Freehand stereotactic ventricular catheter insertion for ventriculoperitoneal shunts based on individualized radio-anatomical landmarks

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Abstract

Introduction

The accurate placement of the ventricular catheter (VC) is critical in reducing the incidence of proximal failure of ventriculoperitoneal shunts (VPSs). The standard freehand technique is based on validated external anatomical landmarks but remains associated with a relatively high rate of VC malposition. Already proposed alternative methods have all their specific limitations. Herein, we evaluate the accuracy of our adapted freehand technique based on an individualized radio-anatomical approach. Reproducing the preoperative imaging on the patient's head using common anatomical landmarks allows to define stereotactic VC coordinates to be followed at surgery.

Material and methods

Fifty-five consecutive patients treated with 56 VPS between 11/2005 and 02/2020 fulfilled the inclusion criteria of this retrospective study. Burr hole coordinates, VC trajectory, and length were determined in all cases on preoperative computed tomography (CT) scan and were accurately reported on patients' head. The primary endpoint was to evaluate VC placement accuracy. The secondary endpoint was to evaluate the rate and nature of postoperative VC-related complications.

Results

Our new technique was applicable in all patients and no VC-related complications were observed. Postoperative imaging showed VC optimally placed in 85.7% and sub-optimally placed in 14.3% of cases. In all procedures, all the holes on the VC tip were found in the ventricular system.

Conclusions

This simple individualized technique improves the freehand VC placement in VPS surgery, making its accuracy comparable to that of more sophisticated and expensive techniques. Further randomized controlled studies are required to compare our results with those of the other available techniques.

Introduction

The accurate placement of the ventricular catheter (VC) plays an important role in reducing the risk of VPS failure. In most cases, the VC placement is still performed by means of a classic freehand technique which is solely based on standard external anatomical landmarks. This method is associated with a relatively high risk of misplacement [1,2,3, 6, 9, 11, 14, 16, 20, 21, 23]. To improve the accuracy of VC placement, several alternative methods have been developed in the last years, based on ultrasonography, neuro-endoscopy, navigation systems, smartphones, and robotic devices (Table 4) [3,4,5,6,7,8,8,9,10, 15,16,17,18, 22, 23]. All these methods require supplementary instrumentation, carry all specific limitations, are expensive, and cannot be easily applied worldwide especially emergency situations [3,4,5,6,7,8,8,9,10, 15,16,17,18, 22, 23]. For these reasons, we developed a new freehand technique aimed at improving the VC placement accuracy without the need of any extra operative device. Our individualized radio-anatomical approach is based on specific landmarks which can be identified on standard preoperative images. Such landmarks are then used to generate a stereotactic reference system which can be reported on the patient's head. On preoperative images, the ideal VC insertion is planned via a posterior parietal approach passing through the lateral ventricle ipsilateral to the burr hole and targeting the frontal horn of the ventricle at the level of the foramen of Monro (FoM). The goal is to place the VC tip at some distance from the choroid plexus and the ventricular walls so that all its holes are patent and surrounded by cerebrospinal fluid (CSF). In the present study, we analyze the results of this technique in terms of accuracy of VC placement and complications.

Patients and methods

Study design

By screening the institutional medical database, data concerning all VPS surgeries performed consecutively by the senior author (MB) at the Neurosurgery Department of the Erasmus Hospital (Bruxelles, Belgium) between November 2005 and February 2020 were retrospectively collected.

The inclusion criteria were posterior parietal VC placement performed according to this innovative individualized radio-anatomical approach described below, age ≥ 15 years, and primary VPS surgery. Exclusion criteria were VC placed by means of others techniques (i.e., frontal VC insertion) or previous surgical interventions (such as shunt surgery, craniotomy or craniectomy) providing supplementary radio-anatomical landmarks possibly facilitating the procedure and artificially improving the results.

The primary endpoint was to evaluate our novel radio-anatomical approach in terms of accuracy of VC placement. The secondary endpoint was to evaluate the rate and nature of postoperative VC-related complications.

Endpoint evaluation

For the assessment of primary endpoint (accuracy of VC placement), the first postoperative head computed tomography (CT) scan was analyzed. All the CT measurements were performed by two investigators (JS and MB) ; in case of uncertainty, a supplementary independent evaluation was performed by another investigator (MR). The degree of accuracy of VC placement was judged according to a new classification system that we adapted from previous publication and which is divided in four grades [4, 19] (Fig. 1). In Grade 1, all holes of the VC were located in the ventricular system away from the choroid plexus and the ependymal walls. Grade 1 was divided in 1A, when the VC's extremity was located in the frontal horn of the lateral ventricle ipsilateral to the burr hole, 1B, when the VC's extremity passed through the midline in a way that the holes were located in both frontal horns in proximity of the FoM, 1C, when the VC's extremity was located in the body of the lateral ventricle ipsilateral to the burr hole away from the choroid plexus and ependyma and 1D, and when the VC's extremity was located in the third ventricle, inserted thorough an inadequate trajectory. In Grade 2, all holes of the VC were located in the lateral ventricle but in contact with the choroid plexus (Grade 2A) or the ependymal walls (Grade 2B). In Grade 3, only some of the holes were found inside the ventricular system. In Grade 4, the VC's extremity was located into brain parenchyma with no holes inside the ventricular system. VC's placements Grade 1A, 1B, 1C were considered as optimally placed, Grade 1D, 2A, 2B were considered as sub-optimally placed whereas Grade 3 or 4 were considered as failures.

For the assessment of the secondary endpoint (rate and nature of complications following VPS surgery), the institutional medical database was searched for VPS malfunctions or any other complication. VPS malfunctions were usually firstly suspected based on neurological deterioration. However, a CT scan showing a pathological modification of the size of the ventricles and/or other complications (i.e., the presence of subdural hygromas) was always required for confirmation. Shunt failures were classified as proximal when involving the VC and as distal when involving the valve or the peritoneal catheter. The segment involved in the malfunction was discriminated by testing the patency of the catheters and the valve at surgical re-intervention.

Data collection and analysis

For each patient matching the inclusion criteria, the following data were extracted: age at intervention, seks, indication for shunting, side of shunt placement, intracranial and intraventricular length of the VC on postoperative head CT scans, number of VC passages before the placement was considered successful by observing CSF outflow, preoperative Evans' index (calculated on axial CT scans by dividing the maximum width of the frontal horns of the lateral ventricles by the maximal internal diameter of skull at the same level), and VPS complications occurring during the follow-up period. Statistical calculations were performed using GraphPad Prism 8.2.1 (GraphPad Software, La Jolla California USA). D'Agostino-Pearson (if $n \geq 8$) or Shapiro-Wilk (if $n < 8$) tests were used to assess the normal distribution of numeric data. When data were normally distributed, they were expressed as means and standard deviations, and unpaired t test with Welch's correction was used for comparison. If data were not normally distributed, they were expressed as medians and interquartile ranges, and Mann-Whitney test was used for comparison. A 2-tailed p value < 0.05 was considered significant.

General principles of the individualized radio-anatomical technique

The technique is based on the concept that the VC position depends on a catheter's entry point (Ep), a length, and a trajectory that can be defined by the crossing of 2 planes. A "radiological stereotactic space" is first generated preoperatively based on landmarks which are identified on standard imaging. Then, in the surgical theater, the same landmarks are used to reproduce such space on the patient's head thereby generating a "surgical stereotactic space." The virtual stereotactic space is centered on the external auditory canal (EAC) ipsilateral to the drain insertion side and it is based on three planes : the reference plane (RP), the catheter plane (CP) and the oblique plane (OP), these last two containing the VC trajectory. As already mentioned, the entire procedure is based on the standard preoperative imaging which is usually performed before evert VPS surgery and no supplementary equipment is required.

Preoperative planning

The individualized radio-anatomical technique starts by a step-by-step planning on the preoperative images. In ideal conditions, the preoperative planning needs to be performed on a three-dimensions (3D) head CT scan (or magnetic resonance imaging (MRI)) in volumetric acquisition allowing multi-planar reconstruction (MPR). However, some correction parameters can be used to adapt this technique to the cases where only standard two-dimensions (2D) CT scans (or MRI) are available.

When a 3D CT scan with MPR is available (Fig. 2a), the RP is first generated by orienting axial slices as passing by the two EACs and the inferior border of the orbit (IBO) ipsilateral to the burr hole. The slides are then moved parallel to the RP up to the level where the size of the lateral ventricles appears to be the largest. This corresponds to the CP where the VC will be inserted. Usually, the CP is located a few millimeters above the plane of the FoMs but it can vary according to the ventricular anatomy of each specific patient. The VC's target point (Tp) corresponds to the orthogonal projection on the CP of the crossing point between the midline and a line passing by the two FoMs. The VC's trajectory is subsequently determined, on the CP, as a line passing by the VC Tp and directed diagonally crossing the longest part of the body of the occipital horn of the lateral ventricle. The posterior extension of the VC's trajectory intersects the skin surface of the head at the VC entry point (Ep). VC Ep x and y coordinates can be determined as follows: Ep-x corresponds to the distance (on the head surface) between the Ep and the orthogonal projection of the EAC on the CP (alternatively, the Ep-x' value corresponds to the distance between the Ep and the midline) while the Ep-y value corresponds to the distance between the RP and the CP. The anterior extension of the VC trajectory intersects the forehead skin surface at the frontal point (Fp). The Fp-x value is then measured by the distance (on the head surface) between the midline and the Fp on the CP. The Fp is fundamental for the generation of the last plane required for VC insertion. This is the OP, it is orthogonal to the CP and is the second plan that contains the VC trajectory, Ep and Fp. Five values need to be measured: (i) the Ep-x value, corresponding to the distance (on the head surface) between the Ep and the orthogonal projection of the EAC on the CP (or alternatively the Ep-x' value, corresponding to the distance between the Ep and the midline); (ii) the Ep-y value, corresponding to the distance between the RP and the CP; (iii) the Fp-x value, corresponding to the distance (on the head surface) between the midline and the Fp; (iv) the VC intracranial length, corresponding to the distance between the VC Tp and the VC Ep; (v) the drain intraparenchymal distance (DID), corresponding to the distance between the Ep and the lateral ventricle on the VC trajectory. Of note, for all the above-mentioned measurements, the cutaneous Ep needs to be considered except for the VC's intracranial length and DID for with the bony Ep needs to be considered.

The preoperative planning can be adapted for two-dimension (2D) head CT scans (Fig. 2b). In this case, MPR will not be possible and only a limited set of axial CT slices will be available. Furthermore, because of slices' orientation, none of them will probably include both the EACs and the ipsilateral IBO. In this setting, the RP corresponds to the CT slice passing by the EACs and the CP corresponds to the CT slice passing by the VC's Tp as defined above. However, in this case, drawing the RP (and consequently the CP) on patient's skin will be difficult, since the slice passing by the EACs will not cross another significant and easily identifiable surface landmark. This problem can be solved calculating the ΔIBO, which corresponds to the distance between the slice passing by the EAC ipsilateral to the burr hole and the slice passing by the ipsilateral IBOs (this value can be obtained by multiplying the CT slices' thickness by the number of slices between the EAC and the IBO planes). On patient's skin, reporting the ΔIBO distance starting from the ipsilateral IBO and moving vertically in craniocaudal direction will allow to identify the second facial landmark (in addition to the EAC) needed for drawing the RP.

Surgical technique
The surgical procedure is showed in Fig. 3. The RP is identified according to the above-mentioned landmarks (EACs and ipsilateral IBO, or alternatively ΔIBO) and reported on the patient's head. Afterwards, the CP is drawn parallel to the RP and at a distance corresponding to the Ep-y value. On the CP, the Ep-x distance is reported posteriorly to the orthogonal projection of the EAC in order to identify the Ep (and Ep-x' distance can be used to check Ep-x coordinates accuracy) and the Fp-x distance is reported anteriorly contralateral to the midline in order to identify the Fp. Lastly, the OP is drawn perpendicularly to the RP and CP and passing by the Ep and Fp. During patient's head positioning, care must be taken in keeping the OP parallel to the floor of the operating room and in placing one sterile drape along the OP: this will facilitate the visualization of VC's trajectory. Draping must be also done in such a way that the CP and OP drawn on the skin remain visible. After drilling the burr hole on the Ep, the VC is slowly inserted horizontally along the OP and along the CP direction. A unique correct VC trajectory can only be obtained by following both planes. As soon as CSF appears, the VC's internal rigid guide is removed and the catheter is furtherly inserted according to the optimal VC's length previously calculated. During the introduction of the VC in the ventricle, it must be checked at each centimeter that the CSF outflow is still present : this confirms that the catheter remains inside the ventricular system. If no CSF appears after having inserted the VC 10 mm deeper than the DID, the trajectory must be inadequate and a new tap was performed.

Results

Patients' population
Between November 2005 and February 2020, the senior author (MB) executed 72 VPS surgeries. Sixteen cases were excluded for the following reasons: 10 because previous surgeries (3 shunt revisions, 5 craniotomies, and 2 decompressive craniectomy) provided supplementary radio-anatomical landmarks that could have made the surgical planning easier and 6 because the VC was placed by means of a frontal approach (this choice was due to slit ventricles in 5 cases (mean Evans ratio 0.20, range 0.12–0.28) and to the presence of a posterior ventricular tumor in 1 case). The remaining 56 VPS procedures

performed in 55 patients met the inclusion criteria and were included in the analysis. Of note, one patient was operated on bilaterally: we considered both surgeries as primary and we included both procedures in the analysis.

In our series, males and females were almost equally represented (28 and 27 patients, respectively) and the median age at shunt placement was 69 years (range from 17 to 87 years). The indications for VPS included normal-pressure hydrocephalus (32 cases, 57.1%), brain tumor (12 cases, 21.5%), intracranial hemorrhage (11 cases, 19.6%), and post-infectious hydrocephalus (1 case, 1.8%). Fifty-five VCs were inserted via the right parietal approach and one VC was inserted via left parietal approach in a patient with a tumor requiring bilateral drainage. Mean preoperative Evans' Index was 0.41 ± 0.05 (range 0.28–0.53). Patients' demographics as well as the details of the surgical procedures are summarized in Table 1.

Primary outcome: accuracy of VC placement

The primary outcome results are summarized in Table 2. The analysis of the postoperative CT scans showed that all the VCs were located into the ventricles. No VC's hole was found inside the brain parenchyma. Out of 56 VCs, 58.9% (33/56) were classified as grade 1A, 8.9% (5/56) as grade 1B, 17.9% (10/56) as grade 1C, 1.8% (1/56) as grade 1D, and 12.5% (7/56) as grade 2A. No VCs were classified as grade 2B, 3, or 4. Overall, 85.7% (48/56) of VCs were classified as optimally placed and 14.3% (8/56) as sub-optimally placed. Of note, one VC tip passed through the ependyma of the ipsilateral frontal horn but since the first holes are located 5 mm away from the VC tip, all holes were in the frontal horn and the drain was classified in grade 1A.

The preoperative Evans' Index did not influence VCs misplacement, as no statistical difference was found for this parameter between patients with optimally versus sub-optimally placed VCs (0.40 ± 0.05 and 0.41 ± 0.06, respectively; $p = 0.6865$). However, the intracranial and the intraventricular VC's length of optimally placed VCs were both significantly longer than the respective values of sub-optimally placed VCs (intracranial 87.7 ± 10.2 vs 76.4 ± 12.3, $p = 0.0366$ and intraventricular 54.3 ± 14.2 vs 38.6 ± 13.2, $p = 0.0116$; Fig. 4). Out of 56 VPS procedures, information concerning the number of passages required for VC's successful placement (demonstrated by CSF outflow) were available in 53 cases. Of these, the first attempt was successful in 86.8% of cases (46/53), while 2 and 3 attempts were necessary in 5.7% (3/53) and 7.5% (4/53) procedures, respectively. Preoperative Evans' index of cases requiring more than one VC's passage did not differ significantly from that of cases for which one passage was enough to reach the ventricle (0.41 ± 0.05 and 0.38 ± 0.04, respectively; $p = 0.1017$).

Secondary outcome: complications

The secondary outcome results are summarized in Table 3. The median follow-up was 576 days (range 2–3808 days). Thirty-eight patients had a follow-up of 1 year or longer. No proximal VPS malfunction due to VC failure was reported. In 12.5% of procedures (7/56), a distal complication requiring re-intervention was reported. These complications were overshunting with development of subdural hematoma (SDH) requiring evacuation and valve replacement (3.6%, 2/56), undershunting with valve and/or distal catheter replacement (7.2%, 4/56), and a shunt infection (1.8%, 1/56). Median delay for the onset of complications requiring re-intervention was 150 days (range 3–3024 days). In 7.2% of cases (4/56), a complication managed conservatively was reported. These complications were the presence of small and asymptomatic hemorrhages around the VC's path with no mass-effect and not impairing CSF drainage (3.6%, 2/56) and overshunting with or without SDH solved with valve re-programming (3.6%, 2/56). Median delay for the onset of complications managed conservatively was 11 days (range 1–138 days).

Discussion

Novel findings

A recent retrospective study including 17,035 patients with a mean follow-up of 3.9 years showed that almost one quarter of VPS patients experienced at least one complication and that the majority of these events happened during the first year after surgery [13]. This demonstrates that the risk of VPS malfunction is relatively high. The inaccurate placement of the VC is one of the leading cause of shunt failure, which can be early if the drain is misplaced with all burr holes within the parenchyma or delayed when some burr holes are partially within the brain parenchyma or in direct contact with the choroid plexus or the ependyma. In the present study, we demonstrate that our new individualized radio-anatomical technique allows achieving a high rate of adequate VC placement by simply reproducing at surgery on the patient's head the data collected on standard preoperative imaging which is normally available for any patient operated on a VPS. The results of this individualized radio-anatomical technique, in our hands, appear to be superior to the 8.5–20% rate of VC misplacement reported with a classical standardized freehand technique. Both the classical procedure and ours are based on a freehand technique. However, an important methodological difference is present: the classical approach relies on standardized anatomical references whereas our technique is based on the personalized identification of reference points and planes on the preoperative CT scans of each individual patient. Such personalized landmarks are then reported on patient's head immediately before surgery in order to create a virtual stereotactic space that is used to drive the insertion of the VC. Our individualized radio-anatomical technique can be accurate and safe provided that the step-by-step process is followed. In this study, 85.7% of VCs were optimally placed and 14.3% of VC were sub-optimally placed. Importantly, all holes of all VCs (including those deemed as sub-optimally placed) where located in the ventricular system and no VC's hole was found in the brain parenchyma on postoperative CT scans. The technique demonstrated to be safe since no serious perioperative complication related to VC insertion occurred, possibly because the total number of attempts to place the VC was limited. Indeed, only few VC need to be replaced after first attempt failure to obtain CSF after VC insertion 10 mm deeper than the DID calculated on the preoperative CT scan. Not surprisingly, a longer intracranial (approximately 10 mm) and intraventricular length of the VC were found in optimally placed compared to sub-optimally placed VCs. This is explained by the fact that to reach the optimal Tp close to the FoM through a parietal approach, a longer VC insertion is necessary.

Relevance, generalizability and implications

Several other groups proposed innovative strategies to improve the accuracy of VC placements such as posterior catheter guiding, frameless neuronavigation systems, ultrasonography, neuro-endoscopy, smartphones, and robotic systems [3,4,5,6,7,8,8,9,10, 12, 15,16,17,18, 22, 23]. According to the research groups that proposed such technical adjuvants, all of them were able to provide better results if compared with the standard freehand method. However, all these approaches require supplementary surgical time and expensive supplementary equipment which has so far impeded from their worldwide diffusion [3,4,5,6,7,8,8,9,10, 12, 15,16,17,18, 22, 23]. Despite its simplicity, our novel radio-anatomical approach reached a level of accuracy which appears comparable with that of the above-mentioned high-technology approaches and higher than the standard freehand technique (Table 4). Most importantly, only standard preoperative imaging is necessary for the application of our technique: this represents a fundamental feature for its worldwide diffusion including emerging countries. However, despite our results already provide a good indication of the potentials of this new approach, a prospective study is necessary to confirm the accuracy and the generalizability of the technique.

Limitations

This technique has one main limitation which is the presence of slit ventricles. In this study, the technique was applied only to patients with enlarged ventricles and 5 patients were excluded due to the presence of slit ventricles. The mean Evans' Index of included and excluded patients was respectively 0.41 and 0.20. The lowest Evans' Index of included patients was 0.28, which corresponds to highest index of excluded patients. Interestingly, the preoperative Evans' index of included patients did not influence the accuracy of the technique since no difference in this parameter was found between optimally and sub-optimally placed VCs. Further studies will be necessary to determine the exact Evans' Index cut-off for the applicability of our radio-anatomical technique.

The present study suffered some limitations. First, despite including consecutive patients with availability of preoperative and postoperative CT scans, this study was retrospective in nature and did not include a control group. Second, this study encompassed patients operated on by a single surgeon. However, despite it can be argued that VC placement is strongly operator-dependent, our technique is simple and highlights the importance of the preoperative planning. When the Ep coordinates and planes guiding the VC introduction are correctly drawn, the technical part of the procedure becomes very straightforward, therefore decreasing the risk of misplacement and inaccuracy due to a lower surgeon's experience. Third, only a limited number of patients were enrolled. Further randomized controlled studies will be necessary to evaluate the reproducibility of our personalized technique and to directly compare its accuracy with that of the standard freehand method and with the above-mentioned high-technology adjuvants.

Conclusions

In the present study, we reported the results of our strategy aimed at improving the accuracy of VC placement in VPS surgery. Such strategy is based on a personalized radio-anatomical approach and its main advantages consist in its relative simplicity and cost-effectiveness. In our hands, this technique showed an accuracy comparable with that of high-technology approaches proposed in the last years.

References

1. Azeem SS, Origitano TC (2007) Ventricular catheter placement with a frameless neuronavigational system: a 1-year experience. Neurosurgery 60(4 suppl 2):243–247
2. Dias MS, Albright AL (1989) Management of hydrocephalus complicating childhood posterior fossa tumors. Pediatr Neurosci 15(6):283–289
3. Garell PC, Mirsky R, Noh MD, Loftus CM, Hitchon PW, Grady MS, Dacey RG, Howard MA (2009) Posterior ventricular catheter burr-hole localizer. J Neurosurg 89(1):157–160
4. Hayhurst C, Beems T, Jenkinson MD, Byrne P, Clark S, Kandasamy J, Goodden J, Nandoe Tewarie RDS, Mallucci CL (2010) Effect of electromagnetic-navigated shunt placement on failure rates: a prospective multicenter study-clinical article. J Neurosurg 113(6):1273–1278
5. Hayhurst C, Byrne P, Eldridge PR, Mallucci CL (2009) Application of electromagnetic technology to neuronavigation: a revolution in image-guided neurosurgery: technical note. J Neurosurg 111(6):1179–1184
6. Howard MA, Srinivasan J, Bevering CG, Winn HR, Grady MS (1995) A guide to placement of parietooccipital ventricular catheters. Technical note. J Neurosurg 82(2):300–304
7. Jakola AS, Reinertsen I, Selbekk T, Solheim O, Lindseth F, Gulati S, Unsgård G (2014) Three-dimensional ultrasound-guided placement of ventricular catheters. World Neurosurg 82(3–4):5–9
8. Khan NR, DeCuypere M, Vaughn BN, Klimo P (2019) Image guidance for ventricular shunt surgery: an analysis of ventricular size and proximal revision rates. Clin Neurosurg 84(3):624–635
9. Kim YB, Lee JW, Lee KS, Lee KC (2006) Image-guided placement of ventricular shunt catheter. J Clin Neurosci 13(1):50–54
10. Levitt MR, O’Neill BR, Ishak GE, Khanna PC, Temkin NR, Ellenbogen RG, Ojemann JG, Browd SR (2012) Image-guided cerebrospinal fluid shunting in children: catheter accuracy and shunt survival: clinical article. J Neurosurg Pediatr 10(2):112–117
11. Lind CRP, Tsai AMC, Lind CJ, Law AJJ (2009) Ventricular catheter placement accuracy in non-stereotactic shunt surgery for hydrocephalus. J Clin Neurosci 16(7):918–920
12. Lollis SS, Roberts DW (2008) Robotic catheter ventriculostomy: feasibility, efficacy, and implications. J Neurosurg 108(2):269–274
13. Merkler AE, Ch’ang J, Parker WE, Murthy SB, Kamel H (2017) The rate of complications after ventriculoperitoneal shunt surgery. World Neurosurg 98:654–658
14. Pang D, Grabb PA (1994) Accurate placement of coronal ventricular catheter using stereotactic coordinate-guided free-hand passage. Technical note. J Neurosurg 80(4):750–755
15. Roth J, Constantini S (2012) Selective use of intra-catheter endoscopic-assisted ventricular catheter placement: indications and outcome. Childs Nerv Syst 28(8):1163–1169

16. Stieglitz LH, Giordano M, Samii M, Luedemann WO (2010) A new tool for frameless stereotactic placement of ventricular catheters. Neurosurgery 67(3 Suppl Operative):131–135
17. Theodosopoulos PV, Abosch A, McDermott MW (2001) Intraoperative fiber-optic endoscopy for ventricular catheter insertion. Can J Neurol Sci 28(1):56–60
18. Thomale UW, Knitter T, Schaumann A, Ahmadi SA, Ziegler P, Schulz M, Miethke C (2013) Smartphone-assisted guide for the placement of ventricular catheters. Childs Nerv Syst 29(1):131–139
19. Thomale U-W, Schaumann A, Stockhammer F, Giese H, Schuster D, Kästner S, Ahmadi A-S, Polemikos M, Bock H-C, Gölz L, Lemcke J, Hermann H, Schuhmann M-U, Beez T, Fritsch M, Orakcioglu B, Vajkoczy P, Rohde V, Bohner G (2016) The GAVCA study-effect of a mobile health application to assist ventricular catheter guidance in a randomized, prospective multicenter trial. Childs Nerv Syst 83(2):252–262
20. Wan KR, Toy JA, Wolfe R, Danks A (2011) Factors affecting the accuracy of ventricular catheter placement. J Clin Neurosci 18(4):485–488
21. Wang C, Du H-g, Yin L-c, He M, Zhang G-j, Tian Y, Hao B-l (2013) Analysis of related factors affecting prognosis of shunt surgery in patients with secondary normal pressure hydrocephalus. Chin J Traumatol 16(4):221–224
22. Whitehead WE, Jea A, Vachhrajani S, Kulkarni AV, Drake JM (2007) Accurate placement of cerebrospinal fluid shunt ventricular catheters with real-time ultrasound guidance in older children without patent fontanelles: technical note. J Neurosurg 107(5 Suppl):406–410
23. Wilson TJ, Stetler WR, Al-Holou WN, Sullivan SE (2013) Comparison of the accuracy of ventricular catheter placement using freehand placement, ultrasonic guidance, and stereotactic neuronavigation: clinical article. J Neurosurg 119(1):66–70

Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest.

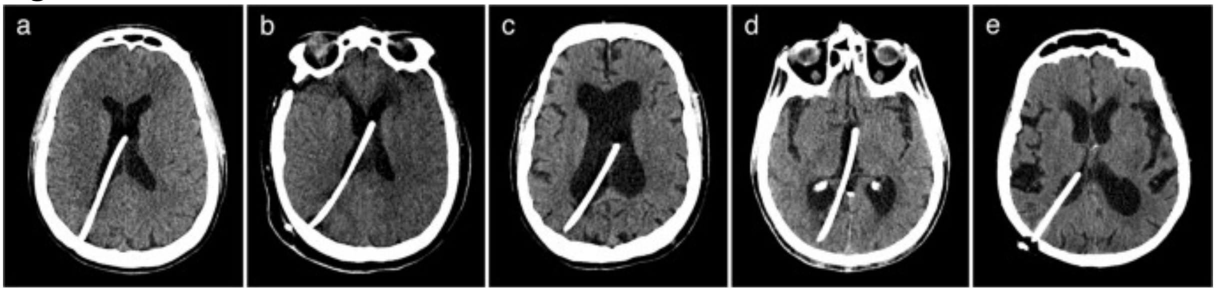
Ethical approval

The authors confirm that the study was approved by the institutional ethics committee of Erasme Hospital and certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed consent

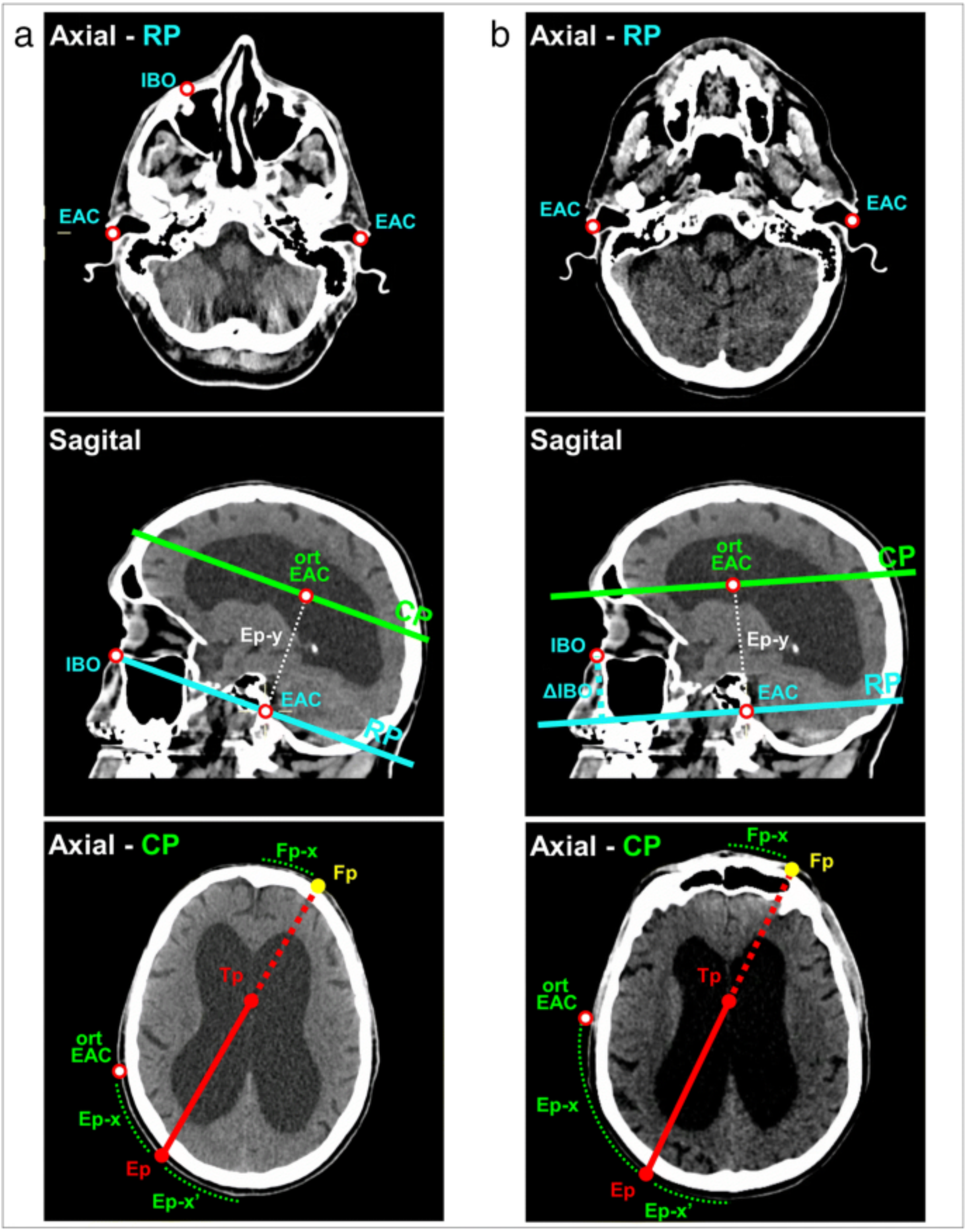
According to ethic committee agreement, patient’s informed consent was deemed not necessary given the retrospective nature of the study.

Fig. 1



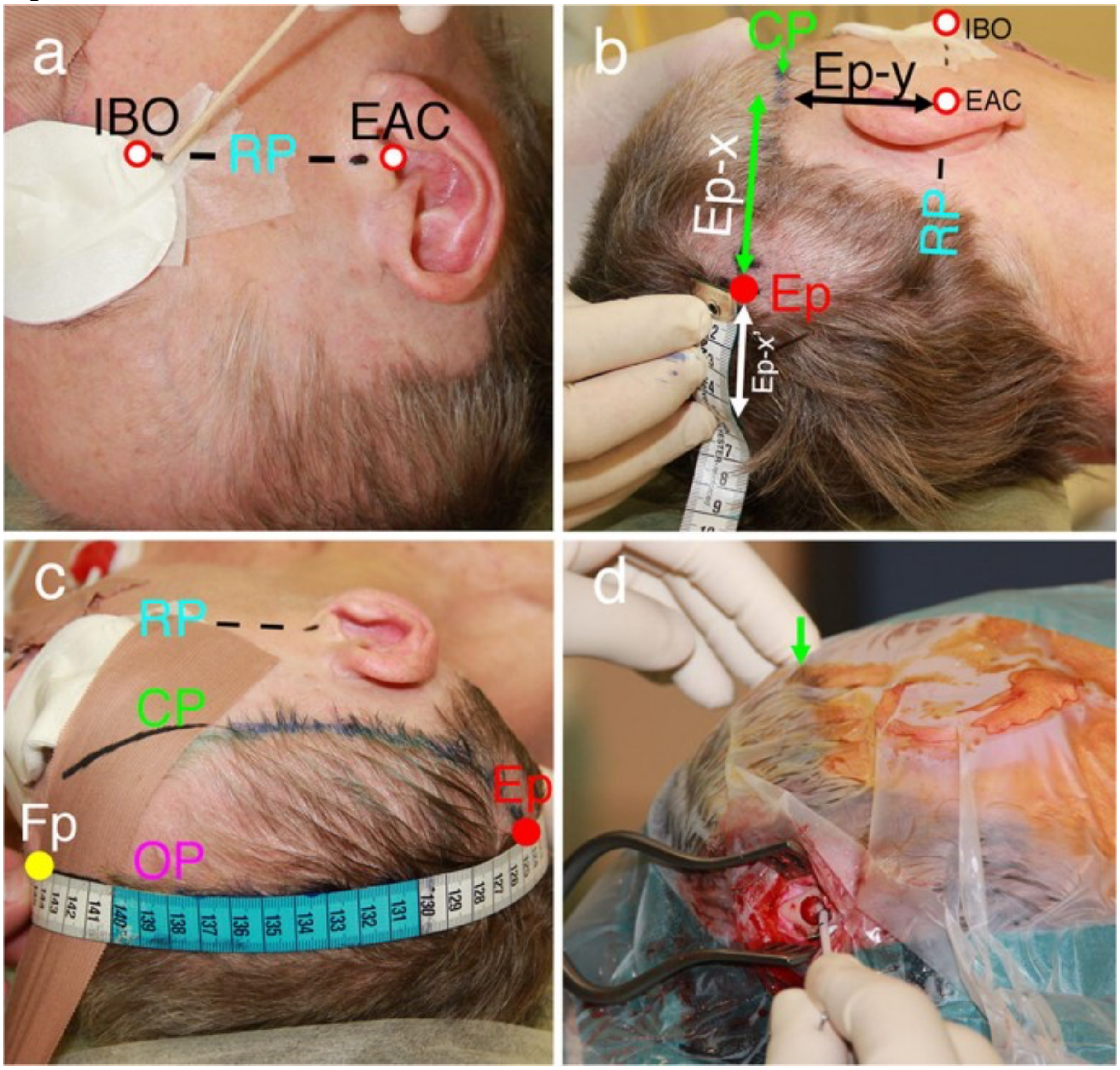
Grading system used to evaluate the accuracy of ventricular catheter's placement. **a** grade 1A: the VC's extremity is located in the frontal horn of the lateral ventricle ipsilateral to the burr hole. **b** grade 1B: the VC's extremity passes through the midline in a way that the holes were located in both frontal horns in proximity of the foramen of Monro. **c** grade 1C: the VC's extremity is located in the body of the lateral ventricle ipsilateral to the burr hole away from the choroid plexus and ependyma. **d** grade 1D: the VC's extremity is located in the third ventricle away from the choroid plexus and ependyma but is inserted thorough an inadequate trajectory. **e** grade 2A: all VC holes are located in the lateral ventricle but in contact with the choroid plexus

Fig. 2



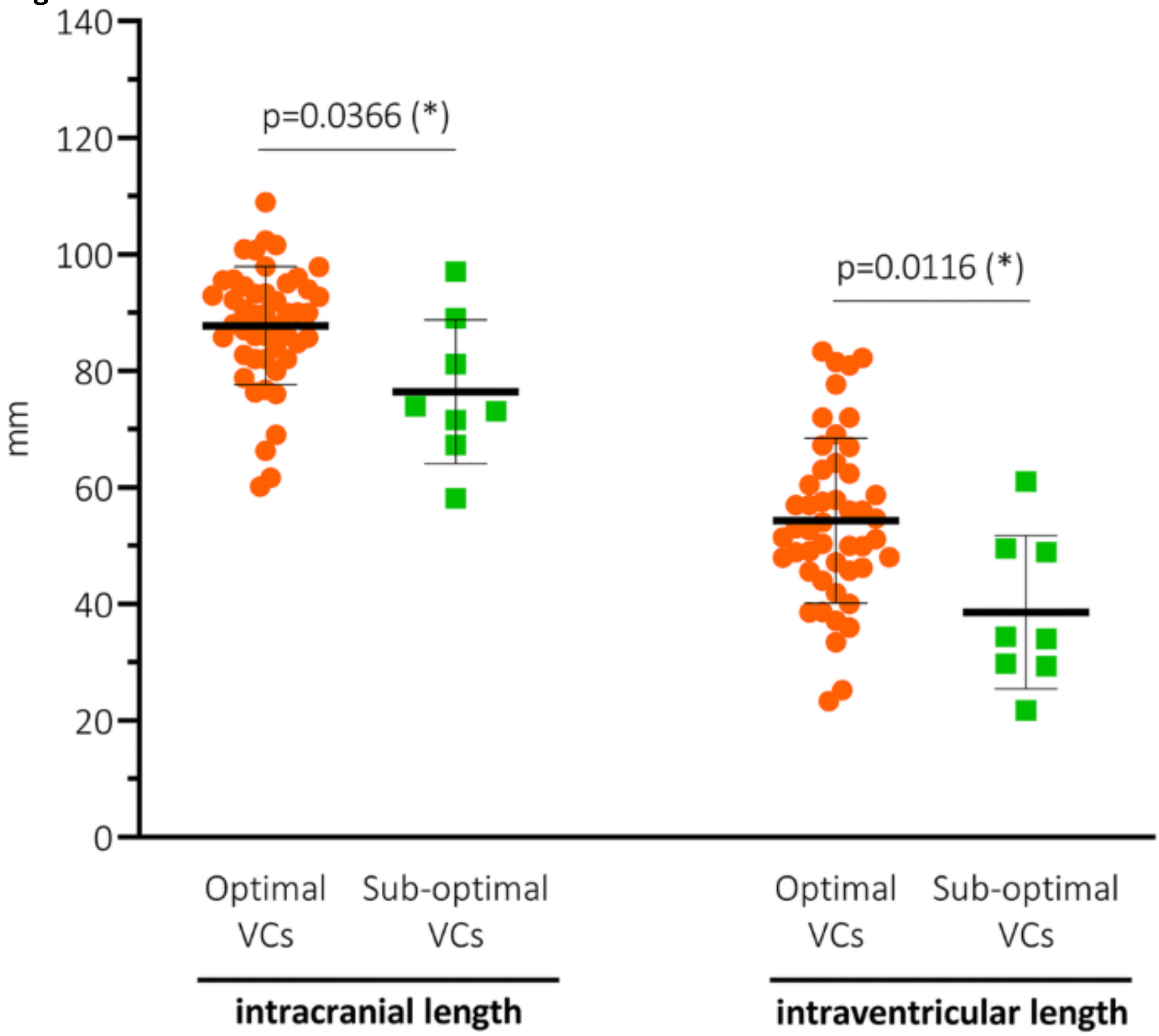
Preoperative radiological planning. Individualized preoperative planning with 3D (**a**) and 2D (**b**) CT scan. From top to bottom: axial view at the reference plane (RP), sagittal view, axial view at the catheter plane (CP). CP, catheter plane; RP, reference plane; IBO, inferior border of the orbit; EAC, external auditory canal; Ep-y: distance between the RP and the AP; ort EAC, orthogonal projection on the CP of the external auditory canal; Ep, entry point of the ventricular catheter; Ep-x: distance between Ep and ort EAC; Ep-x': distance between the Ep and the midline; Tp: target point of the ventricular catheter; Fp, frontal point; Fp-x: distance between FP and the midline

Fig. 3



Intraoperative technique. In the operative theater, the preoperative radiological planning is applied to the patient's head. **a** After identifying the external auditory canal (EAC) and the inferior border of the orbit (IBO) ipsilateral to the burr hole, the reference plane (RP) is drawn. **b** The catheter plan (CP) is drawn parallel to the RP at Ep-y distance gathered from radiological preoperative planning. The entry point (Ep) is then identified based on the Ep-x and/or Ep-x' distances. **c** After the identification of the frontal point (Fp), the oblique plane (OP) is drawn perpendicular to RP and CP and passing by Ep and Fp. The head is placed in such a way that the OP is horizontal, parallel to the floor. **d** The ventricular catheter (VC) is inserted following the intersection line between the horizontal OP and the CP whose direction is indicated by the surgeon's index and green arrow

Fig. 4



Intracranial and intraventricular length of optimally and sub-optimally placed ventricular catheters. Both the intracranial and intraventricular length of optimally placed ventricular catheters were significantly longer than those of sub-optimally placed ventricular catheters. VC, ventricular catheter

Table 1 Patients demographics and surgical procedures

Gender	Number of patients (%)
Female	27 (49.1)
Male	28 (50.9)
Diagnosis	Number of procedures
Normal-pressure hydrocephalus Brain tumor Intracranial hemorrhage Post-infection	(%) 32 (57.1) 12 (21.5) 11 (19.6) 1 (1.8)
Surgical procedures	Number of procedures
Type Primary shunt placement Side Right Left	(%) 56 (100) 55 (98.2) 1 (1.8)
Others	Average (range)/mean
Age at shunt placement (years) Preoperative Evans' Index	± SD 69 (17–87) 0.41 ± 0.05

Table 2 Primary outcome

VC's tip position	Number of procedures (%)
Optimally placed	48 (85.7)
1A: all VC's holes in ipsilateral frontal horn	33 (58.9)
1B: all VC's holes in ipsi and contralateral frontal horns crossing midline	5 (8.9)
1C: all VC's holes in body of ipsilateral ventricle away from choroid plexus	10 (17.9)
Sub-optimally placed	8 (14.3)
1D: all VC's holes in third ventricle	1 (1.8)
2A: all VC's holes in the ventricles but in contact with the choroid plexus	7 (12.5)
2B: all VC's holes in the ventricles but in contact with the ependymal wall	0 (0)
Placement failure	0 (0)
3: Only some of VC's holes inside the ventricular system	0 (0)
4: No VC's hole inside the ventricular system	0 (0)
VC's length (mm)	Mean ± SD
Optimally placed (*n* = 48)	
Intracranial	87.7 ± 10.2
Intraventricular	54.3 ± 14.2
Sub-optimally place (*n* = 8)	
Intracranial	76.4 ± 12.3
Intraventricular38.6 ± 13.2	
P value intracranial	0.0366 (*)
P value intraventricular	0.0116 (*)
Number of attempts before successful VC placement	Number of procedures (%)
Information available in 53 procedures	
One	46 (86.8)
Two	3 (5.7)
Three	4 (7.5)
Preoperative Evans' Index	
Optimally placed VCs	0.40 ± 0.05
Sub-optimally placed VCs	0.41 ± 0.06
P value	0.6865
One VC's passage to reach the ventricle	0.41 ± 0.05
More than one VC's passage to reach the ventricle	0.38 ± 0.04
P value	0.1017

Table 3 Secondary outcome

	Number of procedures (%)
VPS complications requiring re-intervention	7 (12.6)
VC failure	0 (0)
Overshunting with SDH requiring evacuation and valve replacement	2 (3.6)
Undershunting with valve and/or distal catheter replacement	4 (7.2)
Shunt infection with shunt replacement	1 (1.8)
VPS complication not requiring re-intervention	4 (7.2)
Hemorrhage around the VC's path	2 (3.6%)
Overshunting solved with valve re-programming	2 (3.6%)
Total	11 (19.8)

Table 4 Technique-related VC placement accuracy and specific disadvantages

Surgical technique	n° of studies	Parenchymal VC positioning	Adequate VC positioning	Disadvantages
Individualized anatomoradiological approach [present study]	1	0%	100% Optimal 85.7% Sub-optimal 14.3%	– Multiple passages required in 14% of cases – No intraoperative visualization of the position of the VC's tip – Parieto-occipital approach only
Standard freehand method [2, 4, 6, 10, 20, 21, 23]	6	8.5–20%	33–81%	– Multiple passages might be required – No intraoperative visualization of the position of the VC's tip – Difficulty in assessing tapping angles
Posterior ventricular guide [3, 6]	2	0%	92–100%	– Occipital approach only – Possible errors in case of scalp/ear anatomy variation
Frameless navigation system [4, 5, 9, 10, 16, 23]	6	0–9%	88–100%	– Increased time, infection risk and costs – Relatively rigid head fixation
Ultrasonic guidance [7, 22, 23]	3	0%	89–100%	– Increased time, infection risk and costs – Larger burr holes.
Intra-catheter endoscope [16, 17]	2	0–12.5%	76–81% (frontal or occipital horn)	– Increased time, infection risk and costs – No working channel for endoscope – Suboptimal intraoperative visualization of the position of the VC's tip – 1 randomized trial showed no improvement of the rate of VC failure
Robotic assistance [12]	1	0%	100% (Frontal horn)	– Increased time, infection risk and costs
Smartphone assistance [18]	1	0%	92% (Ipsilateral LV)	– Frontal approach only – Possible errors in case of scalp/ear anatomy variation