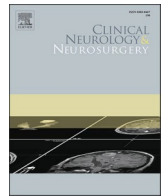




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Burnout among medical students interested in neurosurgery during the COVID-19 era

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ABSTRACT

Objective: The novel Coronavirus Disease 2019 (COVID-19) pandemic has posed unprecedented new stressors to medical student education. This national survey investigated the prevalence of burnout in U.S. medical students interested in pursuing neurosurgical residency during the COVID-19 pandemic.

Methods: A 24-question survey was sent to all American Association of Neurological Surgeons (AANS) medical student chapter members. The abbreviated Maslach Burnout Inventory (aMBI) was used to measure the following burnout metrics: emotional exhaustion, depersonalization, and personal accomplishment. Bivariate analyses were conducted and multivariate analyses were performed using a logistic regression models.

Results: 254 medical students were included (response rate of 14.5%). The majority were male (55.1%), White (66.1%), and between their 2nd and 3rd years in medical school (62.6%). Burnout was identified in 38 (15.0%) respondents, a rate lower than reported in the pre-COVID era. In multivariate analysis, burnout was significantly associated with choosing not to pursue, or feeling uncertain about pursuing, a medical career again if given the choice (OR = 3.40, $p = 0.0075$), having second thoughts about choosing to pursue neurosurgery (OR = 3.47, $p = 0.0025$), attending a medical program in the Northeast compared to the Southeast (OR = 0.32, $p = 0.027$) or Southwest U.S. (OR = 0.30, $p = 0.046$), and indicating that one's future clinical performance will have worsened due to COVID-19 (OR = 2.71, $p = 0.025$).

Conclusions: Our study demonstrates relatively low rates of burnout among U.S. medical students interested in pursuing neurosurgery during the COVID-19 pandemic. Our findings also demonstrate multiple factors may aid in early identification of burnout, highlighting potential opportunities for intervention.

1. Introduction

Medical student education has undergone significant changes in the wake of the COVID-19 pandemic. Medical schools have transitioned to online delivery of education, clinical rotations have been suspended, and away rotations and sub-internships have been postponed or cancelled, leaving students distressed about the uncertainty in their education and residency applications as a result of the pandemic [1,2]. The impact on medical students interested in neurosurgery residency may be particularly significant, as exposure and opportunities in the field that typically occur in the latter years of medical school when

students complete clinical rotations have now been disrupted [3,4]. Furthermore, the pandemic has disrupted board examination preparation, research, and opportunities to learn clinical and surgical skills, all of which are key components of students' application to neurosurgery residency [5]. These disruptions may contribute to medical student burnout, which has already been documented to occur at high levels prior to COVID-19 [6–11].

Burnout is defined as a syndrome of mental and physical exhaustion that accompanies feelings of emotional distress, and often occurs in individuals who must commit emotional resources as part of their work, such as healthcare workers [12]. Burnout has been linked to alcohol and

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substance use, suicide, and medical errors, and has been studied at all levels of medical training [8,13,14]. Due to the many changes the pandemic has imposed on medical students interested in neurosurgery, it will be important to evaluate factors related to the pandemic that may contribute to increased burnout in this population. This study aims to evaluate the prevalence of burnout in students interested in pursuing neurosurgery, to compare the prevalence of burnout to pre-pandemic levels documented in the medical literature, and to identify risk factors related to the pandemic that may contribute to increased burnout.

2. Methods

2.1. Study population

An electronic survey assessing burnout among medical students interested in neurosurgery was created using the Qualtrics online survey platform. In May 2020, a hyperlink to the survey was emailed to all current medical student chapter members of the American Association of Neurological Surgeons (AANS) on behalf of the AANS Young Neurosurgeons Committee. The distributed email also included a cover letter describing the purpose and confidential nature of the study and asking for students' participation (voluntary sampling method). Medical students were encouraged to complete the survey within 2 weeks of receiving the link, and a follow-up email was sent after a 1-week interval in an effort to improve response rate. Survey responses were collected anonymously and did not include identifiable data. Data collection was ceased 2 weeks after the initial recruitment email was distributed. Inclusion criteria included active student AANS membership and a functional email address. Survey responses with missing or incomplete data were excluded from the final analysis. This analytic cross-sectional study was exempt from institutional review board approval due to lack of identifiable participant information. The survey was piloted to 4 independent faculty neurosurgeons (D.D., D.M., J.J., W.S.) to ensure content validity and ease of use prior to distribution.

2.2. Survey design

The survey consisted of 24 questions regarding demographics (including age, gender, race, relationship status, program location, and year in medical school), personal and professional stressors related to COVID-19, and burnout (Appendix; Supplemental Figure 1). Questions related to COVID-19 assessed changes in various aspects of medical students' lives as a result of the pandemic, including ability to schedule and prepare for licensing exams, uncertainty regarding future earnings and health care reform, alteration of elective rotation or vacation schedules, and impact of the pandemic on students' future clinical performance. An optional write-in question allowed students to state what they found to be the most challenging aspects of their role in the response to the pandemic.

The effect of COVID-19 on students' ability to schedule and prepare for medical licensing exams, ability to schedule a sub-internship, future clinical performance, uncertainty regarding future earnings and health care reform, personal life, and professional life were scored along a 5-point Likert scale. Responses were collapsed into three categories (e.g. "improved," "no change," "worsened") for the purposes of statistical interpretation. Responses regarding the alteration of elective rotation or vacation schedules due to COVID-19, whether respondents had been personally exposed to a patient with COVID-19, whether respondents' colleagues had contracted COVID-19, whether respondents would pursue a career in medicine again if given the choice, and whether respondents had second thoughts about pursuing neurosurgery were converted to dichotomous variables, with responses of "No" and "Do not know" combined into a single category.

Burnout was assessed using the abbreviated Maslach Burnout Inventory (aMBI), a previously-validated 9-item questionnaire which assess three indices related to burnout: emotional exhaustion (EE; 3

questions), depersonalization (DP; 3 questions), and personal accomplishment (PA; 3 questions) [15,16]. Each question was scored on a 7-point Likert scale (0 = "Never" and 6 = "Every Day"), and the total score for each aMBI index was categorized as low (0–6 points), intermediate (7–12 points), or high (13–18 points). Burnout was defined as a high score in either EE or DP as consistent with previously published studies reporting burnout among medical professionals [13,17].

2.3. Statistical analysis

Medical student demographics and information assessing the effect of COVID-19 on various aspects of students' lives were tabulated using standard descriptive statistics. As mentioned above, select survey responses were collapsed into dichotomous or trichotomous variables for the purpose of statistical analysis. Descriptive statistics were also used to describe the proportion of medical students receiving low, intermediate, and high scores for each of the 3 aMBI indices (EE, DP, PA) and to assess the proportion of students that scored positive for burnout. Average scores for each aMBI index were reported as mean \pm standard deviation (SD). All descriptive data were summarized into tables displaying the number and proportion of students in each category.

Bivariate analysis was used to identify demographic or COVID-19-related factors associated with burnout, and comparisons between categorical variables were performed using chi-square tests and Fisher's exact tests. Power analysis demonstrated that a sample size of $n = 121$ was needed to detect a medium effect size of 0.3 using the chi-square test (with 3 degrees of freedom) at a significance level of $p = 0.05$ and with a power of 0.8 [18]. All factors found to have a p -value ≤ 0.1 in bivariate analysis were placed in a multivariate binary logistic regression analysis using a forward stepwise manner in order to search for predictors of burnout. The binary logistic regression model generated in multivariate analysis was internally validated using bias-corrected bootstrapping with 1000 samples, and the performance of the regression model was assessed by measuring the area under the receiver operating characteristic (ROC) curve (AUC). Results were reported with p -values, odds ratios (OR), and corresponding 95% confidence intervals (CI). P -values ≤ 0.05 were considered statistically significant. Data analysis was conducted using IBM SPSS Statistics software (Version 25.0; IBM Corp., Armonk, NY) and R Statistical Software (Version 3.3.2, r-project.org).

3. Results

Of the 2727 medical students invited to complete the survey, 550 clicks to the survey link were logged and 395 total survey responses were received. The overall response rate was 14.5% among all AANS medical student members and 71.8% among those who accessed the survey link. Among the total responses received, 141 were excluded on the basis of incomplete responses, yielding 254 complete responses to be included in the final analysis. The majority of medical students who responded were male (55.1%), White (66.1%), between the ages of 20 and 30 (94.5%), and between their 2nd and 3rd years in medical school (62.6%). A significant portion also indicated that they had not yet taken a medical licensing exam (55.1%). A summary of respondent demographic data and practice characteristics can be found in Table 1, and a heat map visualization of respondents by U.S. state has been also provided (Appendix; Supplemental Figure 2).

Among the medical students surveyed, the majority expressed uncertainty regarding future healthcare reform (87.0%) due to COVID-19. Most students stated that their elective rotation or vacation schedules had been altered at least once (72.4%) and noted a worsened ability to schedule medical licensing exams due to the pandemic (60.2%). A large percentage also perceived that their professional life (57.5%), personal life (55.9%), and future clinical performance (46.9%) would worsen due to COVID-19. Since the rise of the pandemic, the majority of medical students surveyed spent increased time participating in remote lectures (75.2%) and engaging in a leisure activity of their choice (57.1%). A

Table 1
Demographic Information and Practice Characteristics of Medical Student Survey Respondents (N = 254).

Characteristics	Number (%)
Age	
20–30	240 (94.5)
30–40	14 (5.5)
Gender	
Male	140 (55.1)
Female	114 (44.9)
Race	
White	168 (66.1)
Asian	51 (20.1)
Black or African American	16 (6.3)
American Indian or Alaska Native	3 (1.2)
Native Hawaiian or Other Pacific Islander	1 (0.4)
Other	15 (5.9)
Ethnicity	
Not of Hispanic, Latino, or Spanish Origin	225 (88.6)
Hispanic, Latino, or Spanish Origin	29 (11.4)
Relationship Status	
Stable Partner	149 (58.7)
Single	105 (41.3)
Region	
Northeast	61 (24.0)
Northwest/Midwest	59 (23.2)
Southeast	85 (33.5)
Southwest	49 (19.3)
Degree Program	
MD or DO	217 (85.4)
MD/PhD or DO/PhD	37 (14.6)
Year in School	
1st	42 (16.5)
2nd	85 (33.5)
3rd	74 (29.1)
4th or Final Year	37 (14.6)
Research or Elective Year	16 (6.3)
Medical Licensing Exams Taken	
None	140 (55.1)
USMLE Step 1	112 (44.1)
USMLE Step 2 CK	26 (10.2)
USMLE Step 2 CS	29 (11.4)
COMLEX-USA Level 1	11 (4.3)

CK: Clinical knowledge; CS: clinical skills; COMLEX: Comprehensive Osteopathic Medical Licensing Examination; DO: Doctor of Osteopathic Medicine; MD: Doctor of Medicine; USA: United States of America; USMLE: United States Medical Licensing Examination.

notable proportion also spent increased time interacting with family members (56.3%) and working on clinical research (52.0%). These and other perceptions related to COVID-19 have been summarized in [Table 2](#).

3.1. Burnout among medical students interested in neurosurgery

Burnout was identified in 38 (15.0%) medical students ([Table 3](#)). The majority of students reported low to intermediate levels of emotional exhaustion (85.8%), low levels of depersonalization (88.6%), and low levels of personal accomplishment (62.2%).

In bivariate analysis, factors strongly associated with burnout since the rise of COVID-19 included location of training program ($p = 0.044$), alteration of one's elective rotation or vacation schedules due to the pandemic ($p = 0.031$), and uncertainty about future earnings due to COVID-19 ($p = 0.050$). Students who were burned out were more likely to perceive that their future clinical performance would worsen due to COVID-19 ($p = 0.004$), indicate that they would not pursue, or were unsure about pursuing, a medical career again if given the choice ($p < 0.001$), and have second thoughts about pursuing neurosurgery ($p < 0.001$). Medical students experiencing burnout were also more likely to have colleagues who were exposed to COVID-19 ($p = 0.056$); however, this factor did not reach statistical significance. The results of the bivariate analysis, as well as the number and row frequency of

Table 2
Medical Students' Perceptions and Stressors Related to COVID-19.

Perception	Number (%)
Uncertainty about future changes in healthcare due to COVID-19	221 (87.0)
Altered elective rotation or vacation schedule due to COVID-19	184 (72.4)
Worsened ability to schedule medical licensing exam(s) due to COVID-19	153 (60.2)
Professional life will not improve due to COVID-19	146 (57.5)
Personal life will not improve due to COVID-19	142 (55.9)
Worsened clinical performance due to COVID-19	119 (46.9)
Uncertainty about future earnings due to COVID-19	119 (46.9)
Worsened ability to prepare for medical licensing exam(s) due to COVID-19	131 (51.6)
Worsened ability to schedule sub-internship(s) due to COVID-19	93 (36.6)
Had second thoughts about pursuing neurosurgery	92 (36.2)
Fellow student contracted COVID-19	86 (33.9)
Would not pursue career in medicine again	38 (15.0)
Personally exposed to COVID-19	15 (5.9)
Since rise of COVID-19, I have spent increased time:	
Participating in remote lectures	191 (75.2)
Engaging in leisure activity	145 (57.1)
Interacting with family members	143 (56.3)
Working on clinical research	132 (52.0)
Partaking in board preparation	122 (48.0)
Working on basic science research	29 (11.4)
Interacting with medical students	26 (10.2)
Providing medical care to patients	8 (3.1)
None of the above	5 (2.0)

Table 3
Burnout indices among 254 medical students.

Burnout index	Score (Mean ± SD)	Number (%)
Burnout		38 (15.0)
Emotional Exhaustion	7.83 ± 4.76	
Low score (0–6)		97 (38.2)
Intermediate score (7–12)		121 (47.6)
High score (13–18)		36 (14.2)
Depersonalization	3.28 ± 3.50	
Low score (0–6)		225 (88.6)
Intermediate score (7–12)		21 (8.3)
High score (13–18)		8 (3.1)
Personal Accomplishment	6.07 ± 5.87	
Low score (0–6)		158 (62.2)
Intermediate score (7–12)		46 (18.1)
High score (13–18)		50 (19.7)

respondents in each category, can be found in [Table 4](#).

In multivariate analysis, five factors were found to be predictors of burnout. Burnout was significantly associated with choosing not to pursue, or feeling uncertain about pursuing, a medical career again if given the choice (OR=3.40, 95% CI: 1.38–8.40, $p = 0.010$), having second thoughts about choosing to pursue neurosurgery (OR = 3.47, 95% CI: 1.57–7.98, $p = 0.0040$), attending a medical program in the Northeast compared to the Southeast (OR = 0.32, $p = 0.027$) or Southwest U.S. (OR = 0.30, $p = 0.046$), and indicating that one's future clinical performance will have worsened due to COVID-19 (OR=2.71, 95% CI: 1.16–6.68, $p = 0.025$). All significant predictors of burnout maintained statistical significance after bias-corrected bootstrapping with 1000 samples. The AUC for the regression model predictive of burnout was 0.799 (95% CI: 0.728–0.869). The results of the multivariate analysis are provided in [Table 5](#).

An optional open-ended question at the conclusion of the survey allowed respondents to report what they found to be the most challenging aspects of their role as a medical student during the COVID-19 pandemic. This question received 125 total responses. Common themes among the responses included difficulty adapting to changes in students' education and academic curriculum (38.4%), feelings of underutilization or helplessness in the face of the pandemic (36.0%), concerns regarding students' neurosurgery residency applications

Table 4
Summary of Bivariate Analysis: Statistically Significant Predictors of Burnout.

Factor	Number Experiencing Burnout (%)	Number Not Experiencing Burnout (%)	p-value
Location of training program			
Northeast	16 (42.1)	45 (20.8)	0.044 *
Northwest/Midwest	7 (18.4)	59 (27.3)	
Southeast	10 (26.3)	65 (30.1)	
Southwest	5 (13.2)	47 (21.8)	
Alteration of vacation or elective schedules due to COVID-19			
Did not alter schedule	5 (7.1)	65 (30.1)	0.031 *
Altered schedule at least once	33 (17.9)	151 (69.9)	
Exposure of fellow students to COVID-19			
No/Do not know	20 (11.9)	148 (68.5)	0.056
Yes	18 (20.9)	68 (31.5)	
Effect of COVID-19 on clinical performance			
Improved performance	3 (12.0)	22 (10.2)	0.004 *
No change	8 (7.3)	102 (47.2)	
Worsened performance	27 (22.7)	92 (42.6)	
Uncertainty about future earnings			
Uncertain	24 (20.2)	189 (87.5)	0.050
Neutral	5 (7.1)	16 (7.4)	
Not uncertain	9 (13.8)	11 (5.1)	
Choice to pursue career in medicine again after COVID-19			
No/Do not know	14 (36.8)	192 (88.9)	< 0.001 *
Yes	24 (11.1)	24 (11.1)	
Second thoughts about pursuing neurosurgery due to COVID-19			
Did not have second thoughts	12 (7.4)	150 (69.4)	< 0.001 *
Had second thoughts	26 (28.3)	66 (30.6)	

* Statistical significance (p < 0.05).

(20.0%), and working with unresponsive or unclear administrators (8.0%). Despite these challenges, one student noted that time off from school due to the pandemic was an “amazing opportunity to reconnect with [oneself] and pursue passions and hobbies that one doesn’t typically have time for during a busy school schedule.”

4. Discussion

4.1. Prior literature and present findings

Neurosurgery is one of the most competitive specialties to match into in the United States, as evidenced by the high average board examination scores, number of research experiences, and quality of clinical experience among successful residency applicants [19,20]. This competition may contribute to increased burnout among medical students interested in pursuing neurosurgery, which has been previously documented to occur at high levels among medical students, residents, and attending neurosurgeons [13,14,21]. A review of burnout published by Dyrbye et al. reported that 45–56% of medical students experience burnout, with the data also suggesting that the highest prevalence of burnout is found in students who are at the later stages of their training [8]. They also reported that burnout among medical students and residents is associated with a multitude of professional and personal

Table 5
Multivariate binary logistic regression analysis of 254 medical students.

Factor	OR	95% CI	p-value	Bootstrap p-value
Would not choose to pursue a career in medicine again due to COVID-19	3.40	1.38 – 8.40	0.0075 *	0.010 [†]
Uncertainty about future earnings due to COVID-19	1.09	0.44 – 2.65	0.85	0.83
Had second thoughts about choosing to pursue neurosurgery due to COVID-19	3.47	1.57 – 7.98	0.0025 *	0.0040 [†]
Program region				
Northeast	Reference	–	–	–
Northwest/Midwest	0.41	0.13 – 1.19	0.11	0.11
Southeast	0.32	0.11 – 0.86	0.027 [*]	0.024 [*]
Southwest	0.30	0.086 – 0.93	0.046 [*]	0.049 [*]
Worsened clinical performance due to COVID-19	2.71	1.16 – 6.68	0.025 [*]	0.017 [*]

CI: Confidence interval; OR: odds ratio.

†Reference group consisted of students from programs located in the Northeast U.S. Diagnosis of COVID-19 among medical student colleagues and alteration of vacation or elective rotation schedule due to COVID-19 did not predict outcome. The AUC = 0.799 (95% CI 0.728–0.869).

* Statistical significance (p < 0.05).

sequelae, including decreased empathy, dishonest behavior, medical errors, suicidal ideation, and a greater sense of stigma regarding mental health problems [8]. Hansell et al. conducted a survey-based study and discovered that the highest rate of burnout (59%) occurred in their cohort among students who had just completed their standard clinical clerkships, and also reported an increase in emotional exhaustion associated with clinical exposure [6]. Frajerman et al. conducted a systematic review and meta-analysis of burnout in medical students and estimated the prevalence of burnout in this population at 44%, with no significant gender difference in burnout observed [10].

To our knowledge, there have been no studies directly assessing the prevalence of burnout in students interested in pursuing neurosurgery in particular. Given the competitive nature of the neurosurgery residency application process, particularly when coupled with mental stress resulting from the COVID-19 pandemic, we aimed to assess the prevalence of burnout among medical students interested in neurosurgery and identify factors related to the pandemic that may contribute to burnout and medical student distress. We discovered an overall burnout rate of 15%, which is lower than previously reported rates of burnout among medical students [6,8,10]. A possible reason for the lower burnout rate noted in our study is that our survey respondents were all members of medical student chapters of the AANS, and were therefore likely medical students who expressed interest in pursuing a career in neurosurgery. The characteristics of this cohort are likely different from those in prior studies, as these studies had no inclusion criteria that would bias towards a specific specialty preference. Previous research has established that burnout rates can vary significantly between different medical specialties, and therefore students seeking to apply into certain specialties may be more predisposed to report symptoms of burnout relative to counterparts applying into different specialties [22,23]. Given that research by Shakir et al. has demonstrated that rates of burnout are lower among neurosurgery residents relative to other surgical residents, it is possible that medical students interested in neurosurgery training may share some of the same underlying traits that cause neurosurgery residents to experience less burnout than their peers, thus explaining our study findings [13]. Further, surveys taken during the pre-COVID era demonstrated that student interested in neurosurgery who participating in a virtual neurosurgery training course had decreased concerns about

perceived negative aspects of the field such as poor-work life balance, neurosurgeon personalities, and lack of diversity [24]. During the pandemic, the proliferation of virtual learning and thus opportunities to engage with neurosurgeons about their work may have had a similar effect upon medical students interested in neurosurgery. Despite unease associated with the pandemic broadly, changes in curriculum, including many institutional shifts to pass-fail grading systems, for instance, may have also contributed to a lower burnout prevalence.

Importantly, our study identified several factors that may contribute to increased burnout or protect against it during the COVID-19 pandemic, including uncertainty regarding one's choice to pursue a career in medicine or in neurosurgery after the onset of the pandemic, geographic location of one's program, and the impression that one's clinical performance would be negatively impacted by the pandemic. Our findings demonstrating that 1) experiencing uncertainty regarding one's career choice and 2) having a negative impression of one's clinical competence are both independently associated with burnout. Further, the significant association between the geographic location of one's program and burnout is likely related to the asymmetric distribution of COVID-19 infection rates across the U.S. [25,26].

4.2. Medical student concerns during the COVID-19 pandemic

The majority of our survey respondents perceive increased uncertainty about changes in healthcare, alterations in elective rotation and vacation schedules, and worsened ability to schedule and prepare for medical licensing exams due to the COVID-19 pandemic. Most survey respondents also perceived that their personal and professional lives would not improve due the pandemic. These changes are corroborated by several reports outlining changes in neurosurgical medical education in the wake of the pandemic. Following guidelines published by the Association of American Medical Colleges in March 2020, clinical rotations were paused for most medical students in the U.S. [27]. For example, Weill Cornell Medicine suspended all medical student teaching, transformed their core clinical curriculum to a remote, online platform for students of all years, and shifted students to virtual clinical electives [5]. Weill Cornell Medicine also reported that many students conducting wet-lab research at their institution have had to modify their projects or create new ones that can be completed remotely, and posited that increasing numbers of students may elect to take a research year to make up for lost research time, potentially leading to less applications to neurosurgery residency in the coming cycle [5]. This matches our finding that 52% of students have spent increased time working on clinical research, whereas only 11% have spent increased time working on basic science research.

These concerns are echoed in a preliminary report of a national survey conducted by Garcia et al. which discovered high rates of dissatisfaction with neurosurgical career planning as well as a significant number of students reporting that they would be less likely to pursue a career in neurosurgery due to the pandemic [28]. Guadix et al. received 127 responses to a national survey of medical students interested in neurosurgery during the COVID-19 pandemic and reported that 63% of students had concerns about conferences and networking opportunities, 59% about clinical experiences, and 42% about board examination scores [4]. Several of the aforementioned disruptions were associated with burnout in our study: second thoughts about pursuing neurosurgery and alteration of vacation or elective rotation scheduling were both statistically significant predictors of burnout. It is clear that almost every aspect of medical education has been impacted by the pandemic, and it will be necessary to closely support students as they pursue neurosurgery residency during this time.

4.3. Impact on recruitment of students to neurosurgery

The cancellation and delay of neurosurgery sub-internships and away rotations is one of the most significant impacts of the pandemic. 72.4%

of our respondents reported some altered elective rotation or vacation scheduling, which matches Guadix et al.'s finding that 76% of students had canceled or postponed at least one neurosurgery rotation [4]. Sub-internships are valuable opportunities for students interested in neurosurgery to acquire letters of recommendation and develop relationships with programs that they are highly interested in. Indeed, 57.5% of applicants to neurosurgery residency rank a program they completed a sub-internship at as their first choice [29]. In addition to the impact on students' sub-internships, the pandemic may significantly alter the residency interview process. Student opportunity to talk to residents, team camaraderie at residency programs, and the number of operative cases performed at a program were all cited as important in selecting a residency [29]. In the wake of the pandemic and resulting social distancing protocols, many residency interviews may occur online, limiting candidate exposure to these aspects of a program. These factors may contribute to increased stress among students and/or decreased likelihood to apply to neurosurgery. Indeed, Guadix et al. discovered that students are now more likely to take one year off from medical school when compared to before the start of the COVID-19 pandemic [4].

The interest in neurosurgery among students who are earlier in their medical school careers may also be impacted. Medical students become interested in neurosurgery due to an interest in the neurosciences, intellectually stimulating work, effect on patients, and research opportunities [24]. Other factors leading to an interest in neurosurgery include exposure to medical student conferences, neurosurgical associations, mentoring, and practical aspects of the field such as surgical approaches and technique [30–32]. In recent times, there has been a decline in the number of neurosurgery residency applicants in the U.S., possibly due to a combination of the lifestyle, duration of training, lack of mentors, and lack of early exposure to the field [33]. The longevity of the field of neurosurgery is dependent on the recruitment of students eager to join the field, and many of the traditional ways students are often exposed to neurosurgery have been disrupted due to the COVID-19 pandemic. In light of this, we must continue to address student concerns during this time to ensure that applicants to neurosurgery residency are cared for.

4.4. Model predicting burnout in medical students

Our model predicting burnout includes students who would not pursue a career in medicine again, those who had uncertainty in future earnings, those who had second thoughts about choosing to pursue neurosurgery, those students who study at a Northeast program (relative to Southeast and Southwest programs), and those who perceived worsened clinical performance due to the COVID-19 pandemic. Our model has an AUC of 0.79, and may enable us to identify students who are at a high risk of burnout during the pandemic. Previous studies have shown that burnout is increased in the latter years of medical school [6,7,10]. In light of the COVID-19 pandemic, students in their final years of medical school who are experiencing second thoughts during the neurosurgery residency application process may therefore be at greater risk of burnout. Furthermore, as the Northeast U.S. has largely become the epicenter of the COVID-19 pandemic, and as several medical programs located in the Northeast have encouraged medical students to graduate early in order to assist with the response to the pandemic, students studying at Northeast programs may be at higher risk of experiencing burnout [25,26].

In addition to the aforementioned disruptions to medical education, there has also been significant disruptions in medical practice, leading to uncertainty regarding future earnings. Elective surgeries have been canceled and clinic visits are now largely conducted using telemedicine. The Coronavirus Aid, Relief, and Economic Security (CARES) Act of March 2020 provided \$130 billion to hospitals for COVID-19-related losses in revenue; however, the true impact of this legislation is yet to be realized, just as the true impact of the pandemic is not fully known

[34]. It will be essential to educate students on the impact of the pandemic on future earnings and medical practice to combat uncertainty and burnout.

4.5. Interventions to combat burnout

A multitude of interventions have been studied to combat medical student burnout prior to the pandemic, and numerous solutions have been proposed to lessen the stress on students during the pandemic. One intervention that has been proposed includes resilience training to help students cope with difficult team interactions, find meaning in their work, and deal with disappointment and setbacks [35]. Mindfulness-based interventions have also been successful and have been reported to decrease rates of depression, stress, and burnout in medical students [36]. Other studies have demonstrated that conversion to a pass/fail grading system, communications exercises, and relaxation exercises are also linked to decreased burnout [37]. It will be essential to continue to study these interventions and convert them to online formats as medical students continue to face burnout during the pandemic. Numerous solutions have also been proposed to ensure the continued recruitment of medical students to neurosurgery and decrease student anxieties related to the neurosurgery residency application. Studies have demonstrated that neurosurgery interest groups, strong mentorship, earlier preclinical exposure, and research opportunities are essential in matching more students into neurosurgery [32,33]. This early exposure is particularly important for students who do not have a home program [38]. Other studies have demonstrated the efficacy of programs such as small conferences or neurosurgery training camps in educating early-career medical students on the lifestyle of neurosurgery and surgical skills and recruiting medical students to the field [24,30]. Similar programs should be implemented during and after the pandemic in order to decrease student uncertainty about the field and support those students who are unsure about pursuing a career in neurosurgery, as these students are also likely to experience burnout. Lastly, interventions related to the residency application cycle have been proposed, such as having programs organize online question-and-answer sessions for interested applicants, alter letter of recommendation requirements for applicants, or organize virtual sub-internships and rotations [3,28].

4.6. Study limitations

Our study has several limitations. We conducted a survey-based study, which may lead to selection bias as only those respondents who had availability to complete a survey may have responded. This may lead to an under-reporting of burnout as we failed to capture those students who were working more or had less spare time to complete our study during the pandemic. Furthermore, we had 254 responses with a response rate of 14.5%, which may have led us to fail to capture certain aspects related to the pandemic associated with burnout due to a low response rate. However, our response rate was similar to a study conducted by Guadix et al. of students pursuing neurosurgery during the pandemic, which reported 127 responses and a response rate of 16% [4]. Third, our survey respondents were all members of AANS student chapters who likely express an interest in neurosurgery or other surgical subspecialties, and therefore may not be representative of medical students more generally. Lastly, our study was survey-based and may have excluded important factors related to the pandemic that can predict burnout, and for this reason we included a “free response” section in our study to capture student opinions.

5. Conclusion

The COVID-19 pandemic has significantly disrupted medical education, in particular for students interested in neurosurgery. Students who are in the later stages of their career, those facing uncertainty in

their decision to pursue medicine, pursue neurosurgery, or in their future career, and those who perceived worsening clinical skills due to the pandemic may be at increased risk of burnout during the pandemic. Despite these changes, we report only a moderate to low level of burnout among medical students interested in neurosurgery. Interventions targeted to these students and interventions designed to decrease stress related to the residency application process will be necessary to ensure student wellness.

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Reporting Guidelines

We found no applicable reporting guidelines that would apply to this article. By following the EQUATOR reporting guidelines decision tree, (<http://www.equator-network.org/wp-content/uploads/2013/11/20160226-RG-decision-tree-for-Wizard-CC-BY-26-February-2016.pdf>), we found that none of the most popular checklists are appropriate for our study design.

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CRediT authorship contribution statement

A.M.K.: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing – original draft, Writing – review & editing. **A.E.J.:** Formal analysis, Investigation, Methodology, Writing – review & editing. **S.L.:** Formal analysis, Investigation, Methodology, Data curation, Writing – original draft, Writing – review & editing. **A.G.:** Formal analysis, Investigation, Methodology, Data curation, Writing – original draft, Writing – review & editing. **D.L.D.:** Writing – review & editing. **W.S.:** Writing – review & editing. **J.N.J.:** Writing – review & editing. **D.M.:** Writing, Supervision, Writing – review & editing.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.clineuro.2021.106958](https://doi.org/10.1016/j.clineuro.2021.106958).

References

- [1] K.E. Calhoun, L.A. Yale, M.E. Whipple, S.M. Allen, D.E. Wood, R.P. Tatum, The impact of COVID-19 on medical student surgical education: Implementing extreme pandemic response measures in a widely distributed surgical clerkship experience, *Am. J. Surg.* 220 (2020) 44–47, <https://doi.org/10.1016/j.amjsurg.2020.04.024>.
- [2] S. Rose, Medical student education in the time of COVID-19, *JAMA* 323 (2020) 2131–2132, <https://doi.org/10.1001/jama.2020.5227>.
- [3] M. Harary, M. Bergsneider, Approaches to mitigate impact of COVID-19 pandemic on neurosurgical residency application cycle, *Neurosurgery* 87 (2020) E212–E213, <https://doi.org/10.1093/neuros/nyaa176>.
- [4] S.W. Guadix, G.M. Winston, J.K. Chae, A. Haghdel, J. Chen, I. Younus, R. Radwanski, J.P. Greenfield, S.C. Pannullo, Medical student concerns relating to neurosurgery education during COVID-19, *World Neurosurg.* 139 (2020) e836–e847, <https://doi.org/10.1016/j.wneu.2020.05.090>.
- [5] J.K. Chae, A. Haghdel, S.W. Guadix, G.M. Winston, I. Younus, R. Radwanski, T. H. Schwartz, J.P. Greenfield, M.L.J. Apuzzo, S.C. Pannullo, Letter: COVID-19 impact on the medical student path to neurosurgery, *Neurosurgery* 87 (2020) E232–E233.
- [6] M.W. Hansell, R.M. Ungerleider, C.A. Brooks, M.P. Knudson, J.K. Kirk, J. D. Ungerleider, Temporal trends in medical student burnout, *Fam. Med.* 51 (2019) 399–404, <https://doi.org/10.22454/FamMed.2019.270753>.

- [7] L.N. Dyrbye, C.P. West, D. Satele, S. Boone, L. Tan, J. Sloan, T.D. Shanafelt, Burnout among u.s. medical students, residents, and early career physicians relative to the general u.s. population, *Acad. Med.* 89 (2014) 443–451, <https://doi.org/10.1097/ACM.0000000000000134>.
- [8] L. Dyrbye, T. Shanafelt, A narrative review on burnout experienced by medical students and residents, *Med. Educ.* 50 (2016) 132–149, <https://doi.org/10.1111/medu.12927>.
- [9] W. Ishak, R. Nikravesh, S. Lederer, R. Perry, D. Ogunyemi, C. Bernstein, Burnout in medical students: a systematic review, *Clin. Teach.* 10 (2013) 242–245, <https://doi.org/10.1111/tct.12014>.
- [10] A. Frajerman, Y. Morvan, M.O. Krebs, P. Gorwood, B. Chaumette, Burnout in medical students before residency: a systematic review and meta-analysis, *Eur. Psychiatry* 55 (2019) 36–42, <https://doi.org/10.1016/j.eurpsy.2018.08.006>.
- [11] J.A. Villwock, L.B. Sobin, L.A. Koester, T.M. Harris, Impostor syndrome and burnout among American medical students: a pilot study, *Int. J. Med. Educ.* 7 (2016) 364–369, <https://doi.org/10.5116/ijme.5801.eac4>.
- [12] C. Maslach, S.E. Jackson, The measurement of experienced burnout, *J. Organ. Behav.* 2 (1981) 99–113, <https://doi.org/10.1002/job.4030020205>.
- [13] H.J. Shakir, M.J. McPheeters, H. Shallwani, J.E. Pittari, R.M. Reynolds, The prevalence of burnout among US neurosurgery residents, *Neurosurgery* 83 (2018) 582–590, <https://doi.org/10.1093/neuros/nyx494>.
- [14] J.H. McAbee, B.T. Ragel, S. McCartney, G.M. Jones, L.M. Michael, M. DeCuypere, J.S. Cheng, F.A. Boop, P. Klimo, Factors associated with career satisfaction and burnout among US neurosurgeons: results of a nationwide survey, *J. Neurosurg.* 123 (2015) 161–173, <https://doi.org/10.3171/2014.12.JNS141348>.
- [15] I.C. McManus, B.C. Winder, D. Gordon, The causal links between stress and burnout in a longitudinal study of UK doctors, *Lancet* 359 (2002) 2089–2090, [https://doi.org/10.1016/S0140-6736\(02\)08915-8](https://doi.org/10.1016/S0140-6736(02)08915-8).
- [16] I.C. McManus, A. Keeling, E. Paice, Stress, burnout and doctors' attitudes to work are determined by personality and learning style: a twelve year longitudinal study of UK medical graduates, *BMC Med.* 2 (2004) 1–12, <https://doi.org/10.1186/1741-7015-2-29>.
- [17] C.C. Lebares, E.V. Guvva, N.L. Ascher, P.S. O'Sullivan, H.W. Harris, E.S. Epel, Burnout and stress among US surgery residents: psychological distress and resilience, *J. Am. Coll. Surg.* 226 (2018) 80–90, <https://doi.org/10.1016/j.jamcollsurg.2017.10.010>.
- [18] J. Cohen. *Statistical Power Analysis for the Behavioral Sciences*, second ed., Lawrence Erlbaum Associates, 1988.
- [19] J.S. Pan, J. Mocco, Are neurosurgery residents burned out? *World Neurosurg.* 116 (2018) 394, <https://doi.org/10.1016/j.wneu.2018.06.131>.
- [20] H. Wadhwa, S.S. Shah, J. Shan, J. Cheng, A.S. Beniwal, J.S. Chen, S.A. Gill, N. Mummaneni, M.W. McDermott, M.S. Berger, M.K. Aghi, The neurosurgery applicant's "arms race": analysis of medical student publication in the Neurosurgery Residency Match, *J. Neurosurg.* 133 (2020) 1913–1921, <https://doi.org/10.3171/2019.8.JNS191256>.
- [21] H.J. Shakir, J.M. Cappuzzo, H. Shallwani, A. Kwasnicki, C. Bullis, J. Wang, R. M. Hess, E.I. Levy, Relationship of grit and resilience to burnout among U.S. neurosurgery residents, *World Neurosurg.* 134 (2020) e224–e236, <https://doi.org/10.1016/j.wneu.2019.10.043>.
- [22] M. Pulcrano, S.R.T. Evans, M. Sosin, Quality of life and burnout rates across surgical specialties: a systematic review, *JAMA Surg.* 151 (2016) 970–978, <https://doi.org/10.1001/jamasurg.2016.1647>.
- [23] Z.X. Low, K.A. Yeo, V.K. Sharma, G.K. Leung, R.S. McIntyre, A. Guerrero, B. Lu, C. Lam, B.X. Tran, L.H. Nguyen, C.S. Ho, W.W. Tam, R.C. Ho, Prevalence of burnout in medical and surgical residents: a meta-analysis, *IJERPH* 16 (2019) 1479, https://scholar.google.com/scholar_lookup?title=Prevalenceofburnoutinmedicalandsurgicalresidents%3Aaameta-analysis&author=Z.X.Low&publication_year=2019.
- [24] S.W. Guadix, I. Younus, G. Winston, M. ElJalby, J. Xia, J.J. Nario, M. Rothbaum, R. E. Radwanski, J.P. Greenfield, S.C. Pannullo, Medical students' perceived interests and concerns for a career in neurosurgery, *World Neurosurg.* 139 (2020) e203–e211, <https://doi.org/10.1016/j.wneu.2020.03.169>.
- [25] S. Bialek, V. Bowen, N. Chow, A. Curns, R. Gierke, A. Hall, M. Hughes, T. Pilishvili, M. Ritchey, K. Roguski, B. Silk, T. Skoff, P. Sundararaman, E. Ussery, M. Vasser, H. Whitham, J. Wen, Geographic differences in COVID-19 cases, deaths, and incidence - United States, February 12–April 7, 2020. *MMWR Morb. Mortal. Wkly. Rep.* 69 (2020) 465–471, <https://doi.org/10.15585/mmwr.mm6915e4>.
- [26] D.E. DeWitt, Fighting COVID-19: enabling graduating students to start internship early at their own medical school, *Ann. Intern. Med.* 173 (2020) 143–144, <https://doi.org/10.7326/M20-1262>.
- [27] A. Whelan, O. Prescott, G. Young, V.M. Catanese, Guidance on medical students' participation in direct in-person patient contact activities, *Assoc. Am. Med. Coll.* (2020) 1–6.
- [28] R.M. Garcia, R.A. Reynolds, H.K. Weiss, L.B. Chambless, S. Lam, N.S. Dahdaleh, G. Rosseau, Preliminary national survey results evaluating the impact of COVID-19 pandemic on medical students pursuing careers in neurosurgery, *Neurosurgery* 87 (2020) E258–E259, <https://doi.org/10.1093/neuros/nyaa214>.
- [29] L.H. Marasa, T.A. Pittman, Factors neurosurgery candidates use when choosing a residency program. Clinical article, *J. Neurosurg.* 120 (2014) 167–172, <https://doi.org/10.3171/2013.7.JNS13290>.
- [30] C. Burford, J. Hanrahan, A. Ansariou, B. Smith, K. Sysum, K. Rajwani, M. Huett, F. Vergani, B. Zebian, Factors influencing medical student interest in a career in neurosurgery, *World Neurosurg.* 122 (2019) e367–e374, <https://doi.org/10.1016/j.wneu.2018.10.056>.
- [31] V. Stumpo, K. Latour, J.J. Traylor, V.E. Staartjes, M. Giordano, V.M. Caccavella, A. Olivi, L. Ricciardi, F. Signorelli, Medical student interest and recruitment in neurosurgery, *World Neurosurg.* 141 (2020) 448–454.e6, <https://doi.org/10.1016/j.wneu.2020.04.248>.
- [32] P. Agarwal, A.M. Khalafallah, E.H. Hersh, M.E. Ivan, D. Mukherjee, Impact of American association of neurological surgeons medical student interest groups on participation in organized neurosurgery, research productivity, and residency match success, *World Neurosurg.* 138 (2020) e437–e444, <https://doi.org/10.1016/j.wneu.2020.02.153>.
- [33] D. Lubelski, R. Xiao, D. Mukherjee, W.W. Ashley, T. Witham, H. Brem, J. Huang, S. Q. Wolfe, Improving medical student recruitment to neurosurgery, *J. Neurosurg.* (2019) 1–7, <https://doi.org/10.3171/2019.5.jns1987>.
- [34] Coronavirus Aid, Relief, and Economic Security Act, H.R. 748, 116th Congress, 2nd Session, 2020.
- [35] J.C. Houpy, W.W. Lee, J.N. Woodruff, A.T. Pincavage, Medical student resilience and stressful clinical events during clinical training, *Med. Educ.* Online 22 (2017), 1320187, <https://doi.org/10.1080/10872981.2017.1320187>.
- [36] Z. Daya, J.H. Hearn, Mindfulness interventions in medical education: a systematic review of their impact on medical student stress, depression, fatigue and burnout, *Med. Teach.* 40 (2018) 146–153, <https://doi.org/10.1080/0142159X.2017.1394999>.
- [37] D. Williams, G. Tricomi, J. Gupta, A. Janise, Efficacy of burnout interventions in the medical education pipeline, *Acad. Psychiatry* 39 (2015) 47–54, <https://doi.org/10.1007/s40596-014-0197-5>.
- [38] J. Dallas, N. Mummareddy, A.M. Yengo-Kahn, R.J. Dambrino, A.M. Lopez, L. B. Chambless, R. Berkman, R.V. Chitale, C.M. Bonfield, R.S. Offodile, S. Durham, J. C. Wellons, R.C. Thompson, S.L. Zuckerman, Neurosurgery elective for preclinical medical students with and without a home neurosurgery program, *World Neurosurg.* 131 (2019) e201–e210, <https://doi.org/10.1016/j.wneu.2019.07.112>.