

Intraoperative technology in skull base and vascular neurosurgery: a two-stage cross-sectional national survey

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Abstract

Background:

Skull base and vascular neurosurgery rely on diverse intraoperative technologies. Although many are well established, contemporary data describing real-world usage patterns across operative paradigms are limited. We aimed to characterise national practice and variation in intraoperative technology use within these surgical fields.

Methods:

We conducted a two-stage cross-sectional survey of UK and Ireland neurosurgeons via the Society of British Neurological Surgeons (SBNS). Six SBNS MedTech Committee members compiled a predefined technology list. Respondents then reported frequency of use of these technologies for three exemplar procedures: transsphenoidal approaches for pituitary adenomas, retrosigmoid approaches for vestibular schwannomas, and pterional approaches for intracranial aneurysms. Use was recorded on a four-point ordinal scale and analysed descriptively. Kendall's tau-b rank correlation explored the relationship between surgeon experience and technology use.

Results:

Twenty-four responses from 21 British neurosurgical units (66% of adult/mixed units) were analysed. Technology use was strongly procedure specific. Neuronavigation was common for transsphenoidal surgery but less frequent for retrosigmoid and pterional approaches. Endoscopy displaced microscopy in transsphenoidal surgery, whereas microscopy remained dominant for retrosigmoid and pterional approaches. Indocyanine green video angiography and micro-Doppler ultrasonography were widely used for aneurysm vascular visualisation. Drills were common across procedures, alongside micro-debriders (transsphenoidal) and ultrasonic aspirators (retrosigmoid). Neurophysiological monitoring was universal in vestibular schwannoma surgery and variably used for aneurysms. Newer technologies, including augmented reality, exoscopes, intraoperative MRI, and robotics, were used infrequently. Surgeon experience showed no significant association with technology use.

Conclusions:

Intraoperative technology use in British skull base and vascular neurosurgery is strongly shaped by operative paradigms. Established technologies cluster around recurring procedural needs: orientation, visualisation, tissue manipulation, and neurophysiological monitoring. Newer technologies remain selectively adopted, with uptake likely influenced by cost, infrastructure, training requirements, and workflow compatibility.

Introduction

Skull base and vascular neurosurgery are among the most technically demanding areas of contemporary neurosurgical practice. These procedures are performed through narrow anatomically complex operative corridors, often around critical neurovascular structures, and depend on accurate approach planning, visualisation, tissue manipulation, and intraoperative monitoring. [1]

Modern neurosurgical practice is therefore increasingly supported by intraoperative technologies.[2] These include established adjuncts, such as neuronavigation, endoscopy, microscopy, high-speed drills, ultrasonic aspirators, indocyanine green video angiography, micro-Doppler ultrasonography, and neurophysiological monitoring, as well as newer technologies such as augmented reality, exoscopy, intraoperative MRI, and robotics. However, adoption of these technologies varies according to factors such as operative paradigm, surgeon preference and training, institutional resources, workflow, and perceived clinical value. [3]

Despite the rapid development of surgical technology, contemporary national data describing its real-world use in skull base and vascular neurosurgery are limited. [4] Such data are important for benchmarking current practice, informing training requirements, guiding service provision, and identifying areas where emerging technologies require further evaluation.

We therefore conducted survey of neurosurgeons in the UK and Ireland to characterise the current use of intraoperative technology in skull base and vascular neurosurgery. Specifically, we aimed to describe patterns of use across three exemplar operative paradigms: transsphenoidal approaches for pituitary adenomas, retrosigmoid approaches for vestibular schwannomas, and pterional approaches for intracranial aneurysms.

Methods

This was a two-stage cross-sectional national survey developed by the Academic Committee of the Society of British Neurological Surgeons MedTech Group. The study was designed to characterise current use of intraoperative technology in skull base and vascular neurosurgery in the UK and Ireland. Ethical approval was not required for this study.

Stage 1: selection of technologies

In the first stage, six members of the MedTech Group were asked to identify intraoperative technologies that they were familiar with or had observed in use across neurosurgical centres. For the purposes of this study, intraoperative technologies were defined as adjuncts requiring an external power supply. Responses were reviewed by the committee and grouped into four functional categories: approach planning and navigation, visualisation, tissue manipulation, and intraoperative monitoring. This process was used to generate a predefined list of technologies for inclusion in the national survey.

Stage 2: national survey

In the second stage, an online questionnaire was distributed to neurosurgeons in the UK and Ireland through the Society of British Neurological Surgeons mailing list. The survey was hosted on Google Forms and opened on 12 August 2025. It was open to consultants and neurosurgical residents.

The survey captured respondent characteristics, including training grade, years of neurosurgical experience and institution of practice. Three index procedures were selected to represent distinct operative paradigms within skull base and vascular neurosurgery - endoscopic transsphenoidal resection of pituitary adenomas, retrosigmoid resection of vestibular schwannomas and pterional clipping of intracranial aneurysms. These procedures were chosen as representative examples of contemporary skull base and vascular practice.

For each exemplar operation, respondents were first asked whether they performed the procedure regularly. Those who did were then asked to report their frequency of use of each predefined intraoperative technology for that procedure. Frequency of use was recorded using a four-point ordinal scale: always or almost always; mostly (> 50% of cases); sometimes (< 50% of cases); or never or almost never. A four-point scale without a neutral middle option was used to encourage respondents to make a judgement regarding routine use.[5] Respondents could also report additional technologies using a free-text field. All questions were optional.

Statistical analysis:

Responses were analysed descriptively. Categorical variables were summarised using counts and percentages. Each exemplar procedure was analysed independently, including only respondents who reported performing that procedure regularly. Technologies were analysed according to their functional category. Free-text responses were reviewed and grouped thematically. To explore whether use varied by surgeon experience

For each adjunct, the correlation between experience and reported use was assessed using Kendall's rank correlation coefficient (tau-b), which accommodates the large number of tied ranks inherent to ordinal data. Adjuncts used identically by all respondents were excluded, and p-values were adjusted within each procedure using the Benjamini–Hochberg procedure. Given the exploratory nature of these analyses and the small sample size, results were interpreted descriptively. Analyses and figures were generated in R version 4.3.1.

Results

Respondent characteristics:

A total of 25 responses were received. One respondent was excluded because they did not report regularly performing any of the exemplar procedures, leaving 24 responses for analysis. Most

respondents were consultants (22/24, 92%), and the remainder were neurosurgical residents (2/24, 8%). Respondents were highly experienced with 14/24 (58%) reporting at least 20 years of neurosurgical experience. Responses were received from 21 distinct neurosurgical units in Great Britain, representing 66% of adult or mixed neurosurgical units in the UK. (Table 1)

Twelve respondents reported regularly performing transsphenoidal approaches for pituitary adenomas, 12 reported regularly performing retrosigmoid approaches for vestibular schwannomas, and 13 reported regularly performing pterional approaches for intracranial aneurysms.

Table 1
– Summary demographics of survey respondents

Years of experience		Count (%)
> 20 years		14 (58%)
15–20 years		3 (13%)
10–15 years		1 (4%)
5–10 years		5 (21%)
< 5 years		1 (4%)
Location	Scotland	2 (8%)
	North of England	8 (33%)
	South of England	6 (25%)
	London	6 (25%)
	Wales	1 (4%)

Transsphenoidal approaches for pituitary lesions.

The frequency of intraoperative technology use for transsphenoidal approaches is shown in Fig. 1. For approach and navigation, neuronavigation was used routinely by most respondents (always or almost always in 8/12, 67%), whereas surgical robots and augmented reality were rarely used.

For visualisation and vascular localisation, endoscopy was universal (all respondents always or almost always), and micro-Doppler ultrasonography was used by every respondent to some degree, although the frequency varied. The microscope, exoscope, intraoperative ultrasound, and intraoperative CT were not used by any respondent, and intraoperative MRI by only a small minority (2/12, 17%).

For tissue manipulation, high-speed drills and micro-debriders were each used always or almost always by 10/12 (83%), and bipolar diathermy was used routinely by most. Ultrasonic aspirators were used by a minority (Sonopet 5/12, CUSA 4/12), mostly sometimes.

In free-text responses, one respondent reported intraoperative cavernous sinus neuromonitoring for extended endonasal cases, and others reported suction monopolar use and Colorado-needle monopolar diathermy.

Retrosigmoid approaches for vestibular schwannoma.

The frequency of intraoperative technology use for retrosigmoid approaches is shown in Fig. 2. For approach and navigation, neuronavigation was used inconsistently, with most respondents (8/12, 67%) never or almost never using it for this approach, augmented reality sometimes used by one respondent, and surgical robots were never used.

For visualisation, the microscope was universal (all respondents always or almost always). Endoscopic assistance was used selectively, with over half of respondents (7/12, 58%) reporting some use. Exoscopy and intraoperative ultrasound were rarely used, with intraoperative MRI and intraoperative CT used by none.

For tissue manipulation, the high-speed drill was universal (all respondents always or almost always), and ultrasonic aspirators were commonly used, with Sonopet (always or almost always in 9/12, 75%) reported more frequently than CUSA (always or almost always in 6/12, 50%).

For monitoring, intraoperative neurophysiological monitoring (facial nerve or brainstem) was universal, used always or almost always by all respondents.

No additional technologies were identified in free-text responses.

Pterional approaches for intracranial aneurysms.

The frequency of intraoperative technology use for pterional approaches is shown in Fig. 3. For approach and navigation, neuronavigation, augmented reality, and surgical robots were all used infrequently, none being reported as routine.

For visualisation and vascular localisation, the microscope and indocyanine green video angiography were both universal (all respondents always or almost always). Micro-Doppler ultrasonography was also used commonly, though not universally (routine in 10/13, 77%). Endoscopic assistance was reported by a minority (6/13, 46%), usually as an occasional adjunct and exoscopy was rarely used.

For tissue manipulation, high-speed drills were used always or almost always by most respondents (11/13, 85%), whereas ultrasonic aspirators were used infrequently.

For monitoring, neurophysiological monitoring was variably used, from frequently (always or mostly) by 7/13 (54%) to rarely or never by 6/13 (46%).

Free-text responses clarified that the augmented-reality use reported by one respondent was part of a research programme rather than routine clinical practice, and one respondent specified the use of a

handheld endoscope.

Effect of experience on adjunct use:

Surgeon experience showed no statistically significant association with the use of any intra-operative technology in any of the three exemplar procedures. Across all testable technologies, rank correlations were weak and inconsistent in direction (Kendall's tau-b ranging from -0.44 to $+0.47$), and none reached significance either before or after correction for multiple comparisons (lowest unadjusted $p = 0.088$; lowest FDR-adjusted $p = 0.49$). Several adjuncts were used uniformly by all respondents, including the operating microscope across all three procedures, the drill and facial-nerve or brainstem monitoring in retrosigmoid approaches, and indocyanine green in pterional approaches, and were therefore not amenable to correlation analysis. These findings should be interpreted in the context of a small, experienced, predominantly consultant sample, which limited the statistical power to detect any effect of experience on adjunct use.

Discussion

Principal findings

This two-stage cross-sectional national survey provides a contemporary overview of intraoperative technology use in skull base and vascular neurosurgery across Great Britain. Across three exemplar procedures, technology use was strongly procedure specific. Each operative paradigm was anchored around a small number of established technologies: endoscopy, neuronavigation, high-speed drills and micro-debriders for transsphenoidal pituitary surgery; microscopy, drilling, ultrasonic aspiration and neurophysiological monitoring for retrosigmoid vestibular schwannoma surgery; and microscopy, indocyanine green video angiography and micro-Doppler ultrasonography for pterional aneurysm surgery.

By contrast, the uptake of more recently introduced technologies was infrequent or absent. Augmented reality and the exoscope showed limited, selective use, whereas intraoperative MRI, intraoperative CT and robotic systems were almost entirely absent across all three procedures.[6–13] Surgeon experience was not shown to be associated with frequency of technology use, although the study was not powered to detect such an association.[14, 15] Overall, these findings suggest that adoption is shaped less by surgeon seniority than by operative paradigm, perceived clinical value, workflow integration and institutional availability.

Results in context

For approach planning and navigation, neuronavigation was most commonly used in transsphenoidal pituitary surgery.[16] This likely reflects the narrow and variable anatomical corridor, the proximity of the internal carotid arteries, and the importance of orientation during endonasal access. In contrast, neuronavigation was used less consistently for retrosigmoid and pterional approaches, where surgeons may rely more heavily on surface anatomy, bony landmarks and microsurgical exposure.

For visualisation, the findings demonstrate a clear division between endoscopic and microscopic operative paradigms. In transsphenoidal surgery, the endoscope had fully displaced the microscope among respondents, consistent with the broader shift towards endoscopic pituitary surgery. In retrosigmoid and pterional approaches, the microscope remained universal, but endoscopic assistance was reported selectively. [17–21] In pterional aneurysm surgery, indocyanine green video angiography was universal and micro-Doppler ultrasonography was commonly used, indicating that vascular visualisation and flow assessment are embedded in routine practice. Their routine co-use suggests a defence-in-depth approach to intraoperative flow verification, in which complementary modalities are combined to confirm vessel patency rather than relied upon individually.

For tissue manipulation, high-speed drilling remained a core technology across all three procedures, although its role differed by approach. In transsphenoidal surgery, drills and micro-debriders were commonly used for nasal and sphenoid work, while ultrasonic aspirators were less frequently reported. In retrosigmoid surgery, drilling was universal and ultrasonic aspirators were commonly used, reflecting the need for controlled bone removal and tumour debulking near critical neurovascular structures. In pterional aneurysm surgery, drills were commonly used, whereas ultrasonic aspirators were rarely required.

For intraoperative monitoring, the pattern was more selective. No routine monitoring technology was reported for transsphenoidal surgery. In retrosigmoid vestibular schwannoma surgery, facial nerve and brainstem monitoring were universal, supporting their status as routine technologies for this procedure. [22] In pterional aneurysm surgery, neurophysiological monitoring showed greater variation, suggesting that its perceived value remains more dependent on surgeon or institutional preference.

These patterns are consistent with the limited comparable literature. A recent national survey of neurosurgical technology use in Germany reported similarly high availability of neuronavigation, neuromonitoring and advanced imaging alongside inconsistent implementation across centres, with more varied technology use reported in academic centres.[23] In another survey of technology use in the USA variable use of ultrasound, microscopes, and loupes was found, the last of which being a technology that did not appear in our survey at all.[24] This survey also suggested that trainees' use of intraoperative equipment tends to mirror that of their supervising surgeons rather than to diverge from it. The increasing adoption of intraoperative neuromonitoring in skull base and vascular neurosurgery reflects not only advances in patient safety but also evolving medicolegal expectations. As surgical interventions become increasingly complex and the standard of care continues to evolve, neuromonitoring provides objective real-time assessment of neural pathway integrity, supporting intraoperative decision-making and potentially reducing the risk of avoidable injury. Consequently, its use is increasingly viewed as an important component of risk mitigation and defensible neurosurgical practice in several centres.

The contrast between near-universal and rarely used technologies can be understood through complementary models of innovation diffusion and normalisation. The entrenched adjuncts such as

indocyanine green angiography, micro-Doppler ultrasonography, and neurophysiological monitoring, share attributes that favour adoption: a clear relative advantage, straightforward compatibility with existing operative workflow, lower complexity, and high observability, in that they provide immediate, visible intraoperative feedback.[25, 26] Although these factors favour the diffusion of innovations, they do not explain how it becomes embedded. Normalisation Process Theory describes how this occurs through four mechanisms.[27] Normalised technologies cohere with the conceptual aims of the operation, so surgeons share a settled understanding of their purpose (coherence). The surgical community has enrolled around them and legitimated them as components of standard practice (cognitive participation). They are workable within the operative workflow and fit the division of theatre labour without disruption (collective action). Finally, they are no longer consciously appraised as discrete "technologies" but evaluated tacitly as part of how the operation is simply done (reflexive monitoring). This shift from explicit to tacit appraisal is the signature of a normalised practice. The operating microscope, the endoscope, and indocyanine green represent this endpoint in our survey results, with transsphenoidal endoscopy offering a worked example of a technology that has firmly completed the trajectory by fully displacing its predecessor.

Intraoperative MRI and robotic systems, by contrast, may be stalling earlier in the diffusion process. Their high complexity, limited trialability, and substantial infrastructure and cost requirements may impede collective and widespread adoption.[25] They are therefore better understood as not yet sufficiently diffused, owing to high barriers to adoption, rather than as rejected.[28] Furthermore, for such technologies that may remain at earlier stages of evaluation with limited proven incremental benefit, selective or cautious use even when available may also represent appropriate, evidence-proportionate restraint rather than a failure to adopt. Frameworks for the staged evaluation of surgical innovations such as the IDEAL framework indicate that the breadth of a technology's use should be proportionate to the maturity of its evidence base, with limited, selective use by fewer operators being the expected mode at earlier stages of evaluation rather than a marker of under-adoption.[29–31] In this reading, "sometimes" on our ordinal scale may indicate targeted deployment, such as intraoperative MRI reserved only for invasive or recurrent adenomas, rather than inconsistency of practice.

The variation in adoption also has implications for equitable access. In a centralised, publicly funded system such as the NHS, capital-intensive technologies may cluster in tertiary and academic centres as seen in aforementioned the German survey.[23] The technologies used universally in our data by contrast constitute core competencies to which surgical training must guarantee exposure, whereas rarely used technologies cannot yet be trained at scale. This is imperative given survey evidence that trainees' equipment use mirrors that of their supervisors.[24]

We did not find clear evidence that surgeon experience was associated with technology use. This finding should be interpreted cautiously, given the limited statistical power of this analysis. Nonetheless, this finding challenges the assumption that newer or less experienced surgeons are necessarily more likely to adopt novel technologies.[14, 15] Instead, the results suggest that established procedural norms, local

availability, training pathways, and perceived usefulness may be more important determinants of use than seniority alone.

Strengths and limitations:

This study has several strengths. It provides national data from 21 neurosurgical units, representing two-thirds of adult or mixed neurosurgical units in Great Britain. The use of three exemplar procedures allowed comparison across distinct operative paradigms, and the four-point ordinal scale provided more granular information than a binary measure of availability or use.

However, the study also has limitations. As with all voluntary surveys, the findings are subject to responder bias, particularly towards surgeons with an interest in technology. The sample size was modest, especially for procedure-specific and experience-based analyses. Responses were self-reported and may not reflect actual intraoperative behaviour. The use of exemplar procedures necessarily simplifies the diversity of skull base and vascular practice, and the survey did not always distinguish between routine clinical use and research use. The survey also captured the frequency of use but not availability or the reasons for use. We could not therefore distinguish deliberate non-use from lack of access, and the determinants of use we discuss are inferred, warranting dedicated qualitative investigation. Finally, no responses were received from paediatric-only units, limiting generalisability to paediatric neurosurgery.

Conclusion

These findings provide a national benchmark for current UK practice and show that intraoperative technology use is strongly shaped by the demands of each operative paradigm. Established technologies appear to cluster around recurring procedural needs: orientation in transsphenoidal surgery, controlled tumour removal and neurophysiological monitoring in retrosigmoid surgery, and vascular visualisation in aneurysm surgery.

Newer technologies, including intraoperative MRI, augmented reality, exoscopy and robotics, remain selectively adopted. Their reduced uptake is likely to depend not only on potential clinical benefit, but also on other factors such as cost, infrastructure, availability, training requirements and compatibility with existing workflows.[32] Interpreting these patterns through the combined lens of innovation diffusion and normalisation suggests that supporting adoption may require attention to trialability, workflow integration, and observable benefit.

Future evaluation should therefore consider technology adoption in context, linking use to operative decision-making, workflow, learning curves, cost-effectiveness and patient outcomes. This study provides a foundation for such work.

Declarations

Disclosures:

HJM is supported by NIHR UCLH/UCL Biomedical Research Centre. He is also an employee and holds shares in Panda Surgical Ltd.

Human Ethics and Consent to Participate declarations

Not applicable.

Clinical trial number

Not applicable.

Competing Interests

HJM is supported by NIHR UCLH/UCL Biomedical Research Centre. He is also an employee and holds shares in Panda Surgical Ltd. AMSA is funded by an NIHR Doctoral Fellowship and received honoraria from Brainlab.

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No funding was received for this study.

Author Contribution

Conceptualisation: AA, AB, DP, PP, HJM Methodology: all authors Analysis: AMSA Data curation: AMSA, JH Writing - original draft: AMSA, JH, HJM Writing – review and editing: all authors Supervision: HJM

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Figures

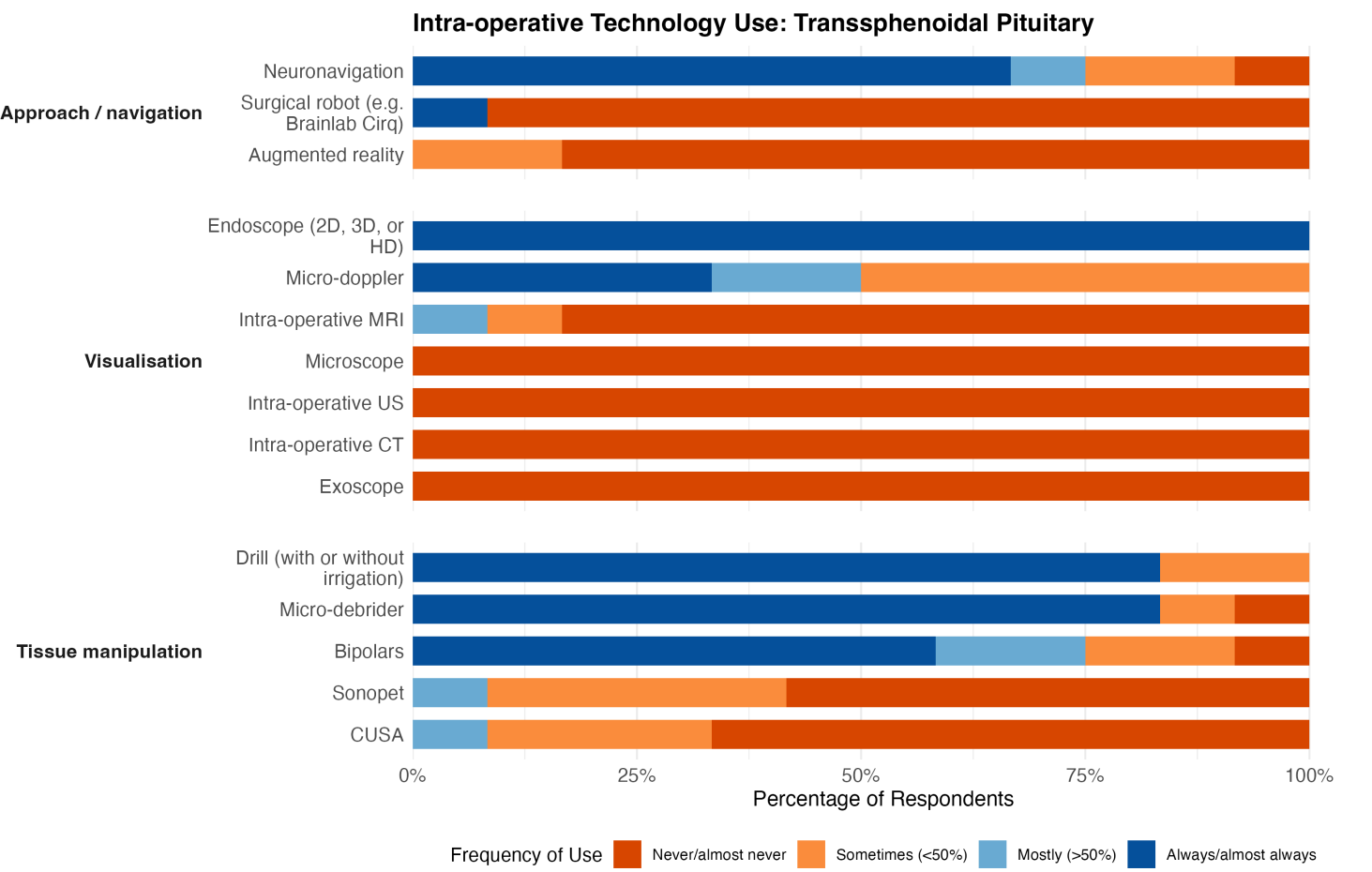


Figure 1

Stacked bar chart demonstrating frequency of adjunct use for transsphenoidal approaches for pituitary lesions organised from most to least used.

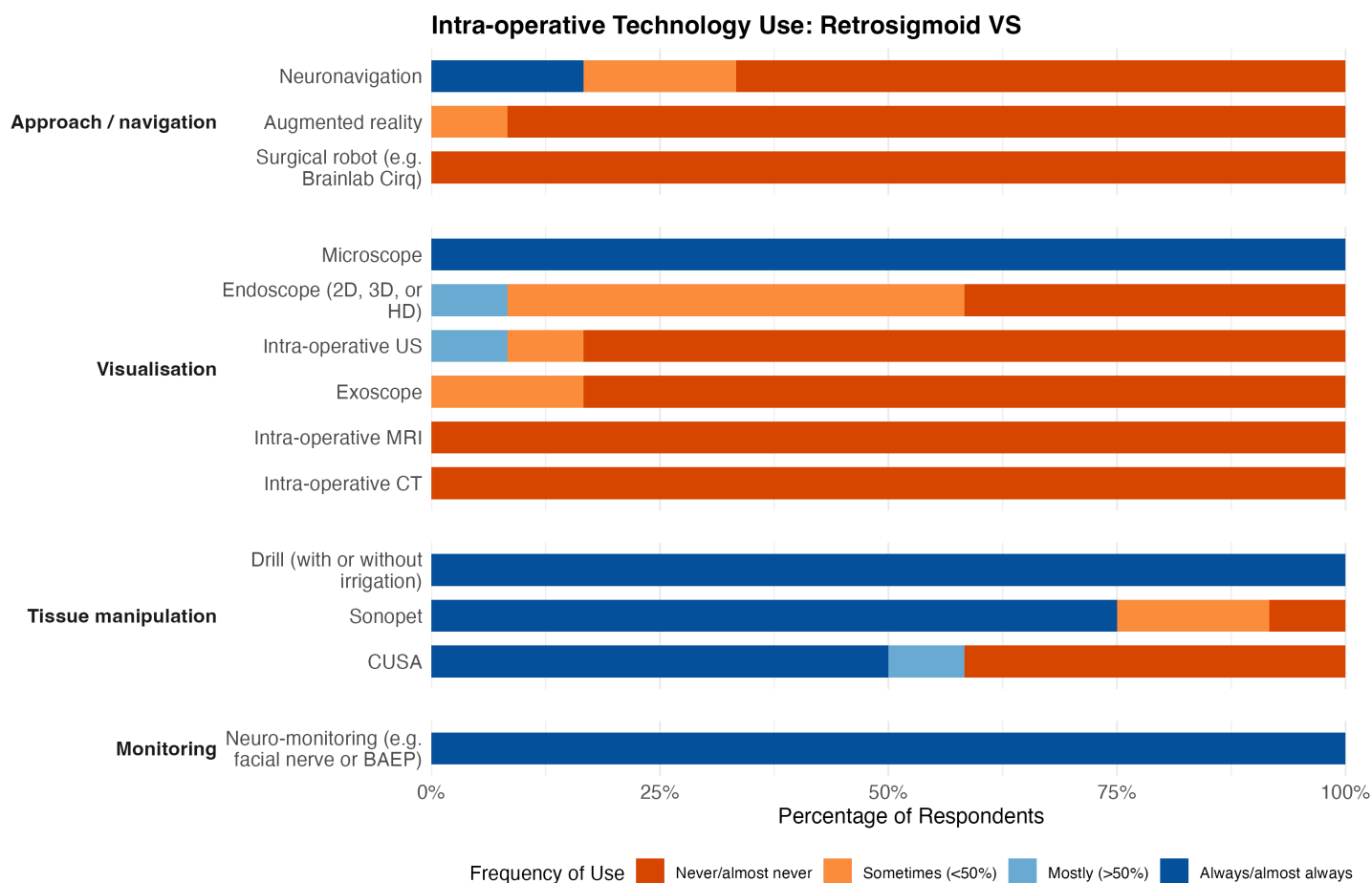


Figure 2

Stacked bar chart demonstrating frequency of adjunct use for retrosigmoid approaches to vestibular schwannomas organised from most to least used.

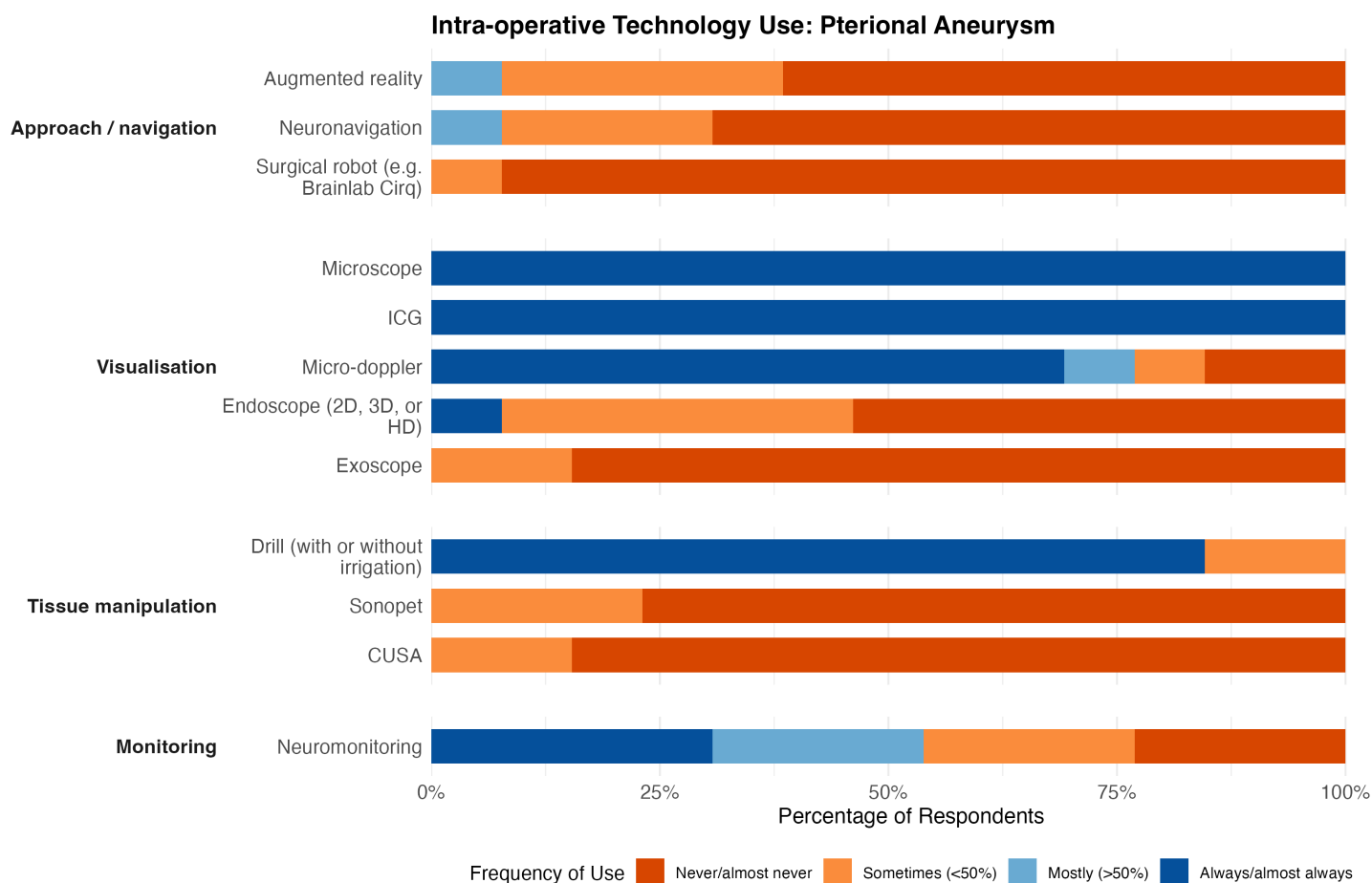


Figure 3

Stacked bar chart demonstrating frequency of adjunct use for pterional approaches for intracranial aneurysms organised from most to least used.