RESEARCH • RECHERCHE

Effect of neurosurgical residency programs on neurosurgical patient outcomes in a single health care system: a cohort study

Shervin Taslimi, MD, MPH
Susan B. Brogly, PhD
Wenbin Li, PhD
Jillian Rodger, BSc
Ekkehard M. Kasper, MD, PhD
Douglas J. Cook, MD, PhD
Ron Levy, MD, PhD

Accepted Dec. 1, 2023

Correspondence to:
S. Taslimi
Division of Neurosurgery
Department of Surgery
Kingston General Hospital
Queen's University
76 Stuart St
Kingston ON K7L 2V7
shervin.taslimi@kingstonhsc.ca

Cite as: *Can J Surg* 2024 May 1;67(3). doi: 10.1503/cjs.008522

Background: The evidence on the benefits and drawbacks of involving neurosurgical residents in the care of patients who undergo neurosurgical procedures is heterogeneous. We assessed the effect of neurosurgical residency programs on the outcomes of such patients in a large single-payer public health care system.

Methods: Ten population-based cohorts of adult patients in Ontario who received neurosurgical care from 2013 to 2017 were identified on the basis of procedural codes, and the cohorts were followed in administrative health data sources. Patient outcomes by the status of the treating hospital (with or without a neurosurgical residency program) within each cohort were compared with models adjusted for a priori confounders and with adjusted multilevel models (MLMs) to also account for hospital-level factors.

Results: A total of 46 608 neurosurgical procedures were included. Operative time was 8%–30% longer in hospitals with neurosurgical residency programs in 9 out of 10 cohorts. Thirty-day mortality was lower in hospitals with neurosurgical residency programs for aneurysm repair (odds ratio [OR] 0.30, 95% confidence interval [CI] 0.20–0.44), cerebrospinal fluid shunting (OR 0.52, 95% CI 0.34–0.79), intracerebral hemorrhage evacuation (OR 0.66, 95% CI 0.52–0.84), and posterior lumbar decompression (OR 0.32, 95% CI 0.15–0.65) in adjusted models. The mortality rates remained significantly different only for aneurysm repair (OR 0.19, 95% CI 0.05–0.69) and cerebrospinal shunting (OR 0.42, 95% CI 0.21–0.85) in MLMs. Length of stay was mostly shorter in hospitals with neurosurgical residents, but this finding did not persist in MLMs. Thirty-day reoperation rates did not differ between hospital types in MLMs. For 30-day readmission rates, only extracerebral hematoma decompression was significant in MLMs (OR 1.41, 95% CI 1.07–1.87).

Conclusion: Hospitals with neurosurgical residents had longer operative times with similar to better outcomes. Most, but not all, of the differences between hospitals with and without residency programs were explained by hospital-level variables rather than direct effects of residents.

Contexte : Les données relatives aux avantages et aux inconvénients de la participation des résidentes et résidents en neurochirurgie aux interventions de cette spécialité sont hétérogènes. Nous avons évalué l'effet des programmes de résidence en neurochirurgie sur les résultats chez les malades concernés au sein d'un volumineux système de santé universel à payeur unique.

Méthodes : Dix cohortes populationnelles composées de malades adultes ayant reçu des soins en neurochirurgie en Ontario entre 2013 et 2017 ont été identifiées à partir des codes d'acte, et suivies au moyen des bases de données administratives sur la santé. Les résultats chez les malades de chaque cohorte selon le statut de leur hôpital (offrant ou non un programme de résidence en neurochirurgie) ont été comparés à des modèles ajustés pour tenir compte de variables de confusion a priori, et à des modèles multiniveaux ajustés (MMN) pour tenir compte aussi de facteurs propres aux hôpitaux.

Résultats : En tout, nous avons inclus 46 608 interventions neurochirurgicales. Le temps opératoire a été 8 %–30 % plus long dans les hôpitaux offrant un programme de résidence en neurochirurgie dans 9 cohortes sur 10. La mortalité à 30 jours a été moindre dans les hôpitaux offrant un programme de résidence en neurochirurgie pour les réparations d'anévrisme (rapport des cotes [RC] 0,30, intervalle de confiance [IC] de 95 % 0,20–0,44), les dérivations du liquide céphalorachidien (RC 0,52, IC de 95 % 0,34–0,79), le drainage des hémorragies intracérébrales (RC 0,66, IC de 95 % 0,52–0,84) et la décompression postérieure lombaire (RC 0,32, IC de 95 % 0,15–0,65) dans les modèles ajustés. Les taux de mortalité sont demeurés significativement différents uniquement pour les réparations d'anévrisme (RC 0,19, IC de 95 % 0,05–0,69) et les dérivations du liquide céphalorachidien (RC 0,42, IC de 95 % 0,21–0,85) dans les MMN. La durée des séjours a été majoritairement moindre dans les hôpitaux offrant un programme de résidence en neurochirurgie, mais cette observation ne se maintenait pas dans les MMN. Les taux de réintervention à 30 jours n'ont pas différé entre les types d'hôpitaux dans les MMN. Les taux de réadmission à 30 jours n'ont été significatifs que pour les cas de décompression d'hématomes extracérébraux dans les MMN (RC 1,41, IC de 95 % 1,07–1,87).

Conclusion : Les temps opératoires ont été plus longs dans les hôpitaux offrant un programme de résidence en neurochirurgie, et les résultats ont été similaires ou meilleurs. La plupart des différences entre les hôpitaux offrant ou non un programme de résidence en neurochirurgie ont pu s'expliquer par des variables propres aux hôpitaux plus que par un quelconque effet direct des programmes de résidence en neurochirurgie.

Evidence from studies that have examined resident influence on the outcome of surgical procedures, in general, is heterogenous.[1–6] This is expected because of the different natures and complexities of these procedures.

Neurosurgery requires in-depth knowledge of neuroanatomy and the ability to perform microsurgery, which is obtained only after years of practice.[7] Therefore an experienced staff neurosurgeon will be heavily favoured over a neurosurgical trainee for key elements of the procedures. Neurosurgical patients usually require specialized perioperative bedside care and instant availability of a neurosurgical team to assess any neurologic deterioration to expedite any potential medical or surgical intervention. The latter setting might be more suitable for resident staff involvement. Existing evidence regarding the effect of neurosurgical residents (NRs) on patient outcome is heterogenous. Some studies have shown that involvement of NRs in North American hospitals does not increase rates of 30-day postoperative morbidity or mortality or even decrease them,[1,5,8–10] while others have shown increased morbidity and mortality.[11–17] Studies have been more consistent in showing that the involvement of residents prolongs neurosurgical procedures[1,10,12,14,16] Of note, involvement of NRs was solely defined on the basis of their presence in the operating room and did not include perioperative care provided by residents.[8,11,13,18] Hospitals with neurosurgical residency programs (NRPs) might be structurally different from hospitals without NRPs (e.g., presence of other trainees such as nursing students, anesthesiology residents). It is therefore important to differentiate between the status of hospitals (those with and without an NRP) and the specific effect of NRs themselves on patient outcomes. This has not been addressed in previous studies.

A recent meta-analysis highlighted the shortcomings of the existing literature.[19] All of the included studies were retrospective, and there was a possibility of duplicate cases as all of the studies used the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database.[1,8–10,12,14,15,17] The NSQIP gathers data from various institutions with substantially different health care infrastructures and training standards; these differences can influence the effect of NRs on patient outcomes and are partly responsible for the heterogenous results in the literature. Moreover, there was a paucity of data on procedure-specific outcomes, with most of the studies reporting only on combined procedures[8,11,12,17] or restricted to spinal procedures.[1,10,13–15] Different outcomes are expected from distinct neurosurgical pathologies, and combining them in analyses can produce conflicting results.

The practice of neurosurgery requires the availability of technology and some basic and specific infrastructures. In the Canadian province of Ontario, approximately half of the hospitals with neurosurgical services also have an NRP. Given the comparable infrastructure in hospitals providing neurosurgical care, the Ontario provincial health care system provides a unique opportunity to quantify possible benefits and drawbacks of resident training hospitals and NRs with respect to patient outcomes. To this end, we sought to examine these effects using a large contemporary database of the single-payer public health care insurance system in Ontario.

Methods

Study cohorts

Ten population-based cohorts of neurosurgical patients aged 18 years or older receiving care in Ontario between 2013 and 2017 were identified and followed in administrative health data sources as available through the single-payer health care system in Ontario. Universal coverage for physician care and hospital services is provided to all Ontario residents through the Ontario Health Insurance Program (OHIP). This study was approved by the Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

To create patient cohorts of the 10 most common neurosurgical procedures at the 11 hospitals with neurosurgical services in Ontario, we used the physician fee-for-service claims file (OHIP database), the mechanism

Table 1. Characteristics of patients in the 10 neurosurgical cohorts combined and characteristics of the patients' neurosurgeon by treatment at hospitals in Ontario with or without an NRP

Characteristic	No. (%) of patients;* hospital type Hospital with an NRP *n* = 30 366	 Hospital without an NRP *n* = 16 242	Standardized difference
Patient characteristics			
Female	13 704 (45.1)	7182 (44.2)	0.018
Year of neurosurgery	6047 (19.9)	2899 (17.8)	0.052
2013	5845 (19.2)	3107 (19.1)	0.003
2014	6028 (19.9)	3266 (20.1)	0.006
2015	6261 (20.6)	3438 (21.2)	0.014
2016	6185 (20.4)	3532 (21.7)	0.034
2017			
Age, yr			
18–34	2747 (9.05)	1172 (7.22)	0.067
35–49	5187 (17.1)	2921 (18.0)	0.024
50–64	10 166 (33.5)	5428 (33.4)	0.001
65–74	6776 (22.3)	4007 (24.7)	0.0556
≥ 75	5490 (18.1)	2714 (16.7)	0.036
Charlson Comorbidity Index score			
0	17 470 (57.5)	10 287 (63.3)	0.119
1–2	8498 (28.0)	4287 (26.4)	0.036
≥ 3	4398 (14.5)	1668 (10.3)	0.128
Elective admission	13 595 (44.8)	10 157 (62.5)	0.362
Attending neurosurgeon characteristics			
Age, yr, mean ± SD	49.87 ± 9.31	51.97 ± 8.88	0.230
Duration of practice, yr, mean ± SD	23.67 ± 10.23	24.51 ± 10.97	0.079
Time from admission to procedure, h, mean ± SD	1.69 ± 4.69	1.23 ± 3.93	0.107

NRP = neurosurgical residency program; SD = standard deviation.
*Unless indicated otherwise.

through which physician services are paid for by the Ontario Ministry of Health. We identified all surgical procedures in the OHIP database as billed by a neurosurgeon for patients 18 years of age or older during the study period (2013–2017). The 10 most common procedures performed at all 11 hospitals with neurosurgical services were identified to create the 10 cohorts. Neurosurgical procedures related to functional, epilepsy, pediatric, or peripheral nerve surgery were excluded from the study because they were not routinely performed at all hospitals.

Patient outcomes

Study outcomes were operative time (defined as length of surgery in minutes), length of index hospital stay (defined as the number of days from admission date to discharge date), 30-day all-cause mortality, 30-day readmission rate, and 30-day reoperation rate. Study outcomes were identified from the hospital Discharge Abstract Database (which includes mandatory submissions from hospitals to the Canadian Institute for Health Information), the OHIP physician billing database, and the National Ambulatory Care Reporting System database, which require mandatory submissions from hospitals for emergency department visits, as well as the Registered Persons Database.

Study determinant

The primary study determinant was whether the hospital had an NRP. We did not have data on the particular involvement of NRs preoperatively, intraoperatively, and postoperatively, but NRs are typically included in each of these aspects of care in hospitals with NRPs, in a way that is appropriate to their level of training. For additional data on the neurosurgical personnel in each hospital, see Appendix 1, eTables 1–6 (available at canjsurg.ca/lookup/doi/10.1503/cjs.008522/tab-related-content).

Confounders

A priori confounders included patient sex, age, socioeconomic status, any known comorbidity at the time of surgery, and the attending neurosurgeon's years of experience and age. Patient socioeconomic status at the time of procedure was determined using postal codes to rank patients' average neighbourhood income among other neighbourhoods in the census area and was classified as

Table 2. Adjusted associations between undergoing neurosurgery at a hospital with or without an NRP and operating time for each of the 10 study cohorts

Neurosurgical cohort	Mean operating time, min; hospital type: Hospitals with an NRP	Mean operating time, min; hospital type: Hospitals without an NRP	Unadjusted effect estimate (95% CI)	Adjusted effect estimate* (95% CI)	Total extra operating room time in hospitals with an NRP,† min	Adjusted multilevel effect estimate‡ (95% CI)
Lumbar posterior spinal decompression through bilateral or unilateral approach	206.59 ± 101.45 (*n* = 5737)	173.87 ± 85.13 (*n* = 6379)	1.19 (1.17–1.21)	1.08 (1.07–1.1)	79 799	1.24 (1.05–1.47)
Oncologic resection (astrocytoma, oligodendroglioma, glioblastoma, or metastatic tumour) performed through supratentorial or infratentorial craniotomy	244.37 ± 116.40 (*n* = 4950)	184.03 ± 76.58 (*n* = 1468)	1.33 (1.29–1.36)	1.20 (1.17–1.23)	182 190	1.17 (0.88–1.55)
Cervical or thoracic posterior spinal decompression performed through bilateral or unilateral approach	260.77 ± 119.55 (*n* = 3622)	193.19 ± 87.11 (*n* = 2229)	1.35 (1.32–1.38)	1.23 (1.20–1.26)	160 939	1.24 (1.05–1.47)
Acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy	112.39 ± 70.23 (*n* = 3994)	96.77 ± 71.76 (*n* = 1448)	1.16 (1.12–1.20)	1.08 (1.05–1.12)	30 920	1.06 (0.77–1.45)
Acute raised intracranial pressure managed with external ventricular drain or transducer	194.23 ± 134.04 (*n* = 3452)	173.86 ± 121.44 (*n* = 1105)	1.12 (1.07–1.18)	1.02 (0.96–1.07)	NA	1.29 (0.83–2.00)
Oncologic resection (meningioma and other tumorous lesions, including pituitary tumours) performed through supratentorial or infratentorial craniotomy or transphenoidal approach	363.73 ± 177.17 (*n* = 2858)	257.76 ± 143.43 (*n* = 1068)	1.41 (1.36–1.46)	1.30 (1.25–1.35)	221 003	1.17 (0.90–1.53)
Anterior spinal decompression performed through disc excision or vertebrectomy	220.93 ± 89.52 (*n* = 2113)	193.68 ± 72.81 (*n* = 1420)	1.14 (1.11–1.17)	1.09 (1.07–1.12)	36 832	1.07 (0.91–1.26)
Cerebral spinal fluid shunting (primary or revision) procedures	135.01 ± 55.20 (*n* = 2265)	116.66 ± 48.31 (*n* = 693)	1.16 (1.12–1.19)	1.09 (1.05–1.13)	23 781	1.29 (0.83–2.00)
Intracranial aneurysm repair of the carotid or vertebrobasilar system	360.57 ± 162.39 (*n* = 764)	226.33 ± 108.04 (*n* = 220)	1.59 (1.49–1.71)	1.26 (1.17–1.35)	44 958	1.29 (0.83–2.00)
Spontaneous intracerebral hemorrhage decompression performed through supratentorial or infratentorial craniotomy	208.45 ± 119.84 (*n* = 611)	162.42 ± 69.80 (*n* = 212)	1.28 (1.19–1.38)	1.09 (1.01–1.17)	8931	1.06 (0.77–1.45)

CI = confidence interval; NA = not applicable; NRP = neurosurgical residency program.

*Adjusted for patient sex, age, Charlson Comorbidity Index score, and income, and physician age and years of practice.

†Calculated as the (mean operating time [in minutes] in hospitals without a NRP) multiplied by (adjusted effect estimate – 1) multiplied by (number of procedures performed in hosptials with an NRP).

‡Two-level hierarchical models to account for the hospital-level factors adjusted for the prior variables.

household size–adjusted income in quintiles. Patient comorbidity at the time of the index hospital admission was determined using the Charlson Comorbidity Index, which has been shown to predict mortality, including in surgical patients.[20–22]

Statistical analysis

The NRP status of the hospital was modelled as a binary variable. Differences in patient characteristics by the NRP status of the treating hospital were assessed using standardized differences; a difference greater than 0.10 was deemed a statistically important difference.[23] The effects of the hospital's NRP status on the study outcomes were estimated in unadjusted models, in models adjusted for the a priori confounders, and in multilevel models (MLMs) that enabled us to account for hospital-level factors in addition to the a priori confounders.

The generalized linear model with the γ distribution was used for operating time.[24] The generalized linear model with negative binomial distribution was used for length of stay (LOS). Surgical time and LOS tended to have a skewed distribution, whereas the γ and negative binomial distributions provided a more flexible fit. The effect size estimated from these models can be interpreted as 100% multiplied by (effect size minus 1) to indicate the relative percentage increase or decrease in outcomes observed in patients at hospitals with or without an NRP. Logistic regression was used for 30-day mortality, 30-day readmissions, and 30-day reoperations. Odds ratios (ORs) and their 95% confidence intervals (CIs) were reported for binary outcomes. Models were run separately for each of the 10 patient cohorts. SAS software version 9.4 was used for all analyses.

Results

During the study period, the most common neurosurgical procedures defining the 10 study cohorts were lumbar posterior spinal decompression (*n* = 12 116); cranial intra-axial oncologic resection (*n* = 6418); cervical or thoracic posterior spinal decompression (*n* = 5851); acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy (*n* = 5442);

Table 3. Adjusted associations between undergoing neurosurgery at a hospital with or without an NRP and length of hospital stay for each of the 10 study cohorts

Neurosurgical cohort	Length of stay, d, mean ± SD; hospital type		Unadjusted effect estimate (95% CI)	Adjusted effect estimate* (95% CI)	Adjusted multilevel effect estimate† (95% CI)
	Hospitals with an NRP	Hospitals without an NRP			
Lumbar posterior spinal decompression through bilateral or unilateral approach	4.70 ± 7.91	4.93 ± 9.42	0.95 (0.92–0.99)	0.89 (0.86–0.92)	1.05 (0.83–1.34)
Oncologic resection (astrocytoma, oligodendroglioma, glioblastoma, or metastatic tumour) performed through supratentorial or infratentorial craniotomy	10.16 ± 15.01	10.93 ± 18.51	0.93 (0.88–0.98)	0.89 (0.84–0.94)	0.88 (0.73–1.06)
Cervical or thoracic posterior spinal decompression performed through bilateral or unilateral approach	11.78 ± 24.07	10.98 ± 25.03	1.07 (1.02–1.14)	0.99 (0.93–1.06)	1.05 (0.83–1.34)
Acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy	14.79 ± 28.69	15.30 ± 33.33	0.92 (0.86–0.99)	0.92 (0.86–0.99)	1.01 (0.79–1.29)
Acute raised intracranial pressure managed with external ventricular drain or transducer	27.56 ± 59.55	29.78 ± 45.38	1.08 (1.01–1.16)	1.13 (1.05–1.22)	1.15 (0.89–1.48)
Oncologic resection (meningioma and other tumorous lesions, including pituitary tumours) performed through supratentorial or infratentorial craniotomy or transphenoidal approach	11.05 ± 28.86	11.35 ± 20.33	0.97 (0.9–1.05)	0.89 (0.83–0.96)	0.83 (0.68–1.01)
Anterior spinal decompression performed through disc excision or vertebrectomy	5.31 ± 18.31	4.57 ± 12.34	1.16 (1.07–1.26)	1.10 (1.01–1.19)	0.97 (0.78–1.20)
Cerebral spinal fluid shunting (primary or revision) procedures	29.60 ± 62.43	22.79 ± 53.44	1.30 (1.16–1.45)	1.33 (1.17–1.50)	1.27 (0.86–1.89)
Intracranial aneurysm repair of the carotid or vertebrobasilar system	17.55 ± 26.80	18.92 ± 28.18	0.93 (0.79–1.09)	1.14 (0.95–1.37)	1.18 (0.90–1.53)
Spontaneous intracerebral hemorrhage decompression performed through supratentorial or infratentorial craniotomy	25.49 ± 33.56	22.41 ± 25.34	1.14 (0.98–1.32)	1.14 (0.97–1.34)	1.11 (0.90–1.37)

CI = confidence interval; NRP = neurosurgical residency program; SD = standard deviation.
*Adjusted for patient sex, age, Charlson Comorbidity Index score, and income, and physician age and years of practice.
†Two-level hierarchical models to account for the hospital-level factors adjusted for the prior variables.

acute raised intracranial pressure managed with external ventricular drain (EVD) or transducer (n = 4557); resection for extra-axial oncologic disease, including pituitary adenoma, performed through a supratentorial or infratentorial craniotomy or via a trans-sphenoidal approach (n = 3926); anterior spinal decompression (n = 3533); cerebrospinal fluid shunting (primary or revision) procedures (n = 2958); intracranial aneurysm repair (n = 984); and decompression for spontaneous supratentorial or infratentorial intracerebral hemorrhage (SICH, n = 823).

The characteristics of all patients in the 10 neurosurgical cohorts combined are provided in Table 1, and the characteristics of the patients in each of the 10 neurosurgical cohorts are provided in Appendix 1, eTables 7–16. There was no clinically important difference between patients who had their procedure performed at a hospital with an NRP and those who had their procedure performed at a hospital without an NRP, despite some standardized differences greater than 0.10, indicating a statistically meaningful difference. These included a slightly larger proportion of patients with a Charlson Comorbidity Index score of 3 or greater, a smaller proportion of elective cases, younger age of the attending neurosurgeon, and longer time from admission to procedure at a hospital with or without an NRP for some cohorts. For most cohorts, more patients were treated at a hospital with an NRP than without an NRP (about 75% v. 25%). An exception was found in the category of oncologic extra-axial resections, where 53% of patients were treated at a hospital without an NRP.

Table 2 shows differences in surgical times for each neurosurgical cohort according to hospital NRP status. As shown, the mean operating time was longer for patients treated at hospitals with an NRP than without an NRP for all procedures in each of our 10 cohorts. The crude difference in cumulative procedural length varied between 12% and 59% longer for a specific set of procedures, depending on the cohort under investigation. After we adjusted for patient and surgeon characteristics, effect estimates appeared to be attenuated but still suggested a longer surgical case time in hospitals with an NRP for all but 1 cohort (acute raised intracranial pressure and EVD insertion). In MLMs, however, operating time did not differ for most neurosurgical cohorts when assessed by NRP status, except for lumbar posterior spinal decompression

Table 4. Adjusted associations between undergoing neurosurgery at a hospital with or without an NRP and 30-day mortality for each of the 10 study cohorts

Neurosurgical cohort	Deaths, no. (%) of patients; hospital type: Hospitals with an NRP	Deaths, no. (%) of patients; hospital type: Hospital without an NRP	Unadjusted OR (95% CI)	Adjusted OR* (95% CI)	Adjusted multilevel OR† (95% CI)
Lumbar posterior spinal decompression through bilateral or unilateral approach	10 (0.2)	33 (0.5)	0.34 (0.17–0.68)	0.32 (0.15–0.65)	0.79 (0.45–1.38)
Oncologic resection (astrocytoma, oligodendroglioma, glioblastoma, or metastatic tumour) performed through supratentorial or infratentorial craniotomy	240 (5.0)	71 (4.8)	1.04 (0.80–1.34)	1.02 (0.77–1.34)	1.03 (0.65–1.63)
Cervical or thoracic posterior spinal decompression performed through bilateral or unilateral approach	69 (1.9)	49 (2.2)	0.87 (0.60–1.25)	–	0.79 (0.45–1.38)
Acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy	362 (9.1)	147 (10.2)	0.89 (0.74–1.07)	0.88 (0.73–1.07)	0.90 (0.58–1.41)
Acute raised intracranial pressure managed with external ventricular drain or transducer	792 (22.9)	284 (25.7)	0.89 (0.79–1.00)	0.97 (0.86–1.11)	0.99 (0.60–1.62)
Oncologic resection (meningioma and other tumorous lesions, including pituitary tumours) performed through supratentorial or infratentorial craniotomy or transphenoidal approach	58 (2.0)	34 (3.2)	0.64 (0.42–0.97)	0.85 (0.53–1.37)	0.73 (0.37–1.45)
Anterior spinal decompression performed through disc excision or vertebrectomy	10 (0.5)	9 (0.6)	0.75 (0.30–1.83)	0.69 (0.28–1.75)	0.49 (0.17–1.37)
Cerebral spinal fluid shunting (primary or revision) procedures	68 (3.0)	36 (5.2)	0.58 (0.39–0.86)	0.52 (0.34–0.79)	0.42 (0.21–0.85)
Intracranial aneurysm repair of the carotid or vertebrobasilar system	52 (6.8)	44 (20.0)	0.34 (0.23–0.49)	0.30 (0.20–0.44)	0.19 (0.05–0.69)
Spontaneous intracerebral hemorrhage decompression performed through supratentorial or infratentorial craniotomy	154 (25.2)	79 (37.3)	0.68 (0.54–0.84)	0.66 (0.52–0.84)	0.56 (0.27–1.14)

CI = confidence interval; NRP = neurosurgical residency program; OR = odds ratio.
*Adjusted for patient sex, age, Charlson Comorbidity Index score, and income, and physician age and years of practice.
†Two-level hierarchical models to account for the hospital-level factors adjusted for the prior variables.

and cervicothoracic posterior spinal decompression; the surgical times for these cohorts were 24% longer in patients treated at a hospital with an NRP (effect estimate 1.24, 95% CI 1.05–1.47).

Table 3 shows differences in the length of hospital admission for each of our study cohorts. In adjusted models, length of hospital admission was about 10% shorter in hospitals with an NRP for the following cohorts: posterior lumbar decompression, intra-axial tumour resection, acute or chronic extracerebral hematoma decompression, and extra-axial tumour resection. In contrast, hospital admission was longer in hospitals with an NRP for the patient cohorts with acute raised intracranial pressure managed with EVD or transducer (13%), anterior spinal decompression (10%), and cerebrospinal fluid shunting (primary or revision) procedures (33%). In MLMs that accounted for variables at the hospital level, length of hospital stay did not differ by the NRP status of the hospital.

For half of the neurosurgical cohorts, 30-day all-cause mortality was less than 5% overall (Table 4); for the other cohorts, 30-day mortality ranged between 5% and almost 40%. In adjusted models, the risk of death at 30 days was lower in patients at a hospital with an NRP who underwent lumbar posterior spinal decompression (OR 0.32, 95% CI 0.15–0.65), cerebrospinal fluid shunting procedures (OR 0.52, 95% CI 0.34–0.79), intracranial aneurysm repair (OR 0.30, 95% CI 0.20–0.44), and SICH decompression (OR 0.66, 95% CI 0.52–0.84). In MLMs, the lower risk of 30-day mortality persisted only for the 2 cohorts of patients who had cerebrospinal fluid shunting procedures and intracranial aneurysm repair.

Table 5 and Table 6 show 30-day readmission and 30-day reoperation rates, respectively, by hospital NRP status. In all models, there was a higher risk for readmission (OR 1.41, 95% CI 1.07–1.87) and for reoperation (OR 1.70, 95% CI 1.07–2.71) in patients who underwent acute or chronic extracerebral hematoma decompression when performed at a hospital with an NRP. In contrast, there was a lower risk of 30-day readmission in patients who underwent intra-axial oncologic resections at a hospital with an NRP and a lower risk of reoperation within 30 days in patients who underwent anterior spinal decompression performed via disc excision or vertebrectomy at a hospital with an NRP. Of note, the latter

Table 5. Adjusted associations between undergoing neurosurgery at a hospital with or without an NRP and 30-day readmission for each of the 10 study cohorts

Neurosurgical cohort	Readmissions, no. (%) of patients; hospital type: Hospitals with an NRP	Hospitals without an NRP	Unadjusted OR (95% CI)	Adjusted OR* (95% CI)	Adjusted multilevel OR† (95% CI)
Lumbar posterior spinal decompression through bilateral or unilateral approach	370 (6.4)	447 (7.0)	0.92 (0.81–1.05)	0.95 (0.82–1.09)	0.86 (0.56–1.32)
Oncologic resection (astrocytoma, oligodendroglioma, glioblastoma, or metastatic tumour) performed through supratentorial or infratentorial craniotomy	952 (19.2)	360 (24.5)	0.78 (0.71–0.87)	0.84 (0.75–0.95)	0.80 (0.62–1.03)
Cervical or thoracic posterior spinal decompression performed through bilateral or unilateral approach	354 (9.8)	221 (9.9)	0.99 (0.84–1.16)	0.92 (0.78–1.09)	1.00 (0.59–1.70)
Acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy	795 (19.9)	214 (14.8)	1.35 (1.17–1.55)	1.32 (1.14–1.53)	1.41 (1.07–1.87)
Acute raised intracranial pressure managed with external ventricular drain or transducer	481 (13.9)	124 (12.1)	1.15 (0.96–1.37)	1.06 (0.88–1.29)	0.99 (0.56–1.73)
Oncologic resection (meningioma and other tumorous lesions, including pituitary tumours) performed through supratentorial or infratentorial craniotomy or transphenoidal approach	421 (14.7)	179 (16.8)	0.88 (0.75–1.03)	0.87 (0.73–1.03)	0.84 (0.61–1.16)
Anterior spinal decompression performed through disc excision or vertebrectomy	92 (4.4)	54 (3.8)	1.14 (0.82–1.59)	1.10 (0.78–1.54)	1.04 (0.57–1.92)
Cerebral spinal fluid shunting (primary or revision) procedures	799 (35.3)	232 (33.5)	1.05 (0.94–1.19)	0.96 (0.86–1.09)	0.99 (0.79–1.24)
Intracranial aneurysm repair of the carotid or vertebrobasilar system	62 (8.1)	18 (8.2)	0.99 (0.60–1.64)	0.87 (0.50–1.53)	0.83 (0.46–1.50)
Spontaneous intracerebral hemorrhage decompression performed through supratentorial or infratentorial craniotomy	64 (10.5)	16 (7.5)	1.39 (0.82–2.35)	1.05 (0.61–1.80)	1.06 (0.53–2.09)

CI = confidence interval; NRP = neurosurgical residency program; OR = odds ratio.
*Adjusted for patient sex, age, Charlson Comorbidity Index score, and income, and physician age and years of practice.
†Two-level hierarchical models to account for the hospital-level factors adjusted for the prior variables.

statistical difference did not persist in MLMs that accounted for hospital-level variables.

We performed sensitivity analyses to assess inclusion of admission category (urgent or elective) into our models. There was no major difference in adjusted models or multilevel models (Appendix 1, eTables 17–18).

Discussion

The main finding we observed in our 10 population-based cohorts of patients undergoing the most frequently performed neurosurgical procedures was a longer operative time when those procedures were performed in hospitals with NRs. This is an intuitively predictable observation, but its effect is financially substantial. This can be illustrated for specific interventions: using the adjusted effect estimate for lumbar decompression, the extra operating room time in teaching hospitals that could have been saved if the procedures had been performed in nonteaching hospitals totals approximately 790 000 minutes (or 13 166 h). Using a rough estimate of about \$40 per minute of operating room time,[25] this translates into an added cost of teaching residents of \$31.5 million over the 5-year period of this study.

Importantly, the amount of time by which each operation was longer at hospitals that have an NRP than at those that do not have an NRP correlated with the level of difficulty of the neurosurgical procedure performed (e.g., aneurysm repairs or oncological resections v. subdural hematoma evacuations or EVD insertions). However, when assessed via our MLMs, only spinal surgeries took significantly longer when performed in hospitals with an NRP, suggesting that hospital-level factors play an important role in prolonging operative time. This suggests that other hospital factors, such as the concomitant presence of nursing students or anesthesiology residents in training, or hospital policies, may also influence the length of surgical procedures and that this observation may be related not just to the involvement of NRs. Nevertheless, operative time was prolonged for 9 of the 10 procedural cohorts when performed in hospitals with an NRP.

The perioperative death rate was lower in hospitals with NRs in patients undergoing cerebrospinal fluid shunting, SICH evacuation, and intracranial aneurysm surgery. This can probably be explained by the reality that academic hospitals often can provide more focused neurological care in intensive care units and have

Table 6. Adjusted associations between undergoing neurosurgery at a hospital with or without an NRP and 30-day reoperation for each of the 10 study cohorts

Neurosurgical cohort	Reoperations, no. (%) of patients; hospital type		Unadjusted OR (95% CI)	Adjusted OR* (95% CI)	Adjusted multilevel OR† (95% CI)
	Hospitals with an NRP	Hospitals without an NRP			
Lumbar posterior spinal decompression through bilateral or unilateral approach	10 (0.2)	33 (0.5)	0.92 (0.73–1.17)	0.97 (0.75–1.25)	1.07 (0.47–2.46)
Oncologic resection (astrocytoma, oligodendroglioma, glioblastoma, or metastatic tumour) performed through supratentorial or infratentorial craniotomy	220 (4.4)	78 (5.3)	0.84 (0.65–1.08)	1.01 (0.75–1.36)	0.94 (0.45–1.97)
Cervical or thoracic posterior spinal decompression performed through bilateral or unilateral approach	82 (2.3)	46 (2.1)	1.10 (0.77–1.57)	0.93 (0.64–1.35)	0.89 (0.46–1.70)
Acute or chronic extracerebral hematoma decompression performed through burr hole(s) or craniotomy	436 (10.9)	109 (7.5)	1.45 (1.19–1.77)	1.51 (1.22–1.88)	1.70 (1.07–2.71)
Acute raised intracranial pressure managed with external ventricular drain or transducer	215 (6.2)	66 (6.0)	1.04 (0.80–1.36)	0.86 (0.65–1.13)	0.89 (0.40–2.00)
Oncologic resection (meningioma and other tumorous lesions, including pituitary tumours) performed through supratentorial or infratentorial craniotomy or transphenoidal approach	123 (4.3)	49 (4.6)	0.94 (0.68–1.3)	1.00 (0.7–1.42)	0.94 (0.56–1.55)
Anterior spinal decompression performed through disc excision or vertebrectomy	19 (0.9)	21 (1.5)	0.61 (0.33–1.13)	0.52 (0.28–0.98)	0.61 (0.21–1.81)
Cerebral spinal fluid shunting (primary or revision) procedures	565 (24.9)	173 (25.0)	1.00 (0.86–1.16)	0.91 (0.78–1.05)	0.88 (0.66–1.18)
Intracranial aneurysm repair of the carotid or vertebrobasilar system	11 (1.4)	≤ 5 (2.3)	0.63 (0.22–1.80)	–	0.66 (0.18–2.49)
Spontaneous intracerebral hemorrhage decompression performed through supratentorial or infratentorial craniotomy	16 (2.6)	9 (4.2)	0.62 (0.28–1.37)	0.47 (0.21–1.09)	0.51 (0.23–1.11)

CI = confidence interval; NRP = neurosurgical residency program; OR = odds ratio.
*Adjusted for patient sex, age, Charlson Comorbidity Index score, and income, and physician age and years of practice.
†Two-level hierarchical models to account for the hospital-level factors adjusted for the prior variables.

greater neurosurgical trainee or staff availability at the bedside. In MLMs, only intracranial aneurysm repair and cerebrospinal fluid shunting were significantly associated with lower mortality rates when performed in hospitals with NRPs, suggesting that NRs are more influential in lowering mortality in these cases, possibly because their availability at the bedside results in more timely interventions for complications such as vasospasm, seizure, infection, and shunt block.[26]

Although others have reported on the effect of NRs on patient outcomes,[1,3,8–18] these studies had important limitations as described above. Our study design and analysis improved upon many of these limitations such as homogenizing the compared groups, collecting data prospectively, and considering hospital-level variables. Our results generally support a recent meta-analysis that suggested that after adjustment for comorbidities, complexity, and procedure type, the presence of NRs did not adversely affect patient outcomes.[19] Our findings also confirm the longer operative time observed by others,[1,10,12,14,15] and thus the higher cost, associated with operations involving NRs in Canadian hospitals.

Limitations

Within each cohort we did not adjust for the severity of disease of patients treated in hospitals with and without NRs. This could have affected the results of our study if disease severity has an influence on the referral to the hospital where the patient is treated. However, this is unlikely to be of great impact as each neurosurgical hospital in Ontario has its own catchment area, and referrals to distant hospitals for common neurosurgical procedures are uncommon. Further, our sensitivity analyses that adjusted for urgent or elective neurosurgery supported our primary results, suggesting no such effect.

Conclusion

In our study, the presence of NRs and the resultant increase in operative time did not adversely affect the clinical outcomes of most neurosurgical patients and was associated with better survival for patients undergoing a few procedures. These minor benefits should be balanced against the substantial cost of providing operative training for NRs at these hospitals when compared with funding human resource departments for similarly skilled non-trainee staff such as nurse practitioners, surgical assistants, and physician assistants. In addition to the more than $30 million dollars of taxpayer money spent to train residents, the number of procedures that could have been performed is staggering when one considers the 2600 hours of operative time that is given each year to training residents in academic centres. Although there are no recent data, reports from 2004 and 2006 indicated that only half of neurosurgical residents were able to find employment in Canada and the problem was predicted to persist.[27,28] However, if new neurosurgical centres are opened or existing centres are enlarged to address the long wait times for surgery in Canada, training additional neurosurgical residents in Canada could be warranted.

Acknowledgements: We thank all participating hospitals and neurosurgery departments for their contribution to this study. This study was supported by ICES, which is funded by an annual grant from the Ontario Ministry of Health (MOH). This study also received funding from the Department of Surgery at Queen's University. Parts of this study are based on data and information compiled and provided by MOH, the Canadian Institute for Health Information, and the Registrar General through ServiceOntario. This research used data adapted from the Statistics Canada Postal Code[OM] Conversion File, which is based on data licensed from Canada Post Corporation, and/or data adapted from the Ontario Ministry of Health Postal Code Conversion File, which contains data copied under licence from Canada Post Corporation and Statistics Canada. The analyses, conclusions, opinions, and statements expressed herein are solely those of the authors and do not reflect those of the funding or data sources; no endorsement is intended or should be inferred.

Affiliations: From the Division of Neurosurgery, Department of Surgery, Kingston General Hospital, Kingston, Ont. (Taslimi, Cook, Levy); the Department of Surgery, Queen's University, Kingston, Ont. (Brogly); ICES Queen's, Kingston, Ont. (Li); the Faculty of Medicine, University of British Columbia, Kelowna, B.C. (Rodger); the Department of Life Sciences, Queen's University, Kingston, Ont. (Rodger); and the Department of Neurosurgery, McMaster University, Hamilton, Ont. (Kasper).

Funding: This study is funded by an annual grant from the Ontario Ministry of Health.

Competing interests: E. Kasper has received travel support from Steward Health Care. No other competing interests were declared.

Contributors: S. Brogly, E. Kasper, and R. Levy conceived the study. J. Rodger acquired the data, which S. Taslimi, W. Li, and D. Cook analyzed. S. Taslimi and D. Cook wrote the article, which S. Brogly, W. Li, J. Rodger, E. Kasper, and R. Levy critically revised. All authors agreed to be accountable for all aspects of the work.

References

1. Kim RB, Garcia RM, Smith ZA, et al. Impact of resident participation on outcomes after single-level anterior cervical diskectomy and fusion: an analysis of 3265 patients from the American College of Surgeons National Surgical Quality Improvement Program Database. *Spine* 2016;41:E289-96.
2. Kiran RP, Ahmed Ali U, Coffey JC, et al. Impact of resident participation in surgical operations on postoperative outcomes: National Surgical Quality Improvement Program. *Ann Surg* 2012;256:469-75.
3. Schoenfeld AJ, Serrano JA, Waterman BR, et al. The impact of resident involvement on post-operative morbidity and mortality following orthopaedic procedures: a study of 43,343 cases. *Arch Orthop Trauma Surg* 2013;133:1483-91.
4. Uecker J, Luftman K, Ali S, et al. Comparable operative times with and without surgery resident participation. *J Surg Educ* 2013;70:696-9.
5. Castleberry AW, Clary BM, Migaly J, et al. Resident education in the era of patient safety: a nationwide analysis of outcomes and complications in resident-assisted oncologic surgery. *Ann Surg Oncol* 2013;20:3715-24.
6. D'Souza N, Hashimoto DA, Gurusamy K, et al. Comparative outcomes of resident vs attending performed surgery: a systematic review and meta-analysis. *J Surg Educ* 2016;73:391-9.
7. van Loveren H. The making of a neurosurgeon: from your hands to theirs. *J Neurol Surg B Skull Base* 2018;79:415-8.
8. Lim S, Parsa AT, Kim BD, et al. Impact of resident involvement in neurosurgery: an analysis of 8748 patients from the 2011 American College of Surgeons National Surgical Quality Improvement Program database. *J Neurosurg* 2015;122:962-70.
9. Lakomkin N, Hadjipanayis CG. Resident participation is not associated with postoperative adverse events, reoperation, or prolonged length of stay following craniotomy for brain tumor resection. *J Neurooncol* 2017;135:613-9.
10. Phan K, Phan P, Stratton A, et al. Impact of resident involvement on cervical and lumbar spine surgery outcomes. *Spine J* 2019;19:1905-10.
11. Bydon M, Abt NB, De la Garza-Ramos R, et al. Impact of resident participation on morbidity and mortality in neurosurgical procedures: an analysis of 16,098 patients. *J Neurosurg* 2015;122:955-61.
12. Seicean A, Kumar P, Seicean S, et al. Impact of resident involvement in neurosurgery: an American College of Surgeons' National Surgical Quality Improvement Program Database analysis of 33,977 patients. *Neurospine* 2018;15:54-65.
13. Lee NJ, Kothari P, Kim C, et al. The impact of resident involvement in elective posterior cervical fusion. *Spine* 2018;43:316-23.
14. Kothari P, Lee NJ, Lakomkin N, et al. Impact of resident involvement on morbidity in adult patients undergoing fusion for spinal deformity. *Spine* 2016;41:1296-302.
15. Zuckerman SL, Lim J, Lakomkin N, et al. Effect of resident and fellow involvement in adult spinal deformity surgery. *World Neurosurg* 2019;122:e759-64.
16. Morgan MK, Assaad NN, Davidson AS. How does the participation of a resident surgeon in procedures for small intracranial aneurysms impact patient outcome? *J Neurosurg* 2007;106:961-4.
17. Ferraris VA, Harris JW, Martin JT, et al. Impact of residents on surgical outcomes in high-complexity procedures. *J Am Coll Surg* 2016;222:545-55.
18. Yamaguchi JT, Garcia RM, Cloney MB, et al. Impact of resident participation on outcomes following lumbar fusion: an analysis of 5655 patients from the ACS-NSQIP database. *J Clin Neurosci* 2018;56:131-6.
19. Baisiwala S, Shlobin NA, Cloney MB, et al. Impact of resident participation during surgery on neurosurgical outcomes: a meta-analysis. *World Neurosurg* 2020;142:1-12.
20. Charlson M, Szatrowski TP, Peterson J, et al. Validation of a combined comorbidity index. *J Clin Epidemiol* 1994;47:1245-51.
21. Neuhaus V, King J, Hageman MG, et al. Charlson comorbidity indices and in-hospital deaths in patients with hip fractures. *Clin Orthop Relat Res* 2013;471:1712-9.

22. Kirkland LL, Kashiwagi DT, Burton MC, et al. The Charlson Comorbidity Index Score as a predictor of 30-day mortality after hip fracture surgery. *Am J Med Qual* 2011;26:461-7.
23. Austin PC, Stuart EA. Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies. *Stat Med* 2015;34:3661-79.
24. Williford E, Haley V, McNutt LA, et al. Dealing with highly skewed hospital length of stay distributions: the use of Gamma mixture models to study delivery hospitalizations. *PLoS One* 2020;15:e0231825.
25. Childers CP, Maggard-Gibbons M. Understanding costs of care in the operating room. *JAMA Surg* 2018;153:e176233.
26. Wan AWZ, Luoma AMV. Postoperative care of neurosurgical patients: general principles. *Neurosurgical Anasthesia*. 2020;21:349-55.
27. Kondro W. New neurosurgeons left jobless: where's the plan? *CMAJ* 2004;170:1377-8.
28. Woodrow SI, O'Kelly C, Hamstra SJ, et al. Unemployment in an underserviced specialty?: The need for co-ordinated workforce planning in Canadian neurosurgery. *Can J Neurol Sci* 2006; 33:170-4.