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Research Article

Clinical exposure to neurosurgery at medical school: The current medical student experience

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ABSTRACT

Background: Medical students may be placed at neurosurgical centres (NCs) or non-neurosurgical centres (non-NCs) during their undergraduate clinical neurosciences placements (CNP). Studies show varied exposure to neurosurgery among medical schools, but comparison of clinical exposure between students at neurosurgical centres and non-neurosurgical centres or its impact on their preparedness, is yet to be fully assessed.
Methods: A questionnaire was electronically distributed to medical students from Cardiff University in the United Kingdom, all of whom completed a clinical neurosciences placement. Recruitment was through email, social media, and in-person. Quantitative data were analysed using descriptive statistics and non-parametric tests, while qualitative data underwent thematic analysis.
Results: Forty responses were collected from medical students. Thirty-four (85.0 %) had their clinical neurosciences placement at a neurosurgical centre, and of these, twenty-four (70.6 %) had a neurosurgical rotation, half of which lasted $\leq$ two days. Significantly more participants at neurosurgical centres attended neurosurgical theatre compared to none at non-neurosurgical centres (54.8 % vs 0.0 %, $p = 0.022$). Significant differences were found in neurosurgical tutorials, small group teaching, case-based discussions, and simulations, with these opportunities being more commonly provided at neurosurgical centres. Three themes from the qualitative data supported the quantitative findings.
Conclusion: There is a difference in clinical exposure between students at neurosurgical centres and non-neurosurgical centres. Students at non-neurosurgical centres have fewer neurosurgical opportunities, potentially impacting their learning, examination performance, and clinical practice.

1. Introduction

Medical students in the United Kingdom are all advised to receive a clinical neurosciences placement, which encompasses conditions relating to neurology, neurosurgery, and neurorehabilitation. On this placement, students may be sent to various sites such that they receive adequate exposure to the clinical neurosciences, and to accommodate the ever-growing number of medical students in annual cohort [3,11]. Students allocated to clinical neurosciences placements outside of large centres may be based at non-neurosurgical centres (non-NC), whereas those allocated to large centres may be based at a Neurosurgical Centre (NC). We hypothesised that students allocated to non-NCs may receive suboptimal training and exposure to neurosurgical pathologies and procedures. Non-NCs may be less equipped to provide neurosurgical teaching to students due to their lack of neurosurgical specialists. This difference may result in varying educational opportunities for students based at NCs versus non-NCs.

Several studies report variable medical student exposure to neurosurgery across medical schools [15,18]. However, no studies were identified looking specifically at differences in clinical exposure between students who have completed a clinical neurosciences placement at NCs versus non-NCs. This is noteworthy as this may result in large variations in students' clinical exposure between medical schools, depending on whether there is an NC within their locality, and within medical schools, depending on where placements are allocated, potentially leading to inequity of experience. One may expect students who

Abbreviations: NC, Neurosurgical centre; non-NC, Non-neurosurgical centre.

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have had very little exposure to neurosurgery would have different feelings of preparedness in dealing with neurosurgical conditions compared to those who have greater exposure.

This study begins to quantify the variability in neurosurgical clinical exposure and educational opportunities between medical students at NCs and non-NCs at a single UK Medical School, Cardiff University. This medical schools randomly allocates approximately two-thirds of students to a NC for their clinical neurosciences placement, with the other third being allocated to a non-NC for their clinical neurosciences placement. This study aimed to describe students' exposure to neurosurgical conditions at NCs and non-NCs, and to explore how differences in neurosurgical exposure might affect students' preparedness for future clinical practice.

2. Methods

2.1. Data collection tool

An electronic questionnaire was created with quantitative and qualitative elements to screen for medical students' experiences at NCs and non-NCs. This questionnaire was disseminated to students at a single UK medical school (Cardiff University). The questionnaire was hosted by the Jisc© Online Forms platform (full questionnaire is available within Supplementary Material). In addition, two medical student participants were recruited via a student neurosurgery interest group, who were students at a separate medical school, but who completed clinical neurosciences placements with learning outcomes that were near identical to those of Cardiff University clinical neurosciences placements.

Consent was taken and recorded digitally. Fourth- and fifth-year medical students received the questionnaire via their university email addresses. Participation was optional. Upon completing the informed consent page, the survey software then allowed participating students to proceed with completing the questionnaire. Demographic data from participants were collected to compare responses across these variables.

Using a Likert scale (a psychometric rating system used to measure attitudes and perceptions by presenting statements followed by a series of answer options, typically with five response levels), participants were asked about their perceived preparedness to perform tasks related to the neuroscience learning outcomes of the Cardiff University Medical School Curriculum. Participants also quantified the number and duration of neurosurgical rotations and described their clinical experiences, specifying whether these experiences were organised by the school or sought out independently. Additionally, participants rated how clinical opportunities contributed to their preparedness, assessing the perceived educational value of each opportunity. Participants also identified and rated the impact of additional learning activities on their preparedness, highlighting what supplementary educational activities were provided at non-NCs. Finally, participants shared their overall perception of neurosurgical education at medical school, offering free-form responses.

2.2. Ethical review

This project was reviewed by Cardiff University School of Medicine research ethics committee (SMREC). Ethical approval was granted prior to data collection (SMREC reference: 22/89).

2.3. Data analysis

2.3.1. Analysis of quantitative data

Descriptive statistics, including medians and quartiles, were calculated for survey questions related to demographics, preparedness, clinical exposure, and educational activities. Subgroup analysis by gender and placement location was performed using odds ratios (OR) and 95 % confidence intervals (95 % CI), with the Mann-Whitney *U* test for skewed data and Fisher's exact test for small sample sizes. The level of statistical significance was set at $p < 0.05$. Preparedness was measured using a composite variable derived from Likert scale responses, using Cronbach's alpha and McDonald's omega to assess internal consistency. Quantitative data were analysed data using SPSS Statistics 27.0.1.0 [5].

2.3.2. Analysis of qualitative data

Thematic analysis of participants' free-text responses was conducted using Braun and Clarke's six-step method [2]. Participant numbers were assigned, responses were repeatedly read, and relevant comments were systematically coded. Emergent codes were collated, themes identified, and descriptions revised to ensure clarity, resulting in a thematic matrix, with quotes which can be seen in the Supplementary Material.

3. Results

Approximately 500 Cardiff University medical students were invited to participate between December 2022 and February 2023. Forty responses were collected. Of these, twenty-seven were female (67.5 %) and thirteen were male (32.5 %). Thirty-eight participants (95.0 %) had completed a clinical neurosciences placement at Cardiff University, and 2 (5.0 %) completed a clinical neurosciences placement outside Cardiff University. Nineteen participants (47.5 %) were final year students, seventeen (42.5 %) were penultimate year students, and four (10.0 %) were intercalating students.

3.1. Neurosurgical clinical rotation

Of the participants, thirty-four had their clinical neurosciences placement at an NC (85.0 %). Of these, twenty-four (70.6 %) received a neurosurgical rotation. Half of these participants (12/24) had a neurosurgical rotation of ≤ 2 days in duration [Table 1], and approximately half of all rotations lasting between three and five days, while one reported a rotation of six-ten days. None of the participants who had placements at non-NCs had any neurosurgical rotation or exposure. There was a significantly higher chance of students receiving a neurosurgical placement when placed at a NC compared to a non-NC ($U = 30.0$, $Z = -2.860$, $p = 0.004$).

3.2. Clinical experience

There was a trend towards participants at NCs having more clinical opportunities than those at non-NCs [Table 2]: Eighty-three percent attended neurosurgical ward rounds, versus fifty percent who attended a ward round (of any type/speciality) at non-NCs (OR = 4.67, 95 % CI 0.75–29.01, $p = 0.115$). Both groups had similar attendance at outpatient clinics (OR = 1.07, 95 % CI 0.19–6.28, $p = 1.000$). Significantly more participants at NCs attended neurosurgical theatre (54.8 % vs 0.0 %, $p = 0.022$). No non-NC participants reported on-calls or multidisciplinary meetings, whereas almost half of students at NCs had opportunities to attend such learning opportunities.

Most participants at NCs agreed or strongly agreed attending neurosurgical wards, theatre, outpatient clinics, on-call and multidisciplinary meetings prepared them for dealing with neurosurgical cases [Table 3].

Table 1
Duration of neurosurgical rotations amongst participants who received a neurosurgical rotation at an NC.

Duration of neurosurgical placement	Number of responses (n = 24)	Percent
< 1 day	6	25.0 %
1–2 days	6	25.0 %
3–5 days	11	45.8 %
6–10 days	1	4.2 %
> 10 days	0	0.0 %

Table 2
Proportion of participants who had receiving clinical opportunities at NCs and non-NCs. ORs were calculated where possible for the likelihood of receiving a clinical opportunity at an NC over a non-NC. A 2-tailed Fisher's exact test was used to calculate a p-value. (% = relative frequency; n = absolute frequency of responses alongside the total responses for each).

	NC % (n)	non-NC % (n)	OR (95 % CI)	p-value
Ward	82.4 % (28/34)	50.0 % (3/6)	4.67 (0.75–29.01)	0.115
Theatre	**54.8 % (17/31)**	**0.0 % (0/6)**	–	**0.022**
Outpatient clinic	51.7 % (15/29)	50.0 % (3/6)	1.07 (0.19–6.28)	1.000
On-call	**40.0 % (12/30)**	**0.0 % (0/6)**	–	**0.079**
Multidisciplinary meeting	**44.8 % (13/29)**	**0.0 % (0/6)**	–	**0.064**

Table 3
Table showing participant perceptions at NCs of the effectiveness of each clinical opportunity at preparing them to deal with neurosurgical cases in future. (% = relative frequency; n = absolute frequency of responses alongside the total responses for each).

	Strongly disagree % (n)	Disagree % (n)	Neither agree nor disagree % (n)	Agree % (n)	Strongly agree % (n)
Ward	0 % (0/24)	8.3 % (2/24)	20.8 % (5/24)	45.8 % (11/24)	25.0 % (6/24)
Theatre	7.1 % (1/14)	7.1 % (1/14)	14.3 % (2/14)	35.7 % (5/14)	35.7 % (5/14)
Outpatient clinic	0 % (0/13)	23.1 % (3/13)	0 % (0/13)	53.8 % (7/13)	23.1 % (3/13)
On-call	0 % (0/9)	0 % (0/9)	11.1 % (1/9)	33.3 % (3/9)	55.6 % (5/9)
Multidisciplinary meeting	8.3 % (1/12)	0 % (0/12)	8.3 % (1/12)	66.7 % (8/12)	16.7 % (2/12)

3.3. Educational activities

Educational activities received by participants on their clinical neurosciences placement were compared between NCs and non-NCs [Table 4]. All participants at NCs received neurosurgical lectures on their placement, compared to eighty-three percent at non-NCs (p = 0.154) [Table 4]. Participants were 1.55 times more likely to receive neurosurgical simulation sessions at NCs (95 % CI 1.09–2.20, p = 0.004). [Table 4].

Table 4
Educational activities received by participants at NCs and non-NCs. ORs were calculated where possible for the odds of receiving an educational activity at an NC over a non-NC. A 2-tailed Fisher's exact test was used to calculate a p-value. (% = relative frequency; n = frequency of responses alongside the total responses for each).

	NC % (n)	non-NC % (n)	OR (95 % CI)	p-value
Lecture	100.0 % (33/33)	83.3 % (5/6)	–	0.154
Tutorial	93.9 % (31/33)	40.0 % (2/5)	23.25 (2.35–229.68)	0.011
Small group teaching	84.8 % (28/33)	33.3 % (2/6)	11.20 (1.60–78.40)	0.018
Case-based discussion	81.8 % (27/33)	33.3 % (2/6)	9.00 (1.33–61.03)	0.028
Simulation	66.7 % (22/33)	0.00 % (0/6)	1.55 (1.09–2.20)	0.004
E-learning	60.6 % (20/33)	16.7 % (1/6)	7.69 (0.81–73.55)	0.077

Significant differences were found for neurosurgical tutorials, small group teaching, case-based discussions, and simulations, all being more likely at NCs despite wide-ranging confidence intervals [Table 5]. Most participants from NCs agreed or strongly agreed that lectures, tutorials, small group teaching, case-based discussions, simulations, and e-learning prepared them for neurosurgical cases [Table 5].

3.4. Preparedness

Most students at both NCs and non-NCs felt prepared (48.3 % vs. 47.6 %) [Fig. 1], to deal with neurosurgical cases. The Mann-Whitney test showed no significant difference in preparedness scores of any type between NCs and non-NCs (U = 19027, Z = −0.755, p = 0.450).

4. Qualitative data

Out of the forty participants, twenty-nine provided free text responses for analysis. Eighteen had received a neurosurgical placement at an NC, with eleven based at a non-NC.

4.1. Limited placement experience

Several participants felt they received very little exposure during their clinical neurosciences placement [Supplementary material], with clinical opportunities perceived to be "limited due to [a] large number of students" on the placement block. Some received no neurosurgical experience, instead focusing more on neurology, which limited their understanding of neurosurgical conditions [Table 6; Fig. 2]. Additionally, it is "not guaranteed every student will have exposure" to neurosurgery on their placements, resulting in a variable experience. Participants actively sought out supplementary neurosurgical opportunities. Seeking out opportunities was perceived to provide very good educational experiences "if you take the initiative". Many participants perceived their neurosurgical experience at non-NCs to be a cursory introduction to the specialty.

4.2. Variable experiences due to contrasting active and passive roles

Experiences varied between active and passive roles. Some participants were actively involved in neurosurgical care, leading consultations, examining patients, assessing acutely unwell patients, and assisting in procedures [Supplementary material]. Participants felt active roles were useful experiential learning opportunities to practice their clinical skills, such as "taking focused histories". Others reported

Table 5
Table showing participants from NCs perceptions of the effectiveness of each educational opportunity at preparing them to deal with neurosurgical cases in future. (% = relative frequency; n = absolute frequency of responses alongside the total responses for each).

	Strongly disagree % (n)	Disagree % (n)	Neither agree nor disagree % (n)	Agree % (n)	Strongly agree % (n)
Lecture	0 % (0/37)	0 % (0/37)	13.5 % (5/37)	54.1 % (20/37)	32.4 % (12/37)
Tutorial	0 % (0/32)	0 % (0/32)	6.3 % (2/32)	43.8 % (14/32)	50.0 % (16/32)
Small group teaching	0 % (0/29)	0 % (0/29)	0 % (0/29)	41.4 % (12/29)	58.6 % (17/29)
Case-based discussion	0 % (0/28)	0 % (0/28)	10.7 % (3/28)	39.3 % (11/28)	50.0 % (14/28)
Simulation	0 % (0/19)	0 % (0/19)	0 % (0/19)	38.1 % (8/19)	61.9 % (13/19)
E-learning	0 % (0/20)	5.0 % (1/20)	10.0 % (2/20)	40.0 % (8/20)	45.0 % (9/20)

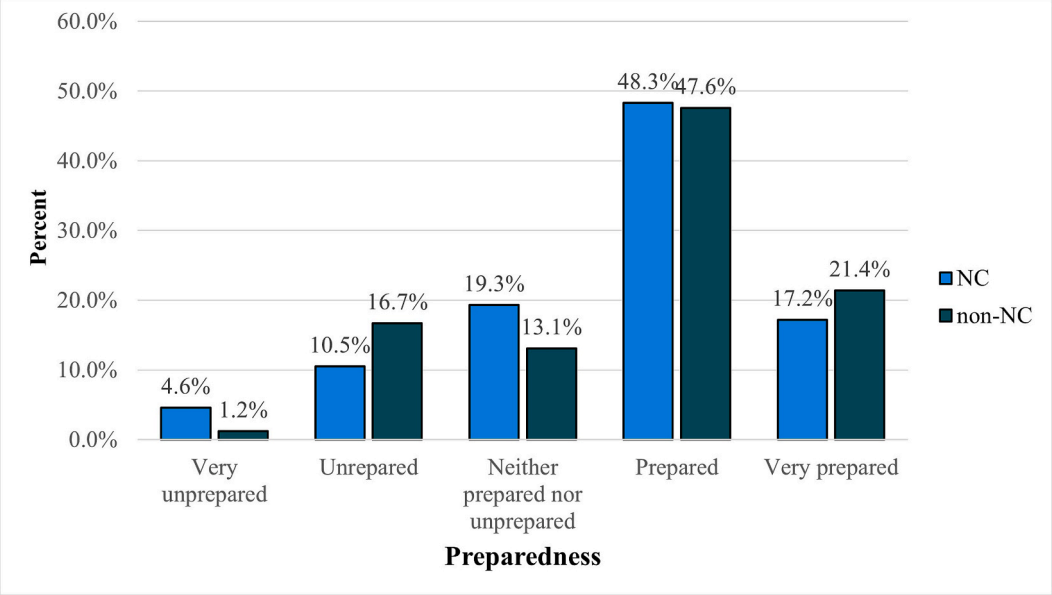

Fig. 1. Relative frequencies of the preparedness of participants at NC and non-NCs to deal with neurosurgical cases.

Table 6
Three major themes with corresponding example quotes.

Themes	Example quotes
Limited placement experience	P#20: "No neurosurgical experience at all". P#13: "My experience involved one neurosurgery ward round." P#05: "Very little exposure have to go out your way to gain the experience" P#08: "Good theoretical teaching, but very limited clinical exposure." P#20: "My personal experience has been largely from lecture teaching and self-study for exams. Clinical placement has been extremely limited."P#23: "Very little exposure- not guaranteed every student will have any exposure to it. One lecture is not sufficient- all students should have at least one day of neurosurgical placement." P#01: "very limited due to large number of students" P#25: "Self-organised paediatric ward round amazing experience"
Variable experiences due to contrasting active and passive roles	P#01: "Clerking a patient at outpatient clinic including a history and examination. Very useful for practice". P#03: "Had chance to review patients myself in clinic and on ward" P#14: "Theatre assistance for CSDH and EDH evacuations"P#28: "Doing an LP, Intrathecal Abx and other basic clinical skills on neurosurgery ward during on-call shift." P#05: "Mainly observing didn't really give insight into specialty"P#12: "I watched wardround but did not actively participate. It was very interesting but as we had a passive role it did limit my learning."
Building of clinical knowledge through a combination of teaching and clinical learning	P#19: "Lots of patients with neurology so able to identify these from the examination" P#07: "Useful to have learnt and understand the knowledge to apply it to patients when seeing neurosurgical patients"P#19: "Simulation really helpful as puts the learning into context." P#27: "This really helped to consolidate what is seen on the wards."

passive roles, mainly observing and shadowing, which were perceived to limit learning.: "[observing] was very interesting but as we had a passive role it did limit my learning". Passive roles were noted proportionately more often at non-NCs.

4.3. Building of clinical knowledge through a combination of teaching and clinical learning

Neurosurgical experiences helped develop clinical skills, particularly in identifying neurological signs. Teaching sessions were seen to support learning in the clinical environment and for understanding the underlying science, helping students to "understand why each symptom occur". Furthermore, neurosurgical teaching sessions were helpful conceptualise and "consolidate what is seen on the wards". Participants felt that "simulation [sessions were] really helpful" at "putting the learning into context".

5. Discussion

Medical students consistently perceive the clinical neurosciences to be the most challenging of specialities [12,14]. Neurophobia refers to a phenomenon in which medical students and healthcare professionals are intimidated by the clinical neurosciences as a result of its perceived difficulty [6]. Exposure to neurosurgical topics could help to improve Neurophobia [7]. The focus of this study was to explore the difference in exposure to neurosurgery and neurosurgical teaching at NCs and non-NCs and any resulting effects on preparedness to deal with neurosurgical cases, and potentially help to combat Neurophobia amongst medical practitioners.

5.1. Clinical exposure to neurosurgery

The published literature provides variable accounts of the clinical exposure to neurosurgery at medical schools across the United Kingdom. A cross-sectional study found half of the neurosurgical programme directors surveyed worked at units which delivered a mandatory neurosurgical rotation to medical students [18].

Another study of medical students' clinical exposure to neurosurgery and their ability to correctly identify neurosurgical conditions suggested, of the eighty-one fifth-year students surveyed, ninety-four percent stated that they had received clinical exposure to

Fig. 2. Major themes from qualitative data collection from NC (left side) and non-NC (Right side).

neurosurgery [15]. However, the extent of the clinical exposure and whether it was at an NC or non-NC was not surveyed. In contrast, a survey of attendees at a neurosurgery careers event reported that only twenty-five percent had received a neurosurgical rotation during medical school [16].

Our findings showed students receiving their placement block at NCs were significantly more likely to receive clinical exposure to neurosurgery than students at non-NCs. Our results also show that receiving a neurosciences placement at an NC does not necessarily guarantee that students will receive a formal neurosurgical rotation, with under a third of students based at NCs reporting receiving a neurosurgical rotation. Of those that received a neurosurgical rotation, half had a rotation lasting two days or less. This suggests a variability exists in the clinical exposure to neurosurgical experience medical students receive at medical school, which may be linked to whether they are based at NCs or non-NCs.

Participants based at NCs were significantly more likely to attend neurosurgical theatre, on-calls, MDTs than in non-NCs, with none at non-NCs receiving these opportunities. An overwhelming majority of students at NCs in this present study agreed that theatres and attending on-calls was beneficial at preparing them for dealing with neurosurgical patients. This is in keeping with the findings from another study that found attendance at operating theatre and neurosurgical on-calls contributed greatly to the learning of neurosurgical subjects for students, further highlighting the potential inequity of experience for students at NCs versus those allocated to non-NCs [7]. Furthermore, other studies described that attending theatre alongside clinical teaching sessions can be beneficial to learning, with students who attended both classroom teaching and theatre more likely to correctly identifying neurosurgical conditions than those without theatre experience [15]. Since the present study identified that completion of a clinical neurosciences placement at an NC significantly increased the exposure of students to neurosurgical tutorials, theatre, and lectures, it stands that placement at an NC has the potential to optimise the learning of neurosurgical concepts for students.

Additional experience may not translate into students' feeling confident in dealing with neurosurgical conditions, with a third of final year medical students perceiving themselves to be competent in identifying neurosurgical conditions and referring appropriately, despite ninety-four percent having completed a neurosurgical rotation [15]. This perceived lack of competence in neurosurgery is also identified in other studies [1]. Despite this, our findings suggest medical students felt well prepared to deal with neurosurgical cases in their professional practice, with a majority feeling 'prepared'. Interestingly, there was no statistical difference between the levels of preparedness between participants based at NCs and non-NCs. This is noteworthy given the differences in both clinical and educational opportunities available at NCs compared to non-NCs. This may be a consequence of adaptive self-regulated learning strategies employed by students at non-NCs students at non-NCs reported utilising other resources to learn about neurosurgery, such as previous lectures and previous acute medicine placements to guide self-directed learning. Self-regulated learning is a cyclical process in which learners generate their own learning goals and formulate their own strategies to accomplish these goals [13]. Such a phenomenon was illustrated in a study of 1127 medical students in Portugal, wherein a cohort of students on a neurology clinical neurosciences placement who were allocated to a placement with fewer structured clinical activities, outperformed those primarily allocated to neurology outpatients, (with greater clinical exposure) in a post-placement neurology OSCE [9]. Fewer prescribed learning actives may drive students to seek their own learning, resulting in self-regulation. In

the context of neurosurgical education, self-regulated learners identify their own learning goals related to neurosurgery and develop strategies to achieve them, such as seeking additional opportunities, with studies showing that self-regulated learning plays a role in learning within operating theatre [8,17]. A systematic review suggested that greater exposure to surgical procedures leads to significantly better operative outcomes across various surgical parameters [10]. Ultimately, the real-world impact of increased clinical exposure is improved health outcomes for patients, especially in the context of surgery.

5.2. Educational activities

Our results showed students at non-NCs were significantly less likely to receive neurosurgical teaching in the form of tutorials, small-group teaching, case-based discussions, simulation and e-learning than students at NCs. This is despite participants rating all educational activities as overwhelmingly beneficial in preparing them for dealing with neurosurgical cases in their future clinical practice. Many of the educational activities above are commonly used methods for teaching neuroanatomy [4]. Poor neuroanatomical knowledge is the largest contributor to "Neurophobia" amongst medical students [12]. This leads to medical students finding the clinical neurosciences to be the most challenging of all specialities, particularly in terms of formulating differential diagnoses based on clinical findings [12].

5.3. Limitations

The main limitation of this research project is the low response rate to the survey, with only a total of 40 responses, affecting the generalisability and precision of the results. There is scope to expand this study nationally to give more generalisable results and better insight into neurosurgical education at undergraduate level. This could be achieved with the aid of neurosurgical specialist interest groups and societies to distribute the survey, though it would increase the self-selection bias by recruiting students with an established interest in neurosurgery. Alternatively, recruitment directly through medical schools, although more challenging, would offer a larger pool of participants less prone to self-selection bias.

6. Conclusion

Medical students' clinical exposure to neurosurgery is variable. Our findings suggest this variability exists between students at NCs and non-NCs creating a potential inequity in student learning opportunities, potentially exacerbating Neurophobia in sub-cohorts of students, through reduced opportunities and exposure to NCs.

While statistical differences in the preparedness felt by students towards dealing with neurosurgical cases were not observed, differences in the clinical and educational opportunities available to students at NCs and non-NCs were noted. However, it is possible learners at non-NCs adapt their learning styles in response to the limited opportunities. Further work assessing formal score at formative and summative neuroscience assessments could provide more objective measures of students' preparedness and learning at NCs compared to non-NCs.

This, combined with multi-centre studies to assess for NC and non-NC differences at national or international level, could inform approaches used to teach clinical subjects where exposure is variable or based at tertiary centres [19]. The effects of over-centralisation of specialised services is particularly pronounced in low-resource nations and requires a thorough understanding of the barriers to access for medical students, as well as creative use of educational resources [19]. Low resource nations have seen significant benefit from the use of visit-based and online electronic learning models to improve the skills and knowledge of surgeons in rural areas [19]. Extending these opportunities to students at the undergraduate level, in both high and low resource settings, could help combat the inequalities seen in early medical education and expand access to higher training, a solution which pertains, but is not limited to, neurosurgery.

CRediT authorship contribution statement

Aled Lester: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ronak Ved:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Gregor Ramage:** Writing – review & editing, Writing – original draft, Visualization, Resources, Data curation. **Stephen Greenwood:** Writing – review & editing, Supervision, Investigation, Formal analysis, Conceptualization. **Daniel Parry:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Paul Leach:** Writing – review & editing, Writing – original draft, Supervision. **Phil Smith:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2025.102185.

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