Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

An Australian Response to the COVID-19 Pandemic and Its Implications on the Practice of Neurosurgery

Joyce Antony[1,2], *William Thomas James*[1], *Anna Jolly Neriamparambil*[1], *Dwarkesh Dharmendra Barot*[3], *Teresa Withers*[1]

■ OBJECTIVE: **This study was designed to assess the impact of public health policy in Australia in response to the coronavirus disease identified in 2019 (COVID-19) pandemic on the delivery of neurosurgical services. Being essential services, we postulated that there would not be a decrease in elective and emergency neurosurgical presentations and surgeries.**

■ METHODS: **This is a prospective, observational, epidemiologic study in strict adherence to the "STROBE" (Strengthening The Reporting of OBservational studies in Epidemiology) guidelines. It is a cross-sectional, multicentric study involving 5 tertiary neurosurgical centers to capture all public neurosurgical admissions in Queensland during the past 3 months (February—April, 2020) of significant public health policy changes to combat COVID-19.**

■ RESULTS: **An analysis of the 1298 admissions for the Queensland population of 5.07 million Australians demonstrated a decrease in the number of elective and emergency admissions. The decline in elective admissions, particularly degenerative spine, benign neoplasms, and vascular pathologies, was a direct response of government strategy to curb activity to urgent surgical interventions only. Moreover, a trend toward fewer emergency admissions was also noted, partly explained by less trauma and also a decline in vascular pathologies including subarachnoid hemorrhage.**

■ CONCLUSIONS: **In comparison with Europe and North America, this study demonstrates the impact of proactive public health measures in Australia that successfully flattened the COVID-19 curve while facilitating ongoing care of acutely unwell neurosurgical patients.**

INTRODUCTION

Coronavirus disease identified in 2019 (COVID-19) was first reported as a pneumonia of uncertain etiology in 44 patients from Wuhan City, Hubei province, China on January 8, 2020.[1] It swept through the province, and further outbreaks were reported in Europe and North America, quickly bringing the health care sector to its knees.[2,3] On January 30, the World Health Organization declared the COVID-19 outbreak a public health emergency of international concern. In the next 3 months, COVID-19 rapidly spread to the rest of the world, facilitated by international commercial travel, and was officially deemed a pandemic by the World Health Organization on March 11, 2020.[2] Hospitals became overcrowded, personal protective equipment and essential medical resources became sparse, and, in some instances, crippling already overwhelmed health care systems.[2,3]

On the contrary, the narrative in Australia was very different with swift, stringent public health policies that quickly flattened the curve. In this prospective epidemiologic study, we documented the Australian response to COVID-19 and the impact of public health policy on the delivery of neurosurgical services.

Being essential services, we postulated that there would not be a decrease in elective and emergency presentations as a result of the public health policies in response to COVID-19. We also postulated that neurosurgical interventions would also remain constant during this period.

Key words
- Australia
- COVID-19
- Neurosurgery
- Public health
- Subarachnoid hemorrhage

Abbreviations and Acronyms
COVID-19: Coronavirus disease identified in 2019

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MATERIAL AND METHODS

Study Design

This is a prospective, observational, multicentric, epidemiologic study of the impact of COVID-19 on neurosurgical practice. This cross-sectional study was undertaken in strict adherence to "STROBE" (Strengthening The Reporting of OBservational studies in Epidemiology) guidelines. A multicentric study, all neurosurgical admissions across 5 tertiary neurosurgical center over the 3 months from February 2020 to April 2020, were collected.

Data Collection

Data were prospectively collected by 5 neurosurgical trainees, 1 from each center, and cross-examined by a senior neurosurgeon to ensure there was no error in interpretation. The data collected pertaining to the neurosurgical admission included institution, month of admission, age, gender, type of admission (Elective or Emergency), region of interest (Cranial, Spine, or Peripheral), etiology (Congenital, Cerebrospinal Fluid flow, Degenerative, Functional, Infection, Oncology, Trauma, and Vascular), and surgery (Yes or No). Depending on institutional practices, some minor procedures were performed in the operating room or by the bedside. Therefore cranial procedures such as external ventricular drain insertion, wound washouts, and intracranial pressure monitoring, although documented, were recorded as not being a surgical procedure. Similarly, image-guided injections were inconsistently performed by neurosurgeons at some centers and interventional radiologists at others and were therefore not recorded as surgical procedures. Magnetic resonance imaging under general anesthetic and diagnostic digital subtraction angiograms were also not recorded as surgical procedures. Data were also collected for the number of COVID-19−positive patients during the same time period.

Bias

In order to account for bias from sampling error, the study incorporated all neurosurgical admissions across all 5 tertiary neurosurgical centers in Queensland. Moreover, to account for bias from confounders, demographic data including age and gender were collected. Descriptive analysis was performed using histograms, point-plots, and bar-plots to study trends. Inferential analysis was performed using the Welch 2-sample *t*-test to examine the difference in means of continuous variables and Pearson chi-squared test for categorical variables to determine if the observed distribution was due to chance.

RESULTS

Descriptive Analysis

Five public tertiary neurosurgical centers (4 adult and 1 pediatric) service the entire Queensland population of 5.07 million. These 5 centers are staffed by 29 neurosurgeons, of varying durations of commitment, and 25 full-time neurosurgical trainees, both accredited and unaccredited. Over the 3 months, 1298 neurosurgical (542 elective and 757 emergency) admissions were recorded, and none of these patients tested COVID-19 positive. While 535 patients were managed conservatively, 763 of them underwent surgical intervention.

During this period, 116,479 tests for COVID-19 were performed in Queensland with 1032 confirmed cases (Figure 1) and 6 recorded deaths. Of these, 980 patients have recovered, with only 9 current hospitalizations and 4 intensive care unit admissions. Queensland performed 22,600 tests per 1 million population, similar to the national average of 23,900 tests per 1 million. Contact tracing demonstrated that the vast majority of confirmed cases were acquired from overseas travel (799) or acquired locally through close contact with a known confirmed case (174), with relatively small numbers of community transmission (44).

Inferential Analysis

The mean age of neurosurgical admissions in February was 51.0 years (95% confidence interval [CI] 49.1−53.0, $P < 0.05$), in March 48.5 years (95% CI 46.6−50.4, $P < 0.05$), and in April 49.6 years (95% CI 47.0−52.1, $P < 0.05$). The Welch 2-sample *t*-test did not demonstrate a statistically significant difference in mean ages during these 3 months. However, the histogram in Figure 2 demonstrates a flattening of the age distribution in April due to the reduced number of patients between 50 and 80 years of age. The point-plot (Figure 3) and bar-plots demonstrate an obvious decline in the number of neurosurgical presentations in April 2020. Despite the decline in presentations, the slight preponderance for males (X-squared = 0.8, df = 2, *P* value = 0.68) was preserved, as demonstrated in Figure 4.

The Pearson chi-squared test demonstrated a *P* value <0.05, therefore rejecting the null hypothesis that urgency of presentation (X-squared = 14.9, df = 2), site (X-squared = 17.3, df = 4), and etiology (X-squared = 38.0, df = 14) are independent of the timing of admission. Although the decrease in elective presentations was planned and therefore anticipated, there was also a decrease in the number of emergency presentations as demonstrated in Figures 5 and 6.

The Pearson chi-squared test demonstrated a *P* value <0.05, therefore rejecting the null hypothesis that site (X-squared = 13.0, df = 4) and etiology (X-squared = 25.0, df = 14) were independent of the timing of elective admissions. While the decline in emergency presentations (X-squared = 21.3, df = 14, *P* value 0.09) could be attributed to the decrease in trauma presentations, there was also a decrease in the number of vascular presentations that could be clinically significant.

Moreover, in patients who underwent surgical intervention, the Pearson chi-squared test demonstrated a *P* value <0.05, therefore rejecting the null hypothesis that site (X-squared = 13.0, df = 4), and etiology (X-squared = 25.0, df = 14) were independent of the timing of admission as demonstrated in Figures 7 and 8.

DISCUSSION

The first confirmed case of COVID-19 in Queensland presented January 28, a day after the group of 9 tourists flew in from Wuhan. Despite attempting strict individual isolation and daily testing, 5 of the 9 individuals subsequently tested positive with varying severity of symptomology. On January 29, the Queensland government declared a public health emergency. The federal government banned gatherings of more than 500 people and advised against nonessential overseas travel on March 12, 2020 with the first

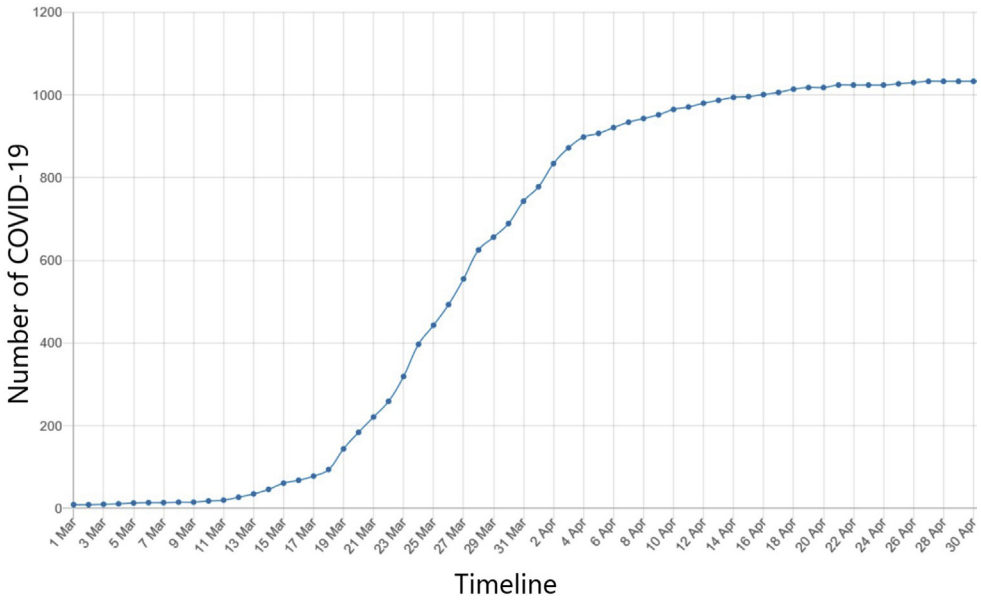

Figure 1. Number of COVID-19 cases over time. This point plot demonstrates the incidence of confirmed COVID-19 cases in Queensland with a spike in mid-March, eventually plateauing in mid-April.

reported death in the state the day after. All individuals returning from overseas travel had a mandatory 14-day isolation period. The testing criteria was sequentially broadened from a positive travel history to Wuhan, to any overseas travel history, to health care workers with respiratory symptoms, and eventually anyone with respiratory symptoms. Contact tracing became a pivotal tool in the armamentarium of the Public Health Unit to understand how the virus was spreading in the community. The COVID SAFE App, approved by the Australian government with contact information being deleted on a 21-day rolling cycle, was rolled out on April 26 to fast track contact tracing.

In response to the increasing number of cases, toward the end of March, the federal government introduced a series of lockdown measures beginning with an Australian ban of arrivals by non-citizens and nonresidents and a shutdown of all nonessential services including pubs, clubs, and restaurants. This was followed by a state government response to shut down state borders and to transition schools to an electronic mode of curriculum delivery with the exception of children of essential service personnel. On March 30, the Queensland government further tightened social distancing restrictions with ban to travel outside the home except for essential reasons and strict policing to ensure compliance. From initial modeling that suggested 30,000 Queenslanders would die from COVID-19 if not contained, these drastic measures produced a significant flattening of the curve within a month. Toward the end of April, with a growth factor of 0.88, the government commenced a gradual relaxation of the stringent travel restrictions while encouraging social distancing. Emergence of a second wave would likely see the reestablishment of more stringent restrictions.

As part of Queensland Health's response to increase capacity and manage the impact of COVID-19, from March 23, 2020, all hospitals were mandated to perform urgent operations only. This was anticipated to increase capacity of emergency care and limit nonessential physical contact to manage the risk to patients and staff.[4] Endoscopic endonasal skull base procedures were postponed if patients were clinically stable, given the high likelihood of aerosolizing virions within the nasal sinuses and infecting the entire operating room staff despite laminar flow.[3] In the setting of clinical deterioration, the general practice was then to consider a craniotomy. COVID-19 operating rooms were also established for confirmed or suspected COVID-19 patients to minimize cross-contamination. While staff received training in the use of COVID-19–specific personnel protective equipment and workflow, this did not require implementation as no COVID-19 positive or suspected patients warranted a neurosurgical procedure. If deemed clinically appropriate, the anesthetic and preadmission reviews were conducted via videoconference by appropriately qualified clinicians using the Queensland Health Telehealth Portal. Similarly, outpatient reviews were converted to telehealth reviews when medically safe to do so, with only new referrals and urgent reviews potentially requiring surgical intervention being reviewed physically in clinics. All departmental meetings, multidisciplinary meetings, and educational sessions were also continued using videoconferencing that facilitated remote and thus safe participation. Interhospital transfer of neurosurgical patients presenting to the peripheral hospital had to be endorsed by the hospital's senior staff management. Visitations were strictly limited to 1 per person per day, and for patients in isolation, visitors were discouraged from attending at all.

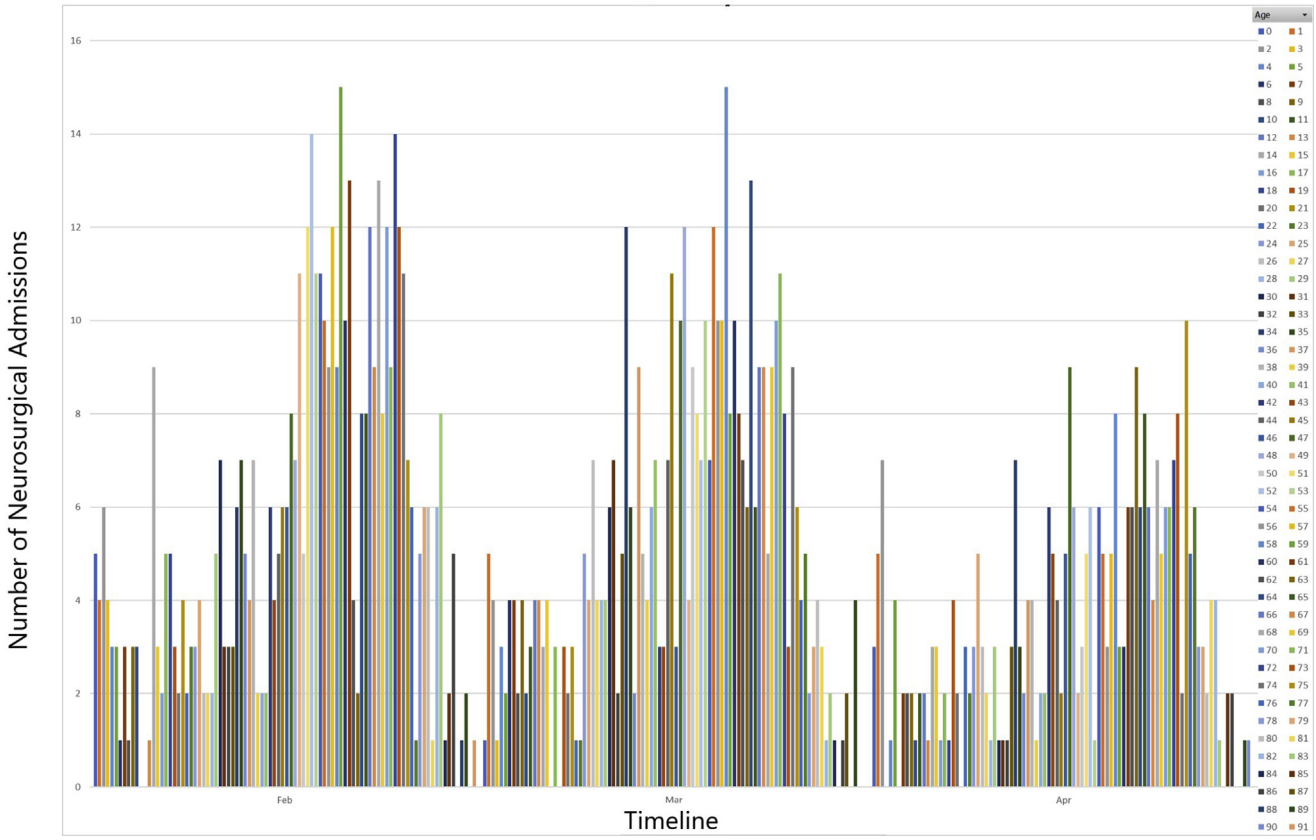

Figure 2. Distribution of age over time. This histogram helps appreciate the flattening of the distribution of age due to a decrease in the number of neurosurgical presentations among patients between 50 and 80 years of age.

Neurosurgical staff were split into 2 teams, 2 weeks on clinical duties and 2 weeks on administrative duties, to ensure continued safe provision of neurosurgical service. Given the successful flattening of the curve, neurosurgical staff members did not require redeployment to COVID-19 wards or fever clinics. Administrative staff members were encouraged to work from home when possible. Toward the end of April, with the relaxation of travel restrictions, the government has proposed a staged reintroduction of semiurgent and nonurgent elective surgery.

An examination of the bar-plots demonstrates an obvious reduction in the number of presentations during the COVID-19 response. As mandated by government policy, there was a planned reduction in the number of elective admissions and surgeries, particularly the degenerative spine, benign neoplastic lesions, and vascular pathologies. However, a surprising trend that was not statistically significant, demonstrating a decrease in emergency presentations, was also noted. Although this could be explained by the reduction in trauma from the strict travel restrictions imposed by the government, there was an obvious reduction in the number of emergency vascular presentations, particularly subarachnoid hemorrhage. Despite the decreased emergency presentations of subarachnoid hemorrhage, those that did present were higher grades with higher mortality. Although contrary to current literature demonstrating the increased incidence of subarachnoid hemorrhage during cold temperatures and influenza epidemics, the noted trend could be explained by the general public's fear of presenting to the emergency department during the COVID-19 pandemic.[5] However, fear alone might not fully explain this trend, as there were similar if not slightly increased emergency presentations for shunt dysfunction and oncology during the same period. One might postulate that perhaps the stringent social distancing laws and travel bans meant that a vulnerable segment of the population may not have received timely attention from a good Samaritan. Therefore larger, multicenter studies across the globe are required to fully comprehend the impact of the numerous, varying public health policies on COVID-19 and health care delivery.

This study has several limitations. First, it could be subject to a sampling bias as other states such as Victoria and New South Wales have a larger migrant population compared with Queensland. Moreover, the data collected do not incorporate a minority of the population who sought private neurosurgical care and some

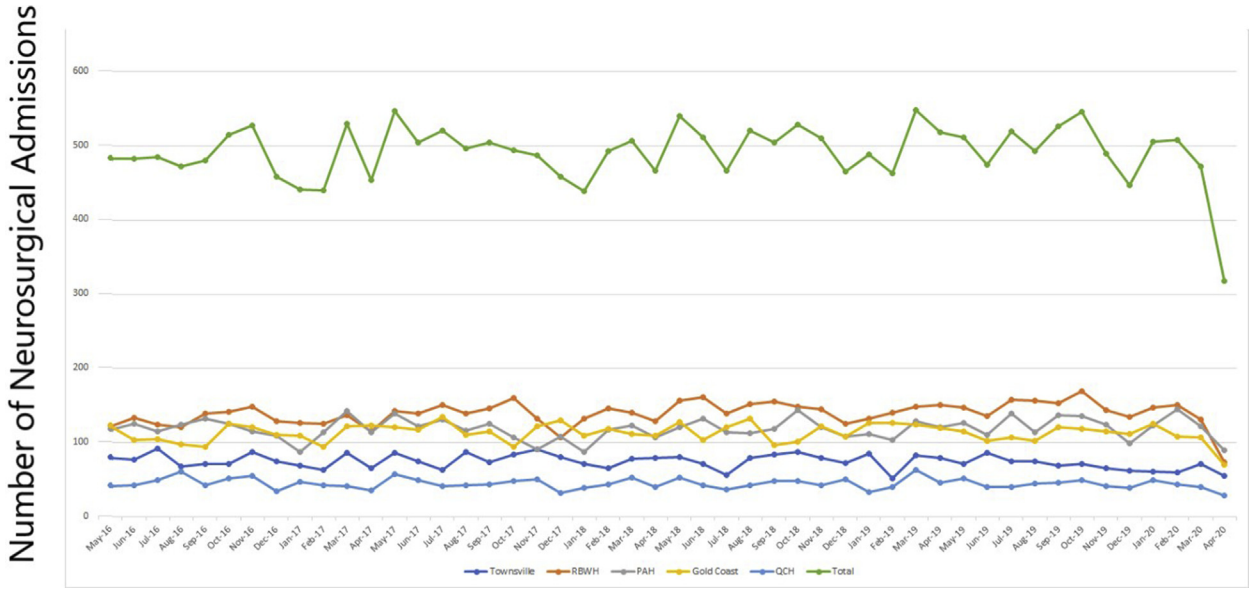

Figure 3. Neurosurgical admissions in Queensland over 4 years. This point-plot demonstrates the steady pattern of neurosurgical admissions (500 ± 50) over the past 4 years with a dramatic decline in admissions during the COVID-19 pandemic.

spinal presentations managed by the orthopedic service. However, it is worth noting that the Queensland data were comparable to the national averages. Second, the study could be subject to confounders. As this study was designed to examine the epidemiologic trends in neurosurgical presentations during the COVID-19 pandemic rather than specifically subarachnoid hemorrhage, known confounders such as ethnicity, history of subarachnoid hemorrhage or hypertension, and aneurysmal

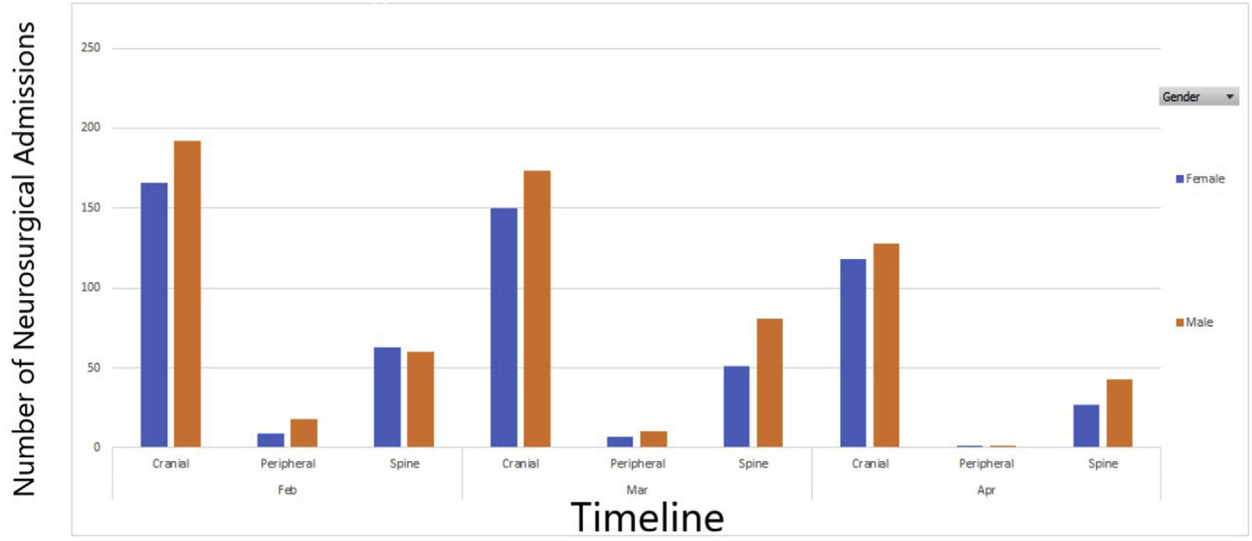

Figure 4. Distribution of gender over time. The bar-plot demonstrates a slight preponderance of male patients that was preserved despite an overall decrease in neurosurgical presentations. The case mix was weighted heavily toward cranial pathologies.

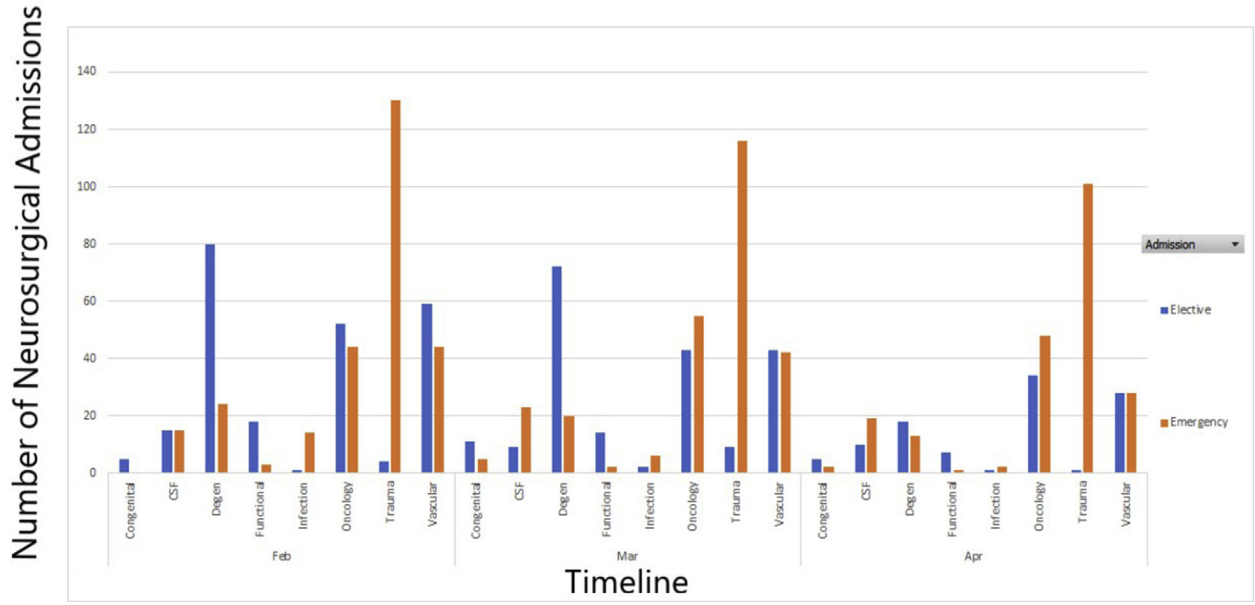

Figure 5. Distribution of neurosurgical admissions over time based on etiology. The decline in elective presentations is accounted for by the decrease in degenerative pathologies, benign neoplasms, and vascular lesions in line with government directives. The decline in emergency presentations, although partly accounted for by the decrease in trauma, is also partly accounted for by the reduced number of vascular presentations. However, presentations from cerebrospinal fluid flow disorders remained steady.

characteristics such as site and size, were not documented.[6] For these reasons, the external validity of the study needs to be cautiously interpreted. Larger studies examining the impact of the various public health policies implemented around the globe on health outcomes would shed further light on those that made the most difference. Moreover, larger studies examining

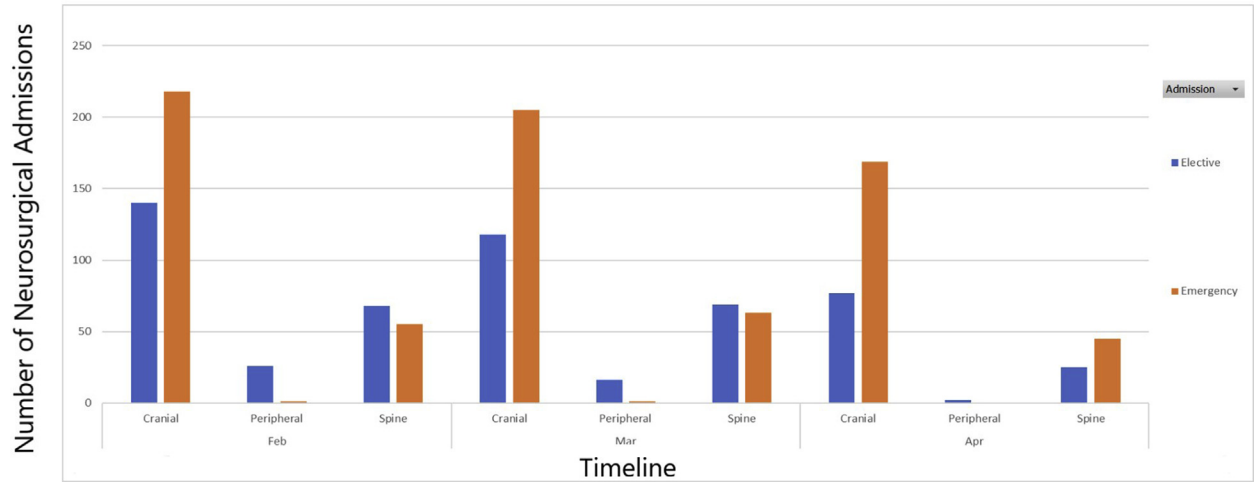

Figure 6. Distribution of neurosurgical admissions over time based on site. While the elective cranial and spinal workload was reduced in line with government directives, the emergency spinal presentations appear more substantially reduced in comparison with cranial presentations.

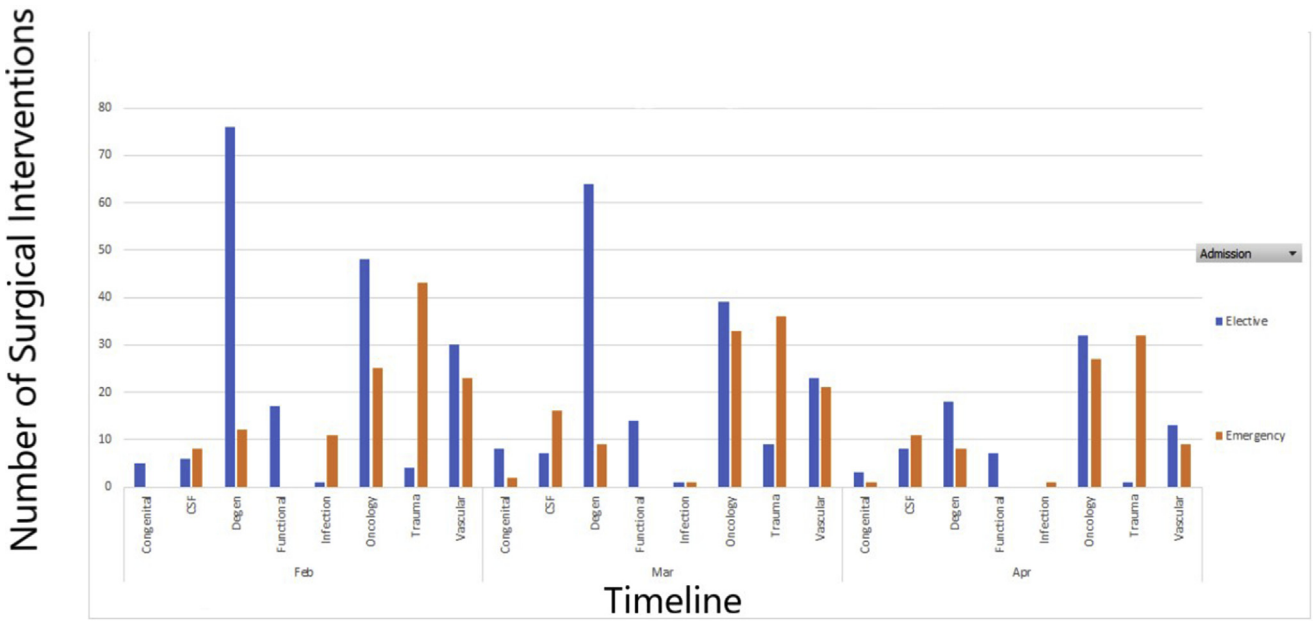

Figure 7. Distribution of surgical intervention over time based on etiology. Surgical management, similar to overall admissions, demonstrated a significant decline in degenerative pathology; moderate decline in oncology and vascular surgeries; slight decline in trauma; and similar number of surgeries for cerebrospinal fluid flow disorders.

emergency vascular presentations including subarachnoid hemorrhage during a viral pandemic could shed further light on a causal rather than an associational inference, if one exists.

CONCLUSIONS

Proactive public health measures in Australia have ensured successful flattening of the curve and conservation of PPE and

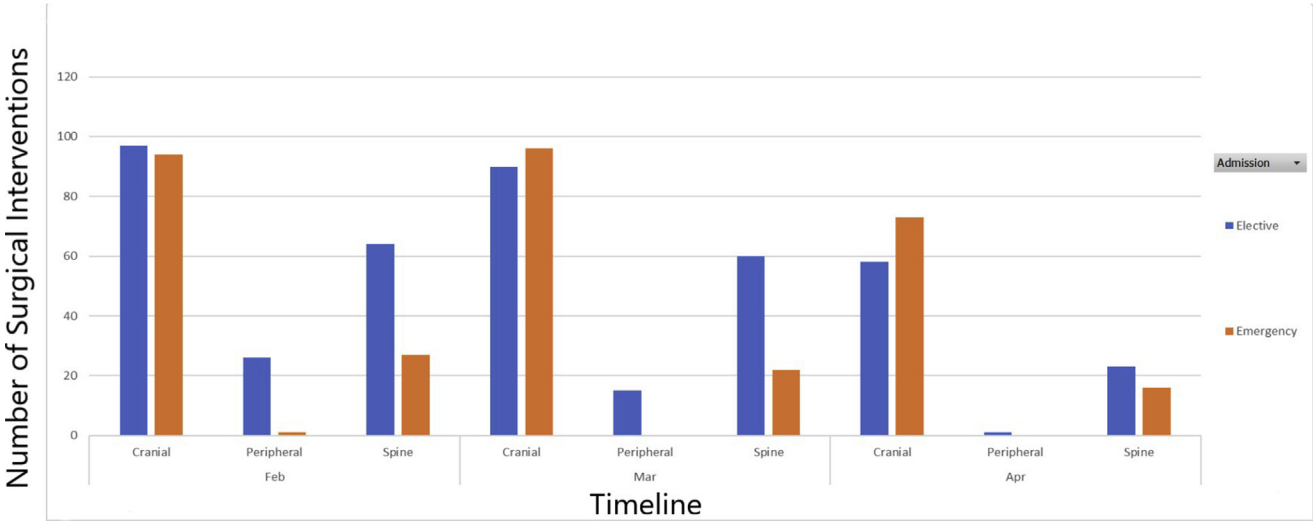

Figure 8. Distribution of surgical intervention over time based on site. Both elective and emergency surgeries were reduced with a more substantial decrease in spinal surgeries in comparison with cranial surgeries and an almost complete obliteration of surgeries of the peripheral nervous system.

essential medical resources while facilitating care of the acutely unwell neurosurgical patients. While stringent public health strategies and their implementation such as limiting elective surgery to urgent surgeries only might help combat a pandemic, they may also have an impact on health care delivery. Lessons learned from this pandemic should guide future health care bureaucrats and politicians to minimize disruption in the delivery of essential medical services.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Joyce Antony: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft. **William Thomas James:** Data curation, Methodology. **Anna Jolly Neriamparambil:** Methodology, Writing - review & editing, Project administration. **Dwarkesh Dharmendra Barot:** Data curation, Methodology. **Teresa Withers:** Conceptualization, Resources, Writing - review & editing, Supervision.

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