Updates on techniques and technology to optimize external ventricular drain placement: A review of the literature

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ABSTRACT

External ventricular drainage is a common and invaluable neurosurgical procedure and is one of the first procedures learned and performed independently by neurosurgical residents. As accuracy and precision are paramount to EVD placement, attention to technique is paid early in a resident’s training. With the advancement of virtual technology, it has become increasingly possible to move away from traditional training situations and human error, and towards automated assistance and superior cyber learning environments. Although there is significant room for improvement, there are promising results with computerized placement guides and virtually augmented practice. Here, we provide a review of the updates on EVD placement techniques, technology and training, all of which serve to improve the precision, accuracy and efficiency of EVD placement.

1. Introduction

Normal cerebrospinal fluid (CSF) outflow and resorption can be disrupted by a myriad of neurosurgical disease processes and is often treated with CSF diversion to prevent elevated intracranial pressure (ICP). External Ventricular Drainage (EVD) is one of the first procedures learned and performed independently by neurosurgical residents [1]. While it was first documented in 1744, it has continued to be performed in a similar manner for the past three centuries [2,3]. The EVD procedure is performed by inserting a small catheter into the lateral ventricle of the brain to drain cerebrospinal fluid (CSF) and is typically performed to alleviate elevated intracranial pressure (ICP) resulting from hydrocephalus, intracranial hemorrhage, bacterial meningitis, tumors, and traumatic brain injuries [1,4–6].

The history of the procedure, as well as a discussion on the expansion of EVD indications, was reviewed in 2014 by Srinivasan et al. [2] Srinivasan and his colleagues highlighted a lack of consensus on infection control, new ways to improve the efficiency of guided EVD placement, and the need to address complications that arise during an EVD procedure. Common complications include suboptimal placement and hemorrhage in up to 40% of cases, as well as infection, CSF leak, inadvertent placement of the catheter, and malfunction or obstruction of the drainage system, although most are asymptomatic hemorrhages [7–17]. An underappreciated complication of a misplaced catheter is the delay in therapeutic and diagnostic capabilities of EVD [18]. The prevalence and possibility of poor neurologic outcomes associated with these complications suggests that there is room for improvement in EVD placement with a focus on the use of guide and early training with simulators.

Here, we present updates on techniques, technology and educational training aimed at optimizing EVD placement.

2. Methods

For this purpose, we performed a review of the current literature to identify the techniques, devices, and training methods that are currently being used to improve the accuracy and efficiency of EVD placement. In order to identify studies reporting on relevant techniques and devices, we queried the Google Scholar, PubMed, and Web of Science databases using the following Boolean search term: (external ventricular drain OR

https://doi.org/10.1016/j.clineuro.2022.107126

Received 21 November 2021; Received in revised form 7 January 2022; Accepted 10 January 2022
Available online 12 January 2022

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EVD) AND (technique OR technology OR residency OR training OR simulation). The results we identified will be discussed in each of the sections that follow.

3. Techniques

Given that EVDs are often placed under emergent conditions, and that incorrect catheter positioning is responsible for roughly two thirds of non-infectious complications [19], it is important to attain quick EVD placement without sacrificing accuracy and functionality. The most commonly used placement technique involves a twist-drill burr hole and EVD insertion at the Kocher’s point, located 2.5 cm lateral from midline and 1 cm anterior to the coronal suture [20]. This point, which aims to avoid the primary motor cortex of the frontal lobe as well as the superior sagittal sinus, is selected on the right side to avoid dominant hemisphere language areas.

Reported accuracy of EVD placement has been found to range widely from 7% to 45.9% [4,20–23], likely due to both inaccurate placement as a multitude of factors can influence accurate placement (such as catheter angle variation) and varying definitions of target EVD placement accuracy. Authors who define an accurate EVD as placed within the foramen of Monro, will likely report significantly lower accuracy than if target placement is defined as within a ventricle with adequate drainage of CSF. O’Leary and colleagues defined the foramen Monro as a point of accuracy and compared angular variation between freehand methods to a technique using the Ghajar Guide (Fig. 1) [19]. The Ghajar Guide, invented in 1985, is a rigid tool that promotes a fast and perpendicular burr-hole entry into the frontal horn of the lateral ventricle [24]. In O’Leary’s prospective study of 49 ventriculostomies for hydrocephalus, subarachnoid hemorrhage, and other causes of increased intracranial pressure, postoperative CT scans were used to compare EVD placement accuracy between Ghajar Guide and freehand technique groups [19]. While the Ghajar Guide technique was associated with fewer placement passes, on average, than freehand techniques, these results were not statistically significant. Furthermore, EVD placement utilizing the Ghajar Guide resulted in catheter tip placement significantly closer to the foramen of Monro than using the freehand technique, indicating an increase in accuracy. One drawback of the Ghajar guide is that it assumes normal anatomical position of the ventricular system; therefore, it is less accurate when pathology such as a neoplasm, hematoma, or cerebral edema causes a ventricular midline shift. However, a recent case series on the next-generation adjustable Ghajar guide claims the adjustable nature of the guide can accommodate midline shift if detected by neurologic imaging, however, this study excluded patients with midline shift [25]. These studies suggest that the Ghajar guide provides improved placement compared to freehand techniques, and that it could also assist neurosurgical trainees in learning proper EVD placement.

4. Technological advances

Several distinct navigation techniques have recently been developed to address issues with inaccurate EVD placement, including smartphone-navigated placement, ultrasound-guided placement, electromagnetic neuronavigation guidance, optical neuronavigation, and wearable technology.

Smartphone-navigated ventricular catheter placement was described in 2013 by Thomale et al. [26]. Briefly, the smartphone application connects with a neuronavigation system (iPlan 3.0, BrainLab) and uses a coronal CT image of the patient with the lateral ventricles shown at the level of the anterior commissure to calculate the appropriate trajectory for insertion of the EVD catheter (Fig. 2). The catheter is inserted by a fixed guiding tool, and the angle of catheter insertion can be confirmed by the trajectory estimated by the smartphone. The authors performed a

Fig. 1. Illustration of Kocher’s Point. This site is the common point of entry for catheter placement during an EVD (left). Illustration of the original Ghajar guide (right) used for ventriculostomy.

Fig. 2. Smartphone interface (upper) and live implementation (lower) of an application used for real-time imaging in ventriculostomy as described by Thomale et al. Reprinted by permission from: Springer, Child’s Nervous System [26].
phantom study using the technology to insert catheters into a Plexiglass box. Out of 27 attempted placements, the authors report a mean angle of deviation of $1.1° \pm 0.7°$. Subsequently, the authors performed a pilot case series on 35 primarily pediatric patients (median age of 9 years). Surgical indications were either placement during shunt implantation ($n = 24$), EVD insertion ($n = 4$) and Ommaya reservoir placement ($n = 7$). Postoperative imaging was available in 25 patients (71%). The authors report 100% first pass success, with accurate catheter placement in 23 out of 25 patients (92%) [26].

Eisenring et al. showed that a smartphone navigation technique for EVD insertion increases the probability of achieving accurate insertion on the first try as compared to conventional freehand insertions in an artificial human head model and cadaveric head [27]. In this study, EVD insertion trajectories were planned on multiplanar 3D reformatted native computed tomography (CT) to identify ideal insertion angles as well as depths of intracranial trajectories for EVD. This technique was previously applied to placement of spinal instrumentation [28], but adapted by the Eisenring for EVD placement (Fig. 3) [27]. An Apple iPhone was used with a commercially available app for angle measurement which served as a protractor for EVD placement, with the smartphone encased in a sterile cover. On average, the smartphone-assisted EVD implantation took an average of 9 min to complete, which included drilling, durotomy, and catheter insertion. EVD implantation using conventional methods last 17–20 min on average according to reports from other studies [29,30]. This technique may increase speed and accuracy of EVD placement when used in patients, which is important for emergent situations in the clinical setting. A significant limitation was the lack of human studies utilizing this technology.

Eftekhar reviewed the Sina technique, another smartphone-assisted EVD placement technique [31]. Sina is a commercially available Android application that superimposes axial images from previous CT or magnetic resonance imaging (MRI) studies of the patient onto the live feed from the smartphone camera. The camera is held by a non-sterile team member, and its position is adjusted such that the coronal suture of the patient’s head overlaps its location on the transposed CT/MRI image. This application was demonstrated to improve the surgeon’s ability to accurately place the EVD into the target ventricle (Fig. 4) [31]. The app has been used in 5 adult patients, with successful placement into the target ventricle on first pass. The authors trained 5 individuals (2 operating room nurses, 2 operative assistants, and 1 orthopedic registrar) in utilizing the smartphone with low rating of difficulty; four out of 5 participants were able to overlap the live smartphone image adequately, and average rating of procedural difficulty was 1.6 (scale of 1–10, 10 being most difficult). Precise overlap of the images is critical to Sina’s functionality; for every 2% increase in image overlapping error, the authors report a 1-mm increase in estimated targeting error. This marks a potential drawback of the technology, as the smartphone does not provide intraoperative feedback that traditional neuronavigation systems do. A similar Android app is described by Nikouei et al., which displays data from CT and MR imaging on a smartphone held at bedside, coupled with a targeting device to gauge in real time [32]. However, the authors did not provide any images of this technology and reported that this application is still in the early stages of development and has yet to be implemented in human subjects.

In the United Kingdom, the standard of care for EVD placement has increasingly moved towards the use of ultrasound (US) navigation [33]. Ultrasound-guided EVD insertion decreases the chance of malposition, thereby decreasing the subsequent need for multiple insertion attempts and the associated morbidities with multiple passes [33]. Historically, US-guided ventriculostomy utilized an ultrasound probe to identify the

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**Fig. 3.** Computed tomography image showing angle trajectories for optimal EVD placement beginning at Kocher’s point (upper). Smartphone protractor application verifying the correct trajectory angle of insertion of the ventricular catheter (lower). Image credit to Eisenring et al., SVD-smartphone-navigated placement of external ventricular drains, included under the Creative Commons license: [http://creativecommons.org/licenses/by/4.0/](http://creativecommons.org/licenses/by/4.0/) No changes were made to the images in any way from their original format.

**Fig. 4.** Sina, a commercially available android app assisting with ventriculostomy in the OR is used to improve accuracy during ventricular catheter placement. Reprinted by permission from Journal of Neurosurgery [31].
catheter trajectory prior to freehand insertion. However, this may lead to deviations from the predicted trajectory as there is no real-time guidance. Multiple variations of real-time US-guided ventriculostomies have since been developed. Manfield et al. described the use of a commercially available and user-friendly burr hole US transducer with a needle guide channel (Fig. 5) [33]. This device is typically used for biopsy surgery but can also accommodate a ventriculostomy catheter for EVD implantation. The authors argue the increased confidence in ventriculostomy placement accuracy using ultrasound guidance may eliminate the need for a postoperative CT. Limitations include the need for a larger burr hole and the lack of patient outcome data to validate this device. Whitehead et al. reported accurate real-time US-guided placement of ventricular catheters for CSF shunts in children, but this also required burr hole enlargement [34]. Jakola et al. describe the use of a phased-array ultrasound burr hole probe developed for EVD placement [35]. In a small case series, four patients underwent ventriculostomy using this technology with optimal placement achieved in a single pass in all patients with no reported adverse events. Coulson and colleagues describe an ultrasound stylet probe with dimensions equal to existing commercial catheter stylets (Fig. 6) [36]. The stylet probe is used with existing ventricular catheters without necessitating a larger burr hole. The authors performed ventricular catheterizations in a porcine model and were able to use the ultrasound to accurately detect depth and width of the lateral ventricle in which it was placed. However, the authors remark that this device is a prototype in early stages of development and currently lacks a clinical trial. Previously, a rigid ultrasonic fiberoptic stylet that can be placed inside of a ventriculostomy catheter was patented (US Patent No. 5690117) for use in real-time US-guided placement of EVD. While a similar technology is widely implemented for intravascular procedures (IVUS) [37] indicating possible application here, widespread implementation of these devices in ventriculostomy has not yet occurred.

Patients with traumatic brain injury (TBI) have been observed to have relatively high rates of EVD misplacement [38]. Electromagnetic navigation involves a computer-aided, image-guided stereotactic system that allows for the simultaneous tracking of instruments and patient anatomy. AlAzri et al. compared the accuracy of EVD placement for 54 patients with severe TBI receiving electromagnetic navigation versus traditional freehand placement [39]. The group receiving EM-navigated EVD placement required fewer passes than the freehand group (1.16 ± 0.38 vs. 1.63 ± 0.88 passes, p = .018). Procedure time was not compared because the data from the group of TBI patients undergoing freehand EVD insertion was acquired retrospectively, but the authors speculate that the higher likelihood of multiple attempts needed in the freehand group increased overall procedure time [39]. One drawback of electromagnetic navigation is the requirement of a navigation head CT scan obtained before the procedure, which may add time to overall procedure length under emergent circumstances if a navigation scan was not obtained on initial radiographic evaluation. There is also less capacity to adapt to real-time changes in ventricular architecture with EM-navigation, a feature afforded by ultrasound-guided ventriculostomy placement.

Optical neuronavigation may provide another means of accurate EVD placement. Ozerov et al. report the use of Stryker® Navigation System II-Cart (Stryker® Instruments, Kalamazoo, Michigan, USA) for placement of Ommaya reservoirs in children for chemotherapy administration [40]. They report accurate placement of the ventricular catheter within the anterior horn of the lateral ventricle in all cases on the first try with no complications. The main limitation of this study was that the procedure was performed in the operating room, requiring significantly more time than desired for emergent EVD placement. Wearable technology represents another potential future direction for ventriculostomy. Díaz et al. describes an application of wearable technology where the Stealth S7 image-guidance system (Medtronic Inc., Littleton, Massachusetts, USA) is connected with a Google Glass (Google Inc., Mountain View, CA, USA) heads-up display (HUD), and subsequently attached to the surgical loupe of the operating surgeon [41]. This allowed the surgeon to visualize optical neuronavigation images from the Stealth S7 in the corner of his visual field, without having to adjust his view away from the patient. This technology was tested for ventriculostomy using a phantom skull, and was subsequently used to successfully resect a left parietal meningioma [41]. However, the application of this technology to ventriculostomy placement has not been attempted. Bedside placement of EVD utilizing optical neuronavigation with and without wearable technology is feasible, but requires preoperative imaging, device calibration, and set up of additional equipment required on the hospital floor.

5. Resident training and simulators

An alternative means of improving EVD placement is through early and widespread implementation of formal resident training and use of EVD simulators. EVD placement is a common procedure often learned by residents during the first two years of postgraduate training. Simulation based training, via virtual reality and physical models, has been shown to accelerate the learning curve and improve residents’ skills in a realistic, yet safe environment [42]. There are several training tools that have been developed including ImmersiveTouch (ImmersiveTouch, Chicago, Illinois, USA), and other physical models. Since 2006, the American Association of Neurological Surgeons’ annual simulation competition, “Top Gun,” features various simulated procedures including EVD placement, while the competition provides neurosurgical trainees with an engaging training experience.

The ImmersiveTouch system is among the more popularly used tools to simulate EVD placement. This system is an augmented virtual reality system that combines real-time haptic feedback with a head-and-hand tracking system and a high-resolution stereoscopic display (Fig. 7) [43]. Yudkowsky et al. studied the impact of simulation-based practice using a library of virtual brains on residents’ performance in simulated and live surgical ventriculostomies [44]. Using CT scans of actual patients with a range of anatomies (normal, shifted, and compressed ventricles), virtual brains were developed for the ImmersiveTouch system. Resident performance improved in ventriculostomy on the simulator and in live procedures after intervention. This system provides an accurate and beneficial training environment for EVD placement, as residents reported the simulations felt realistic. Notably, residents perceived improvements in directing the catheter, sensed pressure change upon entering the ventricle, and gauged how far to advance the catheter within the ventricle to reach the target [44]. ImmersiveTouch has been adapted for use in ventricles with midline shift as well [44-46]. Schirmer and colleagues designed a virtual reality trauma-based

![Fig. 5. Burr hole ultrasound transducer by BK medical (upper), and a diagram of the increased burr hole size required for its implementation (lower). Reprinted by permission from BK medical and Journal of Neurosurgery [33].](image-url)
simulation module to teach ventriculostomy placement in the management of traumatic brain injury [47]. They found improvements in anatomy knowledge ($P < .04$), burr hole placement ($P < .03$), final catheter location ($P = .05$), and procedure time ($P < .004$) following ventriculostomy simulation.

Physical models have been utilized for resident training, as virtual reality systems are expensive and not easily accessible. Using 3D printing and molding technologies, Tai et al. developed a physical model with realistic haptic and visual feedback to simulate EVD placement (Fig. 8) [48]. Their model was designed to be a comprehensive training tool that includes all of the steps involved in EVD placement, including identifying surface anatomy, marking the skin, drilling the burr-hole, opening dura, passing the catheter into the ventricle, closing skin, and tunneling and anchoring the catheter. The model provides immediate visual reinforcement of a successful ventriculostomy, as model ventricles are filled with fluid to simulate CSF. This feature allows trainees to troubleshoot complications which may occur, such as catheter misplacement or occlusion, air locks, a low-pressure system, or catheter strangulation while placing anchoring sutures. These authors are conducting refinements following feedback from 17 surgeons before incorporating this simulator into a comprehensive curriculum to train residents [48].

![Fig. 6. Cadaveric operating room structure for ultrasound stylet for EVD placement. Reprinted by permission from *Journal of Neurosurgery* [36].](image1)

![Fig. 7. ImmersiveTouch virtual reality simulator for EVD placement. Permission from *Simulation in Healthcare pending acceptance of article for publication* [44].](image2)
Innovative technology continues to be developed, tested, and refined in efforts to improve resident training in the placement of EVDs. These training environments can be used to improve accuracy while decreasing morbidity and complications associated with EVD placement with widespread implementation early during a neurosurgical trainee’s career.

6. Conclusions

The last 10 years has seen a significant rise in new EVD technology consisting of smartphones, ultrasound guides, and neuronavigation, as well as ways to advance procedural learning via updated resident training. Despite these advances, new technologies are limited by lack of validated clinical research and as a result are not widely implemented. An emphasis on early ventriculostomy training through new simulators, supervised experience on patients, and implementation of novel guidance systems is likely to reduce the risk of EVD-associated complications in neurosurgical care. The next 10 years should provide clinical validation of these technologies, making navigated EVD placement the standard of neurosurgical care.

Disclosures

The authors report no financial disclosures and no conflicts of interest in publication of this work.

Funding

This review was self-funded by the authors.

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