	67.5 - 71.5	2.4	1.8 - 3.1
Neurovascular	15 (10 - 24)	14 - 15	36.9	36 - 37.8	61.6	60.6 - 62.5	6.2	5.7 - 6.6
Intradural spine	14 (8 - 25)	13 - 14	9.7	8.2 - 11.5	59.4	56.7 - 62.1	2.4	1.7 - 3.4
Dysraphism	12 (7 - 25.5)	9 - 20	41.7	23.3 - 62.7	79.2	57.3 - 91.5	0	–
Cervical spine	11 (5 - 21)	10 - 11	6.0	5.2 - 6.9	59.1	57.4 - 60.8	1.9	1.5 - 2.4
Lumbar spine	4 (2 - 7)	4 - 4	4.7	4.3 - 5.1	86.9	86.2 - 87.6	0.2	0.1 - 0.3
Complex spine	12 (7 - 22)	12 - 12	10.2	9.4 - 11.1	62.6	61.2 - 63.9	2.1	1.8 - 2.5
Spine - other	13 (7 - 24)	13 - 14	7.5	6.5 - 8.6	58.8	56.8 - 60.7	2.7	2.2 - 3.5
Peripheral	4 (0 - 20)	2 - 7	23.4	15.1 - 34.3	74.0	62.9 - 82.7	2.6	0.6 - 10
Diagnostic	8 (4 - 16)	8 - 8	29.1	28.2 - 30	76.2	75.3 – 77.0	2.1	1.8 - 2.4
Non-classified	6 (2 -12)	5 - 6	16.8	14.8 - 19	84.6	82.4 - 86.5	0.7	0.3 - 1.3

Table 3: Patient outcomes following non-elective neurosurgical admissions including average length of stay, proportion having secondary neurosurgical procedures, proportion discharged to usual address and post-operative in-hospital mortality rate. **Note:** The *CSF disorder* category includes patients with conditions where an external ventricular drain (EVD) insertion was the primary procedure.

FIGURE CAPTIONS

Figure 1: Volume of admissions involving neurosurgical care each year from 31 March 2013 to 1 April 2018.

Figure 2: Relative proportions of (a) cranial, spinal and other neurosurgical procedures, and (b) subspecialty neurosurgical procedures (n=287,077).

Figure 3a-f: Incidence rates of cranial, spinal and other neurosurgical procedures (a & b); spinal procedures (c & d); neurosurgical subspecialty procedures (e & f) per 100,000 person-years of the population of England, stratified by age and sex. Error bars show the 95% confidence interval.

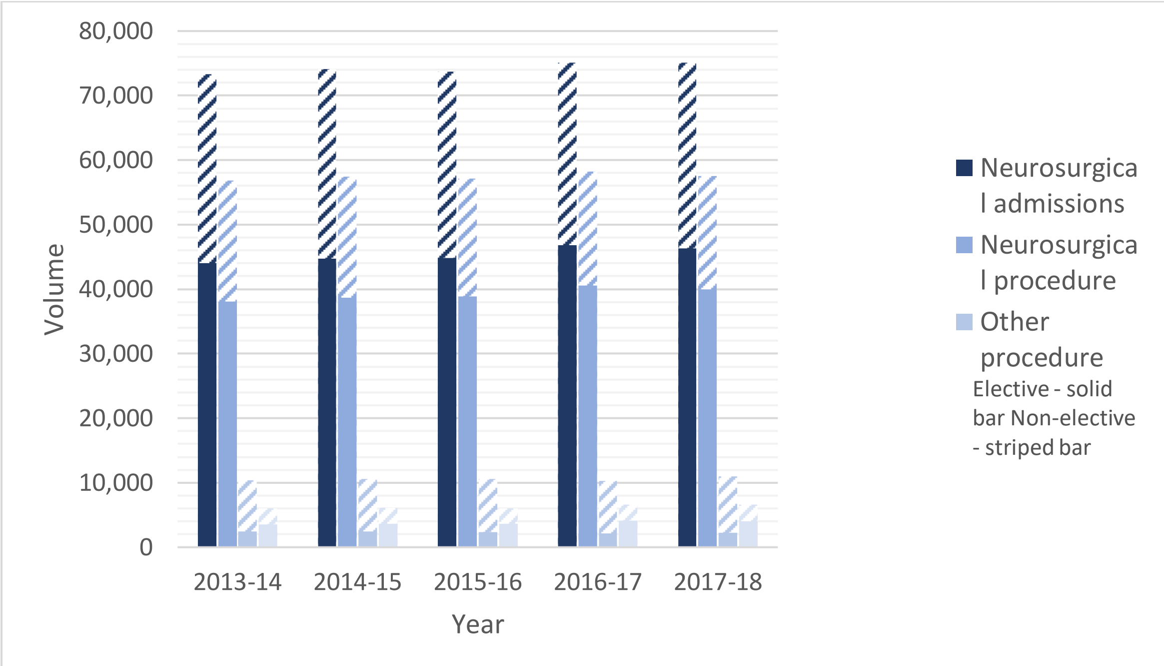

Figure 1: Volume of admissions involving neurosurgical care each year from 31 March 2013 to 1 April 2018.

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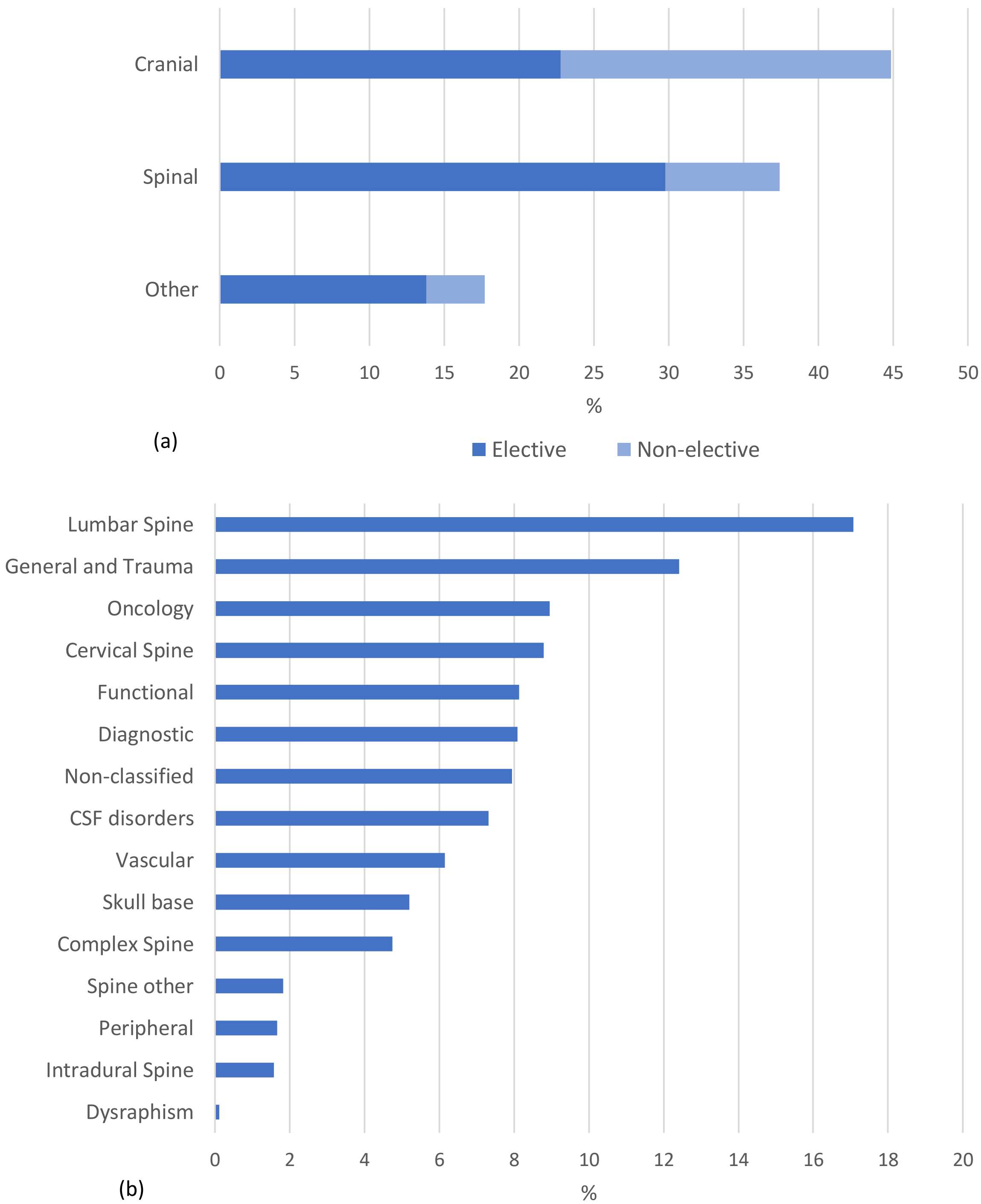

Figure 2: Relative proportions of (a) cranial, spinal and other neurosurgical procedures, and (b) subspecialty neurosurgical procedures (n=287,077).

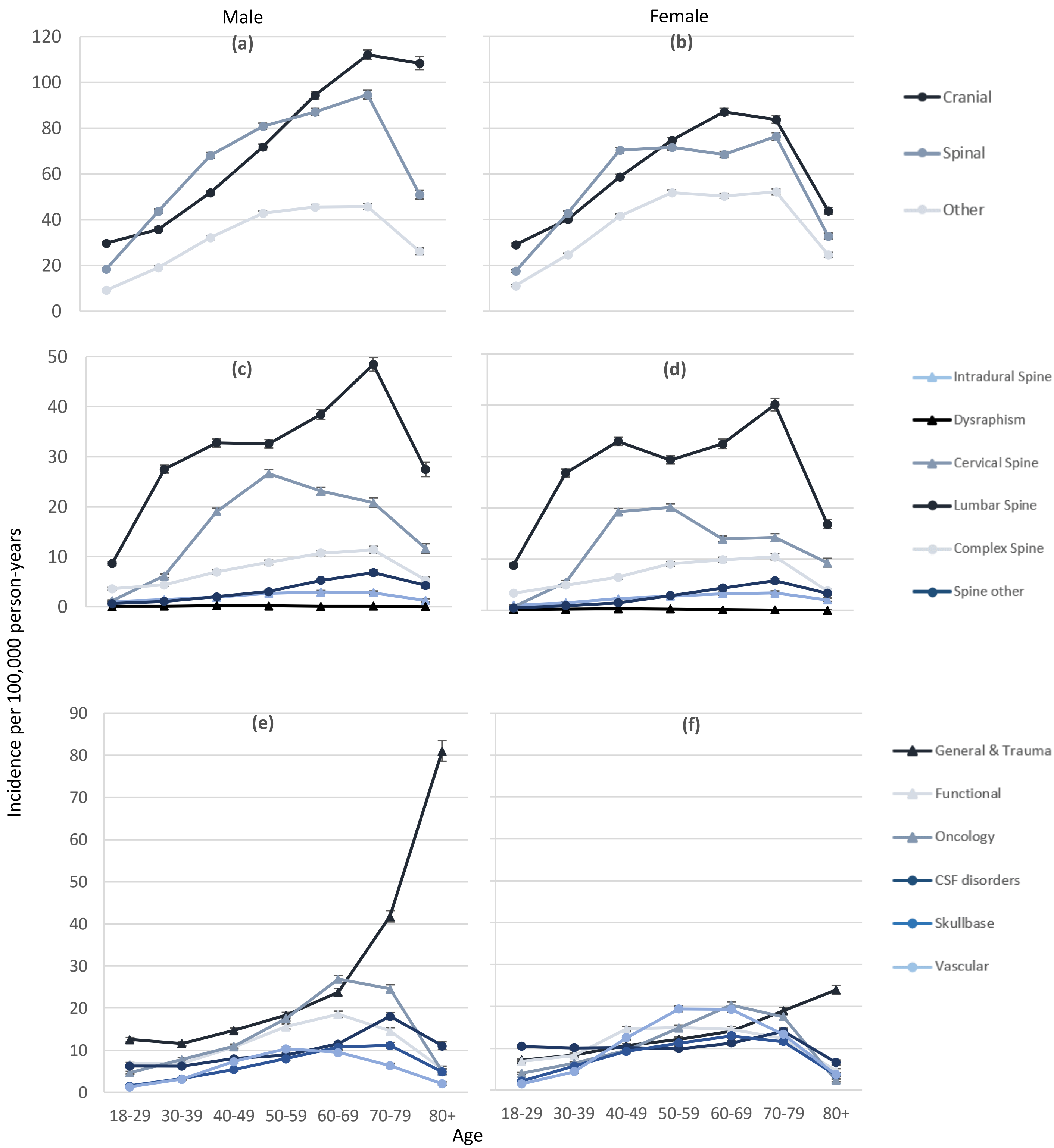

Figure 3a-f: Incidence rates of cranial, spinal and other neurosurgical procedures (a & b); spinal procedures (c & d); neurosurgical subspecialty procedures (e & f) per 100,000 person-years of the population of England, stratified by age and sex. Error bars show the 95% confidence interval.

Supplementary material

Figure S1a: Primary diagnosis in admissions with a non-neurosurgical procedure or no procedure. **Figure S1b:** Primary procedure in admissions with a non-neurosurgical procedure. 'Other' includes diagnoses or procedures that occurred in small numbers and it was not practical to explore these further.

Table S1: Patient demographics for all neurosurgical admissions and procedures, grouped by type of admission, type of procedure and subspecialty.

Figure S2: Comorbidity in neurosurgical patients by disease category. Note: AIDS / HIV comorbidity data were not present in this HES data extract and is probably concealed for patient confidentiality.

Figure S1a: Primary diagnosis in admissions with a non-neurosurgical procedure or no procedure. **Figure S1b:** Primary procedure in admissions with a non-neurosurgical procedure. 'Other' includes diagnoses or procedures that occurred in small numbers and it was not practical to explore these further.

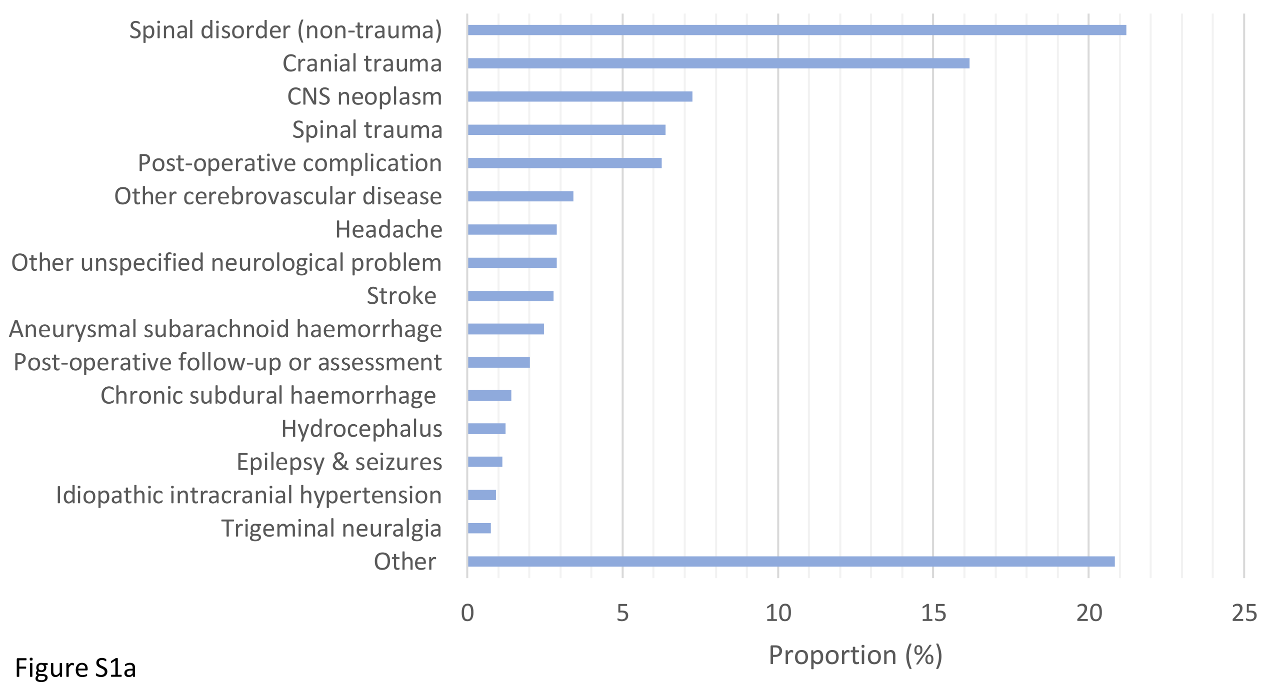

Figure S1a

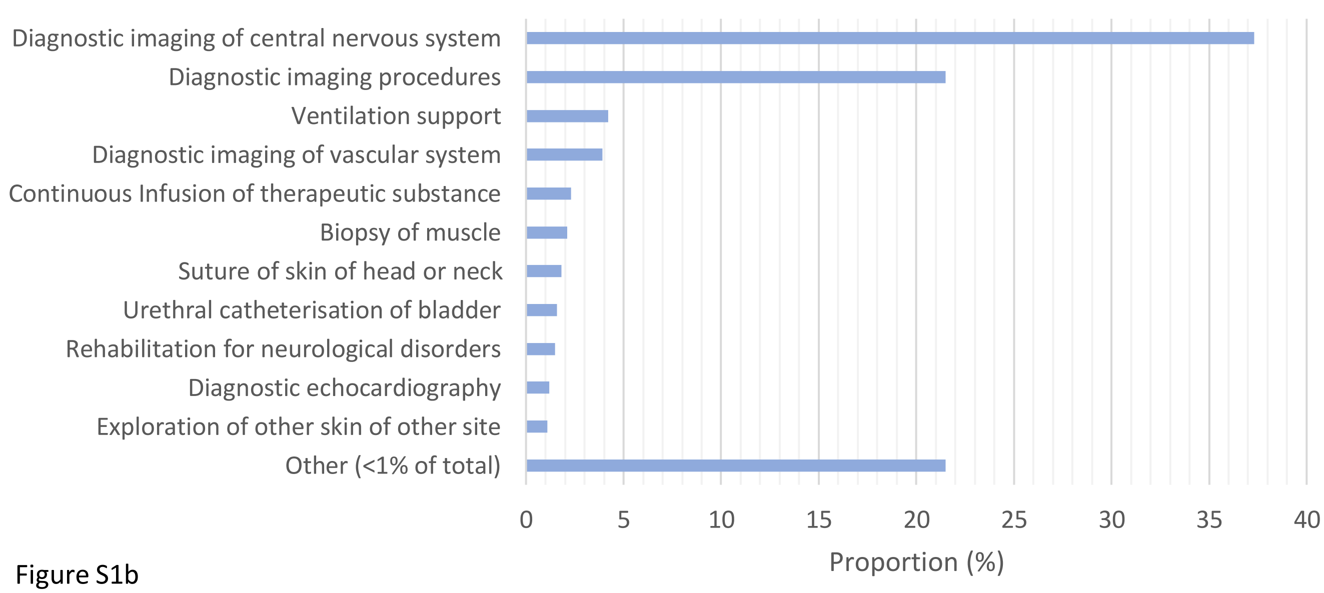

Figure S1b

Table S1: Patient demographics for all neurosurgical admissions and procedures, grouped by type of admission, type of procedure and subspecialty.

	Age (mean (SD))		Sex (% male)	
	Elective	**Non-elective**	**Elective**	**Non-elective**
Type of clinical activity				
All admissions involving neurosurgical care	54.3 (15.6)	53.9 (18.4)	48.4	54.4
Neurosurgical procedure	54.4 (15.6)	55.2 (18)	48.3	53.5
Non-neurosurgical procedure	52.6 (16.4)	51.4 (18.7)	47.8	56.1
No procedure	55.2 (15.5)	52.1 (19.6)	50.4	54.4
Type of procedure				
Cranial	53.6 (16.2)	57 (18.3)	47.4	54.3
Spinal	54.4 (15.2)	52.6 (17.4)	51.2	54.3
Other	55.4 (15.3)	50.6 (15.8)	44.2	48.1
Clinical category				
General and Trauma	46.3 (16.6)	61.5 (20)	47.8	67.2
Functional	51.6 (16.1)	53.3 (15.6)	48.8	55.3
Neuro-oncology	54.9 (15.2)	56.5 (14.6)	55.1	53.9
CSF disorders	54.6 (19.9)	48.6 (17.8)	44.8	46
Skull base	55.3 (14.8)	55.9 (15.7)	41.5	41.6
Neurovascular	54.2 (12.6)	55.9 (13.2)	36.6	32.7
Intradural Spine	52.9 (16)	56.4 (17.7)	45.3	47
Dysraphism	45.2 (13.8)	47.3 (15.8)	35.6	54.2
Cervical Spine	55.2 (12.3)	59.9 (16.4)	55.6	64.4
Lumbar Spine	54.9 (16.1)	47.2 (15.5)	52.1	46.5
Complex Spine	53.7 (15.7)	53.2 (18.4)	43.2	61.1
Spine - other	60.9 (15.3)	60.6 (15.7)	46	60.5
Peripheral	58.1 (13.8)	52.8 (17.2)	47.3	52
Diagnostic	52.7 (15.7)	50.6 (15.7)	43.8	48.8
Non-classified	56.4 (15.1)	50.5 (16.3)	43.8	42.2

Figure S2: Comorbidity in neurosurgical patients by disease category. Note: AIDS / HIV comorbidity data was not present in this HES data extract and is probably concealed for patient confidentiality.