Generating operative workflows for vestibular schwannoma resection: a two-stage Delphi consensus in collaboration with British Skull Base Society. Part 1: the retrosigmoid approach


Affiliations below.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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Abstract:
Objective
An operative workflow systematically compartmentalises operations into hierarchical components of phases, steps, instrument, technique errors and event errors. Operative workflow provides a foundation for education, training, and understanding of surgical variation. In Part 1 we present a codified operative workflow for the retrosigmoid approach to vestibular schwannoma resection.

Methods
A mixed-method consensus process of literature review, small group Delphi consensus, followed by a national Delphi consensus was performed in collaboration with British Skull Base Society (BSBS). Each Delphi round was repeated until data saturation and over 90% consensus was reached.

Results
Eighteen consultant skull base surgeons (10 neurosurgeons; 8 ENT) with median 17.9 years of experience (IQR 17.5 years) of independent practice participated. There was a 100% response rate across both Delphi rounds. The operative workflow for the retrosigmoid approach contained 3 phases and 40 unique steps: Phase 1: approach and exposure; Phase 2: tumour debulking and excision; Phase 3: closure. For the retrosigmoid approach, technique and event error for each operative step was also described.

Conclusions
We present Part 1 of a national, multi-centre, consensus-derived codified operative workflow for the retrosigmoid and approach to vestibular schwannomas that encompasses phases, steps, instruments, technique errors, and event errors. The codified retrosigmoid approach presented in this manuscript can serve as foundational research for future work, such as operative workflow analysis or neurosurgical simulation and education.
Figure 1. Schematic diagram of Delphi process – highlighting the generation of a surgical workflow through iterative consensus from British Skull Base Society expert members. Adapted from Marcus et al., 2021.
Supplementary Material

Supplementary Material A: guidance questions to experts during each consensus rounds for both the retrosigmoid and translabyrinthine approach

Round 1:
Q1. Do you think the presented workflow framework encapsulates your own operative practice and practice that you have observed?
   - Yes / No
   If answered “No” to Q1:
   Q2. Are there any additional operative steps which you feel should be added?

Q3. Are there any instruments used which are not represented in this framework? If so, at which step(s) would they be most appropriately place?
   - Yes (please specify) / No

Q4. Are there any technical errors not listed in the framework? If so, at which step(s) would they be most appropriately place?
   - Yes (please specify) / No

Round 2:
For each phase of each operative approach, experts were asked the following two questions:
Q1. Are there any additional operative steps which you feel should be added OR would you change any of the steps contents?
Q2. If yes, what would you change?

Supplementary Material B: Health Research Authority UK – Ethics requirement decision tool

[Image of Health Research Authority UK – Ethics requirement decision tool]

Retrosigmoid and translabyrinthine approaches for vestibular schwannoma resection – workflow modelling through Delphi consensus

[Text about ethics requirements and decision tool]
Generating operative workflows for vestibular schwannoma resection: a two-stage Delphi consensus in collaboration with British Skull Base Society. Part 1: the retrosigmoid approach

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Keywords

Retrosigmoid; translabyrinthine; vestibular schwannoma; skull base surgery; consensus; Delphi.

Abstract

**Objective** An operative workflow systematically compartmentalises operations into hierarchal components of phases, steps, instrument, technique errors and event errors. Operative workflow provides a foundation for education, training, and understanding of surgical variation. In Part 1 we
present a codified operative workflow for the retrosigmoid approach to vestibular schwannoma resection.

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Conclusions We present Part 1 of a national, multi-centre, consensus-derived codified operative workflow for the retrosigmoid and approach to vestibular schwannomas that encompasses phases, steps, instruments, technique errors, and event errors. The codified retrosigmoid approach presented in this manuscript can serve as foundational research for future work, such as operative workflow analysis or neurosurgical simulation and education.

Introduction

Vestibular schwannomas are typically resected through one of three approaches: retrosigmoid, translabyrinthine, and middle fossa\(^1\). The retrosigmoid and translabyrinthine are the most commonly utilised approaches and provide good outcomes relating to safety and efficacy profiles\(^1-3\). The middle fossa approach is rarely performed in the UK due to the high risks of damage to the facial nerve and
seizures caused by temporal lobe manipulation. There is variability between surgeons and centres on how to perform the operation, based on surgeon preference and training, tumour location and characteristics, all of which may result in differing surgical outcomes. Additionally, lateral skull base procedures are technically challenging, have steep learning curves, and centres have varying degrees of collaboration with ear, nose, and throat (ENT) surgeons for different parts of the operation.

An initial step to understanding how an operation is performed is to deconstruct the operation and create a common language. A technique to systematically deconstruct complex procedures into defined tasks and errors is known as “operative workflow analysis.” The surgical procedure is broken down into phases which contain a series of steps, generating a workflow framework. During each step (e.g. suturing), surgical instruments (e.g. forceps) are used to perform manoeuvres (e.g. knot tying) via a series of gestures (e.g. grasping and pulling suture). Similarly, at each step, there is the potential for technical errors – lapses in surgical technique, and adverse events – an event which may lead to adverse outcomes or postoperative complications. Deconstructing a complex procedure into a systematic operative workflow requires expert consensus. Existing literature has demonstrated subject experts generating comprehensive and standardised workflow framework for non-neurosurgical procedures and more recently a neurosurgical procedure. The Delphi technique allows the generation of group consensus through iterative questionnaires/surveys, interspersed with feedback.

The management of vestibular schwannomas has benefitted from international, multidisciplinary consensus statements relating to stereotactic radiosurgery, reporting outcomes, and, more recently, large vestibular schwannomas. Currently, there is no consensus on the operative workflow for the retrosigmoid or translabyrinthine approaches for vestibular schwannomas. Expert, consensus-driven operative workflows can provide multiple benefits: (1) workflow analysis; (2) training; (3) creation of...
high-fidelity simulation models; (4) objective assessment of procedure-specific surgical skills; (5) evaluation of novel technologies or techniques; (6) operating room efficiency improvements\textsuperscript{9,11,18,19}.

We created an operative workflow for the retrosigmoid approach for vestibular schwannoma, through an expert consensus process in collaboration with the British Skull Base Society (BSBS). This operative workflow aimed to digitise the approaches, and provide foundational research in which to build, for example, the application of artificial intelligence to vestibular schwannoma resection.

**Methods**

**Overview**

The methodology was drawn from previous work from our group\textsuperscript{14}. This process aimed to generate a comprehensive workflow framework which captured how each approach could reasonably be performed. We did not aim to dictate how an operation should be done. The beginning of the operation was taken as the first incision, adhering to the American College of Surgeon’s definition of surgery – “structurally altering the human body by the incision or destruction of tissues”\textsuperscript{20}. Therefore, variation relating to position of the patient and incision analysis was not within the scope of this work, although the authors recognise that positioning plays a critical role for any given procedure. The components for workflow analysis and associated definitions are listed in Table 1. Expert input will be derived through an iterative, mixed-methods consensus process (Figure 1).

**Modified Delphi process & sampling**

**Literature review:**

We performed a literature review of Greenberg’s *Handbook of Neurosurgery*, Youman and Winn *Neurological Surgery*, and *Operative Cranial Neurosurgical Anatomy*, and undertook a PubMed and
EMBASE search using the keywords “retrosigmoid”, “translabyrinthine” and “vestibular schwannoma resection” were used\(^1-3,21-23\) (Figure 1).

**Delphi Round 1:**

The initial literature-based operative workflow was reviewed by a group of five consultant skull base surgeons including neurosurgery and ENT, based at the National Hospital for Neurology and Neurosurgery, London, UK. Each consultant surgeon reviewed the operative workflow individually - via computerised document with the definitions of phases, steps, instruments, technical errors, and adverse events as above (Table 1). Each expert was asked a series of questions via e-mail, seeking to assess the completeness and accuracy of the workflow (Supplementary Material A)\(^14\). Any additional suggestions were reviewed and added to the workflow matrix if in scope and not duplicate. According to the Delphi technique, circulation and iterative revision of the workflow was repeated until data saturation was achieved, that is, all experts were satisfied that the operative workflow was complete and accurate\(^14\).

**Delphi Round 2:**

The refined workflow was circulated nationally with skull base surgeons (neurosurgeons and ENT) who were members of the BSBS\(^24\), the UK and Ireland’s society primarily focused on skull base pathology. The entirety of the BSBS was invited to participate via email. All contributing authors are specialist lateral skull base surgeons with an independent surgical practice in vestibular schwannoma surgery who are members of the BSBS (either neurosurgery or ENT). Consultant surgeon members from the BSBS were asked to assess the workflow and suggest any amendments to encompass possible variation in practice and technique. Additional suggestions were reviewed and added to the workflow if (1) in scope; (2) not duplicate\(^14\). Round 2 was completed until all surgeons agreed that the workflow captured the operative practice and that there were no additional suggestions for the workflow from the participant.
group. Both the retrosigmoid and translabyrinthine approaches were completed in parallel: surgeons within the BSBS were given the opportunity to contribute to either approach depending on their personal clinical practice and expertise. Experience for all authors was calculated from the date they were added to the General Medical Council’s Specialist Register – a list of doctors who have completed their postgraduate training and eligible to work as a consultant\(^ {25} \).

**Administration**

Invitations to participate in the Delphi process were sent via direct email only. Workflow documents were presented using Microsoft Word (Version 16.4, Microsoft, USA) in both rounds and supported by Google Forms in Round 2 (Google LLC, USA).

**Data Collection and Analysis**

Participant demographics collected included surgical specialty and unit. The collected data regarding the surgical workflow were quantitative (whether participants agree it is complete and accurate) and qualitative (additional suggestions or comments)\(^ {14} \). Content analysis was used to analyse free-text responses: to remove out-of-scope suggestions, group similar suggestions together and compare them to existing data points in the workflow. Data analysis and workflow updates were performed in duplicate by two independent analysers (HLH, PG).

**Ethics**

This study is independent of national health services and does not require ethical approval – interrogated via online Health Research Authority decision tool (Supplementary Material B)\(^ {14,26} \).

**Results**
Participants

The Delphi Round 1 was completed by a group of five consultant skull base surgeons. Two neurosurgeons at the National Hospital for Neurology and Neurosurgery, London, UK and three ENT surgeons at the Royal National Throat, Nose & Ear Hospital, London, UK. Cumulatively, they had a median 12.3 years and IQR 16.0 years of experience (IQR1 9.6 years; IQR3 25.5 years). The Delphi Round 1 was repeated four times during a 4-month period (October 2020 – Feb 2021) until saturation.

The Delphi Round 2 was completed by 10 neurosurgeons and 8 ENT surgeons based at 11 centres across the UK. All contributing authors are specialist lateral skull base surgeons with an independent surgical practice in vestibular schwannoma surgery who are members of the BSBS (either neurosurgery or ENT). Cumulatively, they had a median 17.9 years and IQR 17.5 years of experience (IQR1 8.0 years; IQR3 25.5 years). Round 2 was repeated twice during a 3-month period (May – July 2021) until saturation. There was a 100% response rate and no attrition across both Delphi Rounds.

Retrosigmoid approach

Three distinct operative phases were delineated: (1) approach and exposure; (2) tumour debulking and excision; (3) closure. The operative workflow had 40 unique steps. Pre-operative set-up and post-operative protocols were recognised as important, but not included as per the defined study scope.

Phase 1: Approach and exposure

This phase consisted of 10 steps from retroauricular incision, approaching the cerebello-pontine angle and dissection of the arachnoid plane from the tumour capsule (Table 2).

Phase 2: Tumour debulking and excision
This phase consisted of 21 steps, starting with identification of the facial nerve using a stimulator, tumour debulking at the superior and inferior poles, with lateral-medial and medial-lateral dissection, and culminating with stepwise rolling and debulking of the tumour (Table 3). It is acknowledged that the exact order of the tumour debulking is surgeon and tumour characteristic dependent. As such, each operation will contain the steps listed within this phase, but perhaps in a different order as written depending on intraoperative findings. Further, facial nerve reanimation may or may not take place intraoperatively, and the type of nerve graft used is surgeon dependent.

**Phase 3: Closure phase**

This phase consisted of 9 steps, beginning with facial nerve stimulation, haemostasis, dural repair and multi-layer closure (Table 4).

**Discussion**

**Principal findings**

We present a consensus-derived codified operative workflow for retrosigmoid approach to vestibular schwannoma that considers the phases, steps, technique errors, and event errors of the operation. The operative workflow was achieved through national collaboration with the British Skull Base Society following an open invitation to all members to participate. This comprised 18 independently practicing neurosurgeons and ENT surgeons from 11 centres across the UK.

The retrosigmoid approach operative workflow comprised three distinct phases: (1) approach and exposure; (2) tumour debulking and excision; (3) closure, with a total of 40 individual steps. Participants felt strongly about protecting the petrosal vein and avoiding sacrifice if it all possible to prevent the risk of venous infarct or haemorrhage. Regarding tumour debulking and excision – Phase 2 – the aim is to
achieve maximal tumour resection whilst preserving the facial nerve. As such, the tumour debulking and excision phase presented is an illustrative example. The exact sequence of resection is tumour and surgeon specific. We acknowledge that it is a systematic, stepwise debulking of the superior and inferior poles, and joining of medial-lateral and lateral-medial dissections, but that depending on local experience and expertise, and intraoperative findings, the sequence of resection might differ from our operative workflow.

Vestibular schwannoma resection is challenging surgery, with nuance relating to many aspects of the procedure. The retrosigmoid approach can be performed with the patient in a sitting, lateral or supine position. Further, the incision and how to deal with the muscles during opening is important to avoid muscle atrophy or numbness. We acknowledge the heterogeneity in practice relating to local expertise and surgeon preference. The codified retrosigmoid approach presented in this manuscript can serve as foundational research for further work, such as operative workflow analysis or neurosurgical education.

**Utilising the operative workflow for simulation and education**

Vestibular schwannomas cause unilateral hearing loss, tinnitus, imbalance, and headaches. Zhang et al. report a large retrospective series of 1006 patients undergoing vestibular schwannoma resection. The mortality was 0.3%, risk of meningitis 1.2%, and risk of CSF leak in 9% of cases. Their reported CSF leak rate and the need for revision surgery decreased over time, whilst House-Brackmann facial nerve grade and hearing preservation after surgery improved over time. The authors cite improvement in functional outcomes is due to increasing experience on smaller vestibular schwannomas. In modern practice smaller vestibular schwannomas are often managed non-surgically with stereotactic radiosurgery. This heralds an issue for current neurosurgical and ENT trainees as there is a reduction in the number of smaller tumours to resect, train on and enhance operative skills. Additionally, the learning
curve for vestibular schwannoma resection is steep\textsuperscript{29} such that limited surgical experience in low-volume centres can result in poor functional outcomes and increased morbidity\textsuperscript{30}. Adequate training and experience are essential to reducing mortality and morbidity. Operative workflows can provide a medium to explore and improve simulation, through the creation of high-fidelity models\textsuperscript{31}. This can improve training experience, and reduce mortality and morbidity.

Post-operative complications resulting from intraoperative errors during microsurgery for vestibular schwannoma resection are well known and have been well reported traditionally\textsuperscript{32,33}. Seventy-five percent of errors within neurosurgery are deemed as preventable and technical in nature\textsuperscript{34}. For example, injury to the venous sinuses or the cerebellar arteries can have devastating consequences for patients during vestibular schwannoma resection\textsuperscript{32,33,35,36}. Our operative workflows contain information on technique errors and event errors\textsuperscript{37}, paired with an exact sequence of phases and steps. This provides a framework for the development of high-fidelity models which encompass the importance of error awareness, avoidance and management. This can be integrated with a model using augmented reality overlay to simulate a vessel injury and subsequent bleeding\textsuperscript{38}. This gives the surgical trainee the opportunity to face and deal with intraoperative complications in a safe environment with no harm to patients. High-fidelity simulation models incorporating the operative workflows as presented here, may become an integral component of surgical training in the future. For example, Realists spinal models (https://www.realists.de/realspine) already simulate bleeding and complications.

Models must be valid, and appropriate for the task. “Validity” comprises face validity (realism), content validity (usefulness as a training skill) and construct validity (experts perform better than novices)\textsuperscript{39}. To validate the content of a model simulating the retrosigmoid approach, there must be an agreed operative workflow with which to compare. The operative workflows presented in this study therefore offers a
means to validate the content of retrosigmoid surgical simulators. The codified operative workflow also provides the opportunity to generate a specific technical skills assessment for trainees, adapting traditional examples such as the Objective Structured Assessment of Technical Skills (OSATS), which can be further used to examine construct validity of the model. The retrosigmoid approach in this codified operative workflow is related to vestibular schwannoma resection, but Phase 1 Approach and exposure, and Phase 3 Closure, could be applicable to all retrosigmoid approaches to the cerebellopontine angle. Therefore, future research could explore the different pathologies to generate codified workflows for different skull base pathologies utilising the retrosigmoid approach.

**Strengths and Limitations**

This study presents the first consensus-derived operative workflow that considers and digitises the phases, steps, technique errors and event errors for the retrosigmoid to vestibular schwannoma resection. Our methodology follows the precedence of existing literature and includes national experts with many years of experience of performing such surgeries. The operative workflows provide a platform to further explore the complexity of vestibular schwannoma resection within an existing framework and common language. It also provides a framework in which to assess and validate “cadaver freed training models”, such as UpSurgeon’s Retrosigmoid model (www.upsurgeon.com).

The operative workflows do not include some controversial aspects of vestibular schwannoma surgery, such as the indications for the approach, patient positioning or intraoperative decision making if aiming for sub-total resection. However, we took a constraint-based, pragmatic approach to create a foundational digitised operative workflow as the first stage in developing this operative workflow research. Although we reached consensus with colleagues from the British Skull Base Society, the
operative workflows only reflect practice across the UK. Further collaboration with our European and international colleagues to generate worldwide consensus would broaden the scope of application.

Conclusion

We present a national, multi-centre, consensus-derived codified operative workflow for the retrosigmoid approach to vestibular schwannoma resection. The workflows provide a framework detailing the phases, steps, technical errors, and event errors. The codified retrosigmoid approach presented in this manuscript can serve as foundational research for future work, such as operative workflow analysis or neurosurgical simulation and education.

Previous presentations

This work has not been presented, either partly or wholly.

Author contributions

Study conception and methodology was led by HJM, JWC, MF, MG, DZK, CHK, HLH, WM. Material preparation, data collection and analysis were performed by HLH. SC, SF, NG, SH, CH, RI, NK, AK, SK, CK, CL, RO, OP, IR, JS, DS, MT, JT and SS contributed to data collection. The first draft of the manuscript was written by HLH, HJM and PG. All authors reviewed and edited subsequent versions of the manuscript. All authors read and approved the final manuscript.

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Conflicts of Interest

JWC receives research grants and consultancy fees from Medtronic (Dublin, Ireland). JWC is the associate medical director of CMR surgical (Cambridge, UK). DS is a shareholder in Odin Vision Ltd (London, UK) and is an employee of Digital Surgery (London, UK). All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Ethics and Informed Consent

Ethical approval and informed consent were unnecessary due to the nature of the study (consensus process amongst health care professionals).

Data availability

Available upon reasonable request.

References


Figure 1. Schematic diagram of Delphi process—highlighting the generation of a surgical workflow through iterative consensus from British Skull Base Society expert members. Adapted from Marcus *et al.*, 2021.
Table 1. Definition of operative workflow terminology per domain.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase</strong></td>
<td>A major event occurring during a surgical procedure, composed of several steps⁴</td>
<td>Approach and exposure - encompassing the beginning of surgery until tumour debulking</td>
</tr>
<tr>
<td><strong>Step</strong></td>
<td>A sequence of activities used to achieve a surgical objective⁵</td>
<td>Seal mastoid air cells</td>
</tr>
<tr>
<td><strong>Instrument</strong></td>
<td>A tool or device for performing specific actions (such as cutting, dissecting, grasping, holding, retracting, or suturing) during a surgical step</td>
<td>Bone wax</td>
</tr>
<tr>
<td><strong>Technical error</strong></td>
<td>Lapses in operative technique whilst performing a surgical step⁶</td>
<td>Failure to seal mastoid air cells</td>
</tr>
<tr>
<td><strong>Adverse event</strong></td>
<td>An intraoperative event which is a result of a technical error and has the potential to lead to a post-operative adverse outcome/complication⁷</td>
<td>Cerebrospinal fluid rhinorrhoea</td>
</tr>
</tbody>
</table>

Table 2. Retrosigmoid operative workflow phase 1: approach and exposure.

<table>
<thead>
<tr>
<th>#</th>
<th>Steps</th>
<th>Instruments</th>
<th>Technique error</th>
<th>Event error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Retroauricular incision to bone +/- pericranial graft</td>
<td>Scalpel, monopolar, retractors</td>
<td>• Vertebral artery injury</td>
<td>• Vertebral artery bleeding or infarct</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Soft tissue dissection too far lateral</td>
<td>• Laceration</td>
</tr>
<tr>
<td>2</td>
<td>Haemostasis</td>
<td>Monopolar, bipolar, suction, bone wax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>+/- Retrosigmoid craniectomy +/- collection of bone dust</td>
<td>Cutting burr, Kerrison punch, periosteal elevator, bone wax</td>
<td>• Dural sinus injury</td>
<td>• Haemorrhage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Opening of mastoid air cells without repair</td>
<td>• Air embolism</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Sinus thrombosis</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• CSF rhinorrhoea</td>
</tr>
<tr>
<td>4</td>
<td>+/- Retrosigmoid craniotomy</td>
<td>Perforator, Penfield dissector, McDonald dissector, matchstick burr, cutting burr, craniotome, bone wax</td>
<td>• Dural sinus injury</td>
<td>• Haemorrhage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• CSF rhinorrhoea</td>
</tr>
<tr>
<td>5</td>
<td>Seal mastoid air cells</td>
<td>Bone wax</td>
<td>• Failure to seal mastoid air cells</td>
<td>• CSF rhinorrhoea</td>
</tr>
<tr>
<td>6</td>
<td>Durotomy</td>
<td>Scalpel, blunt hook, cottonoid patties, dural scissors</td>
<td>• Dural sinus injury</td>
<td>• Haemorrhage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Air embolism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Sinus thrombosis</td>
</tr>
<tr>
<td>7</td>
<td>Suture to dural edges</td>
<td>Suture</td>
<td>• Dural sinus injury</td>
<td>• Haemorrhage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Air embolism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Sinus thrombosis</td>
</tr>
<tr>
<td>8</td>
<td>Cisterna magna opening</td>
<td>Microscope, brain retractor, scalpel, sharp hook, cottonoid patties</td>
<td>• Failure to open cisterna magna</td>
<td>• Cerebellar swelling and retraction injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Insufficient CSF egress</td>
<td>• Haemorrhage</td>
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<td></td>
<td></td>
<td></td>
<td>• Excessive retraction</td>
<td></td>
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<tr>
<td>#</td>
<td>Steps</td>
<td>Instruments</td>
<td>Technique error</td>
<td>Event error</td>
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<td>------------------------------------------------------------------------------------------------</td>
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<td>----------------------------------</td>
</tr>
<tr>
<td>9</td>
<td>Approach to cerebello-pontine angle &amp; retraction of cerebellum</td>
<td>Microscope, microdissector, microscissors, suction, retractors, lintees, cottonoid patties, rubber dam</td>
<td>• Stretching of cranial nerves</td>
<td>• CN VII, XI, X palsy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Excessive retraction</td>
<td>Superior petrosal vein injury</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Tearing of bridging veins and haemorrhage</td>
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<tr>
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<td></td>
<td></td>
<td>Cerebellar swelling and retraction injury</td>
</tr>
<tr>
<td>10</td>
<td>Dissection of arachnoid plane from tumour capsule</td>
<td>Microscope, bipolar, suction, microdissector, microscissors, cottonoid patties, nontoothed bayonet fine tip forceps</td>
<td>• Loss of arachnoid plane or entry into incorrect plane</td>
<td>Haemorrhage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Excessive traction on capsule</td>
<td>CN injury</td>
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</tbody>
</table>

Table 3. Retrosigmoid operative workflow phase 2: tumour debulking and excision. Nb We appreciate the exact order of the following steps will be surgeon and tumour characteristic dependent.
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Equipment</th>
<th>Potential Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Identification and protection of petrosal vein, +/- coagulation and division of petrosal vein only if absolutely necessary</td>
<td>Microscope, bipolar, suction, microdissector, microscissors, cottonoid patties, scalpel</td>
<td>- Traction on petrosal vein&lt;br&gt;- Injury to SCA&lt;br&gt;- Sinus injury&lt;br&gt;- Venous infarct or haematoma&lt;br&gt;- Air embolism&lt;br&gt;- Sinus thrombosis</td>
</tr>
<tr>
<td>11</td>
<td>Dissection of tumour capsule from CN V</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties</td>
<td>- Injury to CN IV or V&lt;br&gt;- Injury to SCA&lt;br&gt;- CN IV or V palsy&lt;br&gt;- SCA infarct&lt;br&gt;- CN VII palsy&lt;br&gt;- Peduncle or brainstem infarct</td>
</tr>
<tr>
<td>12</td>
<td>Medial to lateral dissection and rolling of the tumour from cerebellar peduncle and brainstem</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties, tumour holding forceps, ultrasonic aspirator</td>
<td>- CN VII injury at root entry zone&lt;br&gt;- Injury to perforating vessels&lt;br&gt;- Incomplete tumour excision&lt;br&gt;- Hearing loss&lt;br&gt;- CSF leak&lt;br&gt;- Haemorrhage&lt;br&gt;- Air embolism&lt;br&gt;- CN VII or cochlear nerve palsy</td>
</tr>
<tr>
<td>13</td>
<td>Drilling of internal auditory canal</td>
<td>Drill, irrigation, (+/- cutting, +/- diamond burr), curette, bone wax, facial nerve stimulator</td>
<td>- Air cell opening without repair&lt;br&gt;- Opening of the labyrinth or endolymphatic duct&lt;br&gt;- Jugular bulb injury&lt;br&gt;- Injury to CN VII or cochlear nerve&lt;br&gt;- Hearing loss&lt;br&gt;- CSF leak&lt;br&gt;- Haemorrhage&lt;br&gt;- Air embolism&lt;br&gt;- CN VII or cochlear nerve palsy</td>
</tr>
<tr>
<td>14</td>
<td>Incise dura of IAM and reflect away from tumour</td>
<td>Drill, irrigation, (+/- cutting, +/- diamond burr), curette, bone wax, facial nerve stimulator</td>
<td>- CN injury&lt;br&gt;- Vessel injury&lt;br&gt;- Haemorrhage&lt;br&gt;- CN palsy</td>
</tr>
<tr>
<td>15</td>
<td>Locate fundus of IAM and dissect superior vestibular nerve as laterally as possible</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties, knife</td>
<td>- Injury to CN VII or cochlear nerve&lt;br&gt;- Incomplete tumour excision&lt;br&gt;- CN VII or cochlear nerve palsy</td>
</tr>
<tr>
<td>16</td>
<td>+/- Sacrifice of cochlear nerve in large tumours</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, knife, blunt hook, facial nerve stimulator</td>
<td>- Failure to identify CN VII in distal canal as distinct from tumour and other CN&lt;br&gt;- Injury to cochlear nerve in attempted hearing preservation surgery&lt;br&gt;- CN VII palsy&lt;br&gt;- Hearing loss</td>
</tr>
<tr>
<td>17</td>
<td>Continue dissection with lateral to medial dissection to the porous</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties, knife</td>
<td>- Failure to keep CN VII visualised at all times&lt;br&gt;- Failure to maintain plane between tumour and CN VII&lt;br&gt;- Incomplete tumour excision&lt;br&gt;- CN VII palsy&lt;br&gt;- Haemorrhage&lt;br&gt;- CN palsy</td>
</tr>
<tr>
<td>18</td>
<td>Resection of tumour in the CPA until lateral-medial and medial-lateral dissections to join together</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties, ultrasonic aspirator, tumour holding forceps</td>
<td>- CN injury&lt;br&gt;- Vessel injury&lt;br&gt;- Incomplete tumour excision&lt;br&gt;- Haemorrhage&lt;br&gt;- CN palsy&lt;br&gt;- Brainstem or peduncle oedema or infarct</td>
</tr>
<tr>
<td>19</td>
<td>Removal of tumour after stepwise rolling and debulking of tumour as above</td>
<td>Microscope, facial nerve stimulator, bipolar, suction, microdissector, microscissors, cottonoid patties</td>
<td>- CN injury&lt;br&gt;- Vessel injury&lt;br&gt;- Brainstem or peduncle injury&lt;br&gt;- Haemorrhage&lt;br&gt;- CN palsy&lt;br&gt;- Brainstem or peduncle oedema or infarct</td>
</tr>
</tbody>
</table>
- Incomplete tumour excision

Table 4. Retrosigmoid operative workflow phase 3: closure.

<table>
<thead>
<tr>
<th>#</th>
<th>Steps</th>
<th>Instruments</th>
<th>Technique error</th>
<th>Event error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CN VII stimulation to confirm response at low level (0.05mA)</td>
<td>Facial nerve stimulator</td>
<td>No stimulation</td>
<td>CN VII palsy</td>
</tr>
<tr>
<td>2</td>
<td>Haemostasis</td>
<td>Bipolar, fibrin sealant, oxidised cellulose matrix, cottonoid patties</td>
<td>Incomplete haemostasis</td>
<td>Haematoma</td>
</tr>
<tr>
<td>3</td>
<td>Seal mastoid air cells</td>
<td>Bone wax, fibrin glue</td>
<td>Failure to seal mastoid air cells</td>
<td>CSF leak</td>
</tr>
<tr>
<td>4</td>
<td>Resection cavity inspection</td>
<td></td>
<td>Failure to identify residual tumour</td>
<td>Recurrence or incomplete tumour resection</td>
</tr>
<tr>
<td>5</td>
<td>Dural repair</td>
<td>Suture, +/- synthetic dural substitute, +/- dural sealant glue, +/- pericranium graft</td>
<td>Incomplete closure</td>
<td>CSF leak, Pseudomeningocoele</td>
</tr>
<tr>
<td>6</td>
<td>+/- Replacement of bone flap</td>
<td>Bone flap, miniplates, screws, +/- bone substitute, +/- bone flap clamp system</td>
<td>Incomplete closure</td>
<td>CSF leak, Pseudomeningocoele</td>
</tr>
<tr>
<td>7</td>
<td>+/- Replacement of bone dust or bone cement</td>
<td>Bone dust or bone cement</td>
<td>Incomplete closure</td>
<td>CSF leak</td>
</tr>
<tr>
<td>8</td>
<td>Closure of muscle layer and fascia</td>
<td>Suture</td>
<td>Incomplete closure</td>
<td>CSF leak, Infection</td>
</tr>
<tr>
<td>9</td>
<td>Skin closure</td>
<td>Suture, clips</td>
<td>Poor opposition of skin edges</td>
<td>CSF leak, Wound infection</td>
</tr>
</tbody>
</table>