Neuronavigation-Assisted Bedside Placement of Bolt External Ventricular Drains in the Intensive Care Setting: A Technical Note

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Abstract

Background: The insertion of bolt external ventricular drains (EVD) on the intensive care unit (ICU) has enabled rapid cranial cerebrospinal fluid (CSF) diversion. However, bolt EVDs tend to be perceived as a more challenging technique, particularly when dealing with small ventricles or when there is midline shift distorting the ventricular morphology. Furthermore, if neuronavigation guidance is felt to be necessary, this usually assumes a transfer to an operating theatre. In this technical note, we describe the use of electromagnetic neuronavigation for bolt EVD insertion on the ICU and assess the protocol's feasibility and accuracy.

Methods: Case series of neuronavigation-assisted bolt EVD insertion in ICU setting, using Medtronic Flat Emitter for StealthStation EM.

Results: Neuronavigation-guided bolt EVDs were placed at the bedside in n=5 patients on ICU. Their widest frontal ventricular horn diameter in the coronal plane ranged from 11 to 20 mm. No procedural complications were encountered. Post-procedural CT confirmed the optimal placement of the EVDs.

Conclusions: Electromagnetic neuronavigation is feasible at the ICU bedside and can assist the insertion of bolt EVDs in this setting. The preference for a bolt EVD to be inserted in ICU – as is standard practice at this unit – should not prohibit patients from benefitting from image guidance if required.

Keywords: Bolt external ventricular drain; electromagnetic neuronavigation; intensive care unit; ventriculostomy.

Introduction

The traditional technique for external ventricular drain (EVD) insertion is based on burr-hole trephination, typically using a compressed-air or electric drill in the operating theatre, through which the drain is introduced into the brain and then tunnelled subcutaneously to its point of exit at the skin. The alternative, "bolt EVD" technique relies on a manually-driven twist-drill to create a transcranial shaft into which a skull screw is inserted; the EVD is then passed through this bolt into the brain [6].

The design of cranial rapid access kits and bolt external ventricular drains (EVD) has responded to the clinical demand for rapid cranial cerebrospinal fluid (CSF) diversion in patients with time critical indications to CSF drainage or who are too unstable for safe transfers between ICU, the CT scanner and the operating theatre. Their use in the intensive care unit (ICU) [16] is further supported by their favourable CSF infection and leakage rates [17,2], their decreased rate of pull-out [3], and their cost-effectiveness [16].

However, bolt EVDs come with their own unique challenge, notably the limited possibility for correcting errors in trajectory [12]. This is in contrast to the traditional technique where a change in catheter trajectory is possible if the initial attempt at reaching the ventricle is unsuccessful, owing to the burr-hole's relatively larger diameter. As a consequence, despite their several advantages, bolt EVDs may be technically daunting, particularly in patients with small ventricles, abnormal anatomy, proximity to vascular pathology, or midline shift, precluding the use of traditional trajectories.

Electromagnetic (EM) neuronavigation has been shown to significantly improve the accuracy of traditional EVD placement [1], but its use for bolt EVD insertion has not been reported so far. This may be owing to a perception that bolt EVDs are either not compatible with neuronavigation, or to perceived time and space constraints in the ICU.

At this single centre, patients intubated on the ICU requiring acute cranial CSF diversion would undergo bolt EVD insertion on the unit as standard care. In this technical note, we describe the use of EM neuronavigation for bolt EVD insertion in ICU and assess the technique's feasibility and accuracy.

Methods

This article follows the "Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement" checklist [18] and the "Innovation, Development, Exploration, Assessment, and Long-Term Study (IDEAL) model" statements [14]. This study was registered as a Service Improvement study with the University College London Hospitals NHS Foundation Trust Clinical Audit Committee, under the Registration number 28-202021-CA.

Study design

A single centre prospective cohort of patients undergoing bolt EVD insertions with EM neuronavigation in the ICU setting. This study is at Stage 1 of Surgical Innovation (i.e. Idea phase) according to the IDEAL model [14].

Inclusion and exclusion criteria

Included in this study were patients admitted to the ICU, in whom a bolt EVD was clinically indicated and who were recommended to having neuronavigation for ventricular catheter placement on the basis of their radiological findings. Excluded were patients who were not already intubated on the ICU, patients who were unable to have a bolt EVD (such as those without a bone flap to anchor the bolt) or patients in whom neuronavigation was not found to be indicated (due to the absence of "difficult" or abnormal anatomy on radiological investigations).

Outcome

Clinical records were reviewed for patient baseline demographic information and clinical indications for bolt EVD insertion. Operative records were reviewed for surgical details and complications.

Frontal horn diameter was defined as the widest point on pre-procedural computed tomography (CT), in the coronal plane, on a slice passing through the foramen of Monro. The target was defined as the ipsilateral foramen of Monro or proximal to it within a 5 mm range.

Feasibility was assessed by whether the procedures could be performed as per protocol (detailed below), unhindered by technical aspects or by the ICU environment. In view of the relatively subjective nature of this evaluation, procedural time was also monitored for each case, as a more objective reflection of feasibility.

Procedural time was defined respective to a 30-minute timeframe from the moment the decision to place an EVD was taken to the catheter's actual placement within the ventricle.

Accuracy was assessed on a post-procedural CT performed during the patient's admission and the position of the ventricular catheter's tip was assessed respective to the ipsilateral foramen of Monro.

Bedside neuronavigation-assisted bolt EVD insertion protocol

A StealthStation^{TM} S8 surgical AxiEM electromagnetic navigation system (Medtronic Navigation, Louisville, CO, USA) was placed at the patient's bedside (Fig. 1a). Fig. 1b-i demonstrates the step-by-step approach for set-up of the system and for placement of the bolt EVD.

Ethics and consent

All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethics committee approval was not required for this type of study as local institutional protocols were followed and techniques used all form part of normal standard care at this single centre. All patients had representation for consent for insertion of bolt EVD.

Study size and analysis

Seeing that this study is at IDEAL model Stage 1 – "Idea" phase of surgical innovation [14] – the number of cases during the study period determined the sample size.

Patients' frontal horn diameters are presented as a range and a median. The rate of accurately placed catheters is given.

Results

Demographics and frontal horn diameters on pre-procedural CT

Five patients (4 male and 1 female; age range: 22-58) underwent EM neuronavigation-assisted insertion of a bolt EVD at their bedside on the ICU. The indications were hydrocephalus secondary to aneurysm-related Fisher grade 4 subarachnoid haemorrhages (SAH) in 2 patients, hydrocephalus secondary to rupture of a posterior fossa arteriovenous malformation (AVM) in 1 patient, hydrocephalus and haemorrhagic ventricular moulding following rupture of an AVM of the splenium in 1 patient, and 1 patient underwent a right frontal EVD following the removal of his right parieto-occipital ventriculoperitoneal shunt for infection. The range of frontal horn diameters in the coronal plane on pre-procedural CT was 11-20 mm (median: 13 mm).

Outcome

Feasibility: All five procedures were performed as per planned setup. Failure of registration was not encountered. EVDs were all inserted in a timely manner (EVD placed into ventricle within 30 minutes of decision).

Accuracy: All (100%) EVD insertions were successful on first pass. Three EVDs were placed in the right frontal horn and two in the left. Post-procedural CT confirmed that all EVDs reached the target. Fig. 2 illustrates a result of the bolt EVD technique.

Patient and EVD outcome: No procedural complications were encountered. Post-procedural CT confirmed the absence of intra-/extra-axial haematoma associated with EVD insertion. None of the EVDs required revising. One of the two patients with SAH and one of the two patients with a ruptured AVM died from cerebro-ischaemic injury caused by the vascular insults. A parieto-occipital ventriculoperitoneal shunt was ultimately placed in the remaining 3 patients.

Discussion

Principal findings

To our knowledge this is the first demonstration of the use of EM neuronavigation to assist the hardware-specific placement of a bolt EVD. Here we show that the proposed technique is not only feasible but that this is also the case in the very particular setting of an ICU. Furthermore, it can be done in a timely and safe manner while also facilitating critical patient care.

Rationale

The rationale for using neuronavigation during the insertion of bolt EVDs in the ICU setting includes: (1) Enabling EVD insertion to be performed at the patient's bedside despite the presence of abnormal (Fig. 2a) or shifted anatomy, or of small ventricles; and (2) preventing inaccurate EVD insertion, resulting from the bolt EVD technique-limited possibility to correct catheter trajectory.

(1) Bolt EVD insertion in ICU

Bolt EVDs are gaining increasing acceptance over the traditional burr-hole technique among both the neurosurgical and neuro-intensive care communities. This is following a number of reports over the past years that have demonstrated their more favourable rate of procedure-related complications [2,3,17] (or, at the least, comparable to that of traditional external ventriculostomy [16,12]). Furthermore, bolt EVDs placed in ICU impart a non-measurable logistical and medical advantage by avoiding transfer of potentially unstable patients to the operating theatre. It therefore appears as a natural evolution that intraoperative adjuncts in the operating theatre, such as neuronavigation, should also make their way in some form to the patient's bedside in the ICU, to be used when required.

In contrast to light-emitting diode tracking systems, which typically require immobilisation of the patient's head in a pinned clamp to the surgical table, current EM neuronavigation technology with a flat emitter (StealthStation^{TM} EM, Medtronic Navigation, Louisville, CO, USA) represents a particularly well-suited solution for the ICU bedside setting, as it is simply placed under the patient's pillow (Fig. 1a-b). An adhesive patient tracker (StealthStation^{TM} EM, Medtronic) is then stuck onto the patient's skin and registration can take place in the same manner that it would in the operating theatre.

(2) Enhancing accuracy of EVD placement

The traditional EVD technique – with its wider trephination – allows for trajectory correction should the first pass be unsuccessful (Fig. 3a). The bolt EVD technique, however, is limited to a single trajectory per bolt (Fig. 3b). The only way to amend the trajectory is to create a wholly new trephination (albeit usually possible via the same incision). Therefore, when inserting a bolt EVD, thought must be given to its trajectory during the very initial steps – i.e. during the drilling phase. In contrast, in the traditional technique the main concern at the drilling stage is to ensure that the burr-hole is made over Kocher's point with consideration for trajectory given only after the burr-hole has been made. This early emphasis on trajectory accuracy at the drilling phase of bolt EVD insertion may result in uncertainty for operators who are inexperienced with this technique. Therefore, for bolt EVDs, it is essential to enhance the chances of "hitting the ventricle" on the first attempt, and neuronavigation has the potential of being a useful tool in this regard.

Interestingly, Bergdal et al. found the bolt EVD technique to be more accurate than the traditional burr-hole method, although the authors themselves conclude that there is nonetheless still margin for improvement and suggest that image guidance may have a role to play in achieving this [3]. Mahan et al. and AlAzri et al. showed that an increase in accuracy can indeed be reached during traditional EVD placement with the use of neuronavigation [11,1].

The novel experience presented here shows that neuronavigation can also be used to aid in the placement of *bolt EVDs* and shows how it can be successfully adapted to the particular hardware specificities of these devices. The technique is described in Figure 1. To achieve an accurate catheter insertion, we use neuronavigation to address the bolt EVD technique-specific difficulty of adhering to a catheter trajectory *at the twist-drill phase already*. This is in contrast to the two previous studies in the ICU setting, where the traditional technique was used and where navigation was used only *after* trephination [11,1].

Future development

To optimise accuracy

As described in Figure 1, currently our setup relies on siding the twist-drill parallel to the neuronavigation stylet, and then translating the twist-drill over the short distance to the point where the stylet lay. This phase of the procedure is admittedly user dependent and therefore potentially carries a residual degree of inaccuracy. So, the likeliest next immediate developmental step to further facilitate image-guided bolt EVD placement at the ICU bedside will be the direct navigation of the twist-drill itself, and not only an indirect navigation as is currently the case in this report.

Neurosurgery is highly dependent on image guidance and interest has therefore been directed towards augmented reality (AR) technology in view of its potential to meaningfully integrate elements from preoperative radiological studies into the live surgical field [4,5]. It is likely that an AR-based solution will arise to facilitate bedside EVD placement, including that of bolt EVDs; but reports of AR-aided ventriculostomy to date lack sufficient accuracy for clinical use due to their reliance on manual registration [9,7].

Thinking yet further into the future, it is conceivable that technically challenging EVDs will be placed with robot assistance even in the setting of the ICU. The robot-guided optimisation of endoscope trajectories during ventricular procedures has already been described [8] as has robot-guided catheter ventriculostomy [10]. The main setbacks of these systems however include their very large size, complexity and cost [13]. Nonetheless, the trend in robot innovation is towards smaller, simpler and less costly devices [15].

To optimise time-critical workflow on the ICU

The use on the ICU of a portable CT scanner with volumetric data acquisition for the purpose of neuronavigation would allow the entire process to take place at the patient's ICU bedside, circumventing not only the transfer to the operating theatre but also the patient's transfer to the CT scanner if up-to-date image acquisition is required. Moreover, certain systems allow for automatic registration via face masks that do not require the head to be immobilised. They are based on optical registration and are therefore not compatible with the EM setup described here, but would allow to shorten the process even further by coupling image acquisition and patient co-registration into one single step.

Limitations

This patient series is not large enough to draw comparative conclusions on the efficacy of the technique. Being at IDEAL stage 1 of surgical innovation [14], the study's sample size was determined by the number of cases during the study period. As such, this report is intended as a technical note to demonstrate the feasibility of EM neuronavigation for ICU bedside bolt EVD placement.

Conclusion

We demonstrate that the implementation of EM neuronavigation in the setting of the ICU is feasible, with the aim of enhancing bolt EVD accuracy for cases with difficult anatomy, whilst also reducing errors resulting from the bolt EVD technique-inherent limitation to correct catheter trajectory. In terms of future development, it is conceivable that the twist-drill itself will be directly neuronavigated to further facilitate the technique and that portable CT image acquisition and automatic patient registration may further smoothen the workflow on the ICU.

Conflicts of interest: L. D. Watkins has received honoraria and served on advisory boards for Medtronic, Codman, and B Braun. A. K. Toma's research time was supported by the National Institute for Health Research University College London Hospitals Biomedical Research Centre. H. J. Marcus is personally supported by the Wellcome/EPSRC Centre for Interventional and Surgical Sciences (WEISS) and NIHR BRC Neuro-oncology. The remaining authors have no conflicts of interest to report.

Funding: No funding was received for this research.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Figure legends

Fig. 1 (**a**) Set-up for neuronavigation station, patient and ICU bed for electromagnetic navigation for bolt EVD insertion. (**b-i**) Step-by-step approach for ICU bedside bolt EVD placement with EM neuronavigation (demonstrated by H.A.). (**b-c**) An electromagnetic flat emitter (StealthStation^{TM} EM, Medtronic) was placed under the patient's pillow, on their ICU bed. The CT scan should be specified to be performed in Stealth-compatible mode (with zero gantry angle, for example) for patients in whom it is probable that they will require a neuronavigation guided procedure. The patient's neuronavigation CT has been loaded onto the StealthStation^{TM}. Hair was shaved over Kocher's point. (**d**) An adhesive patient tracker was stuck onto the patient's brow and registration of the patient's facial and cranial features with the neuronavigation station was performed with an EM stylet. (**e**) The surgical site was disinfected and draped. A stab point incision was performed over Kocher's point (10-11 cm posterior to the nasion and in the mid-pupillary line), which was additionally verified with a sterile neuronavigation stylet for use within the established sterile field. (**f**) Once upon bone, the trajectory was first defined anatomically (aiming at the ipsilateral medial canthus in the coronal plane and at the tragus in the sagittal plane) and then verified using the EM stylet. (**g**) The twist-drill was then brought side-to-side with the stylet, so as to parallel its trajectory. Once the operator was satisfied with the trajectory shown on the neuronavigation screen, the correspondingly angulated drill was translated over the short distance to where the tip of the stylet lay. A twist-drill trephination was performed at that point and at that angulation. (**h**) The bolt (Spiegelberg Silverline®, Hamburg Germany) was screwed into the skull and the EVD (Spiegelberg Silverline®, Hamburg Germany) was inserted through it to a depth of 5.5 cm, and then secured into place by the bolt. (**i**) A Biopatch® (Ethicon, Johnson & Johnson, NJ, USA) was placed in the interface between skin and bolt

Fig. 2 An example of a left frontal bolt EVD placed using EM neuronavigation in a 25-year-old patient with hydrocephalus and haemorrhagic ventricular moulding following rupture of an AVM of the splenium. (**a**) Pre-procedural coronal CT slice. A left frontal bolt EVD was inserted immediately after this CT. (**b-c**) Post-procedural oblique coronal and oblique sagittal CT slices, performed 9 days later, in the axis of the bolt EVD

Figure 3. (**a**) A burr-hole, classically performed during the traditional tunnelled EVD technique, allows for a greater correction in catheter trajectory than with (**b**) the narrow trephinations performed during the bolt EVD

technique. A bolt does not leave any margin of angulation to the ventricular catheter and therefore only allows it to take a single trajectory

Figure 1

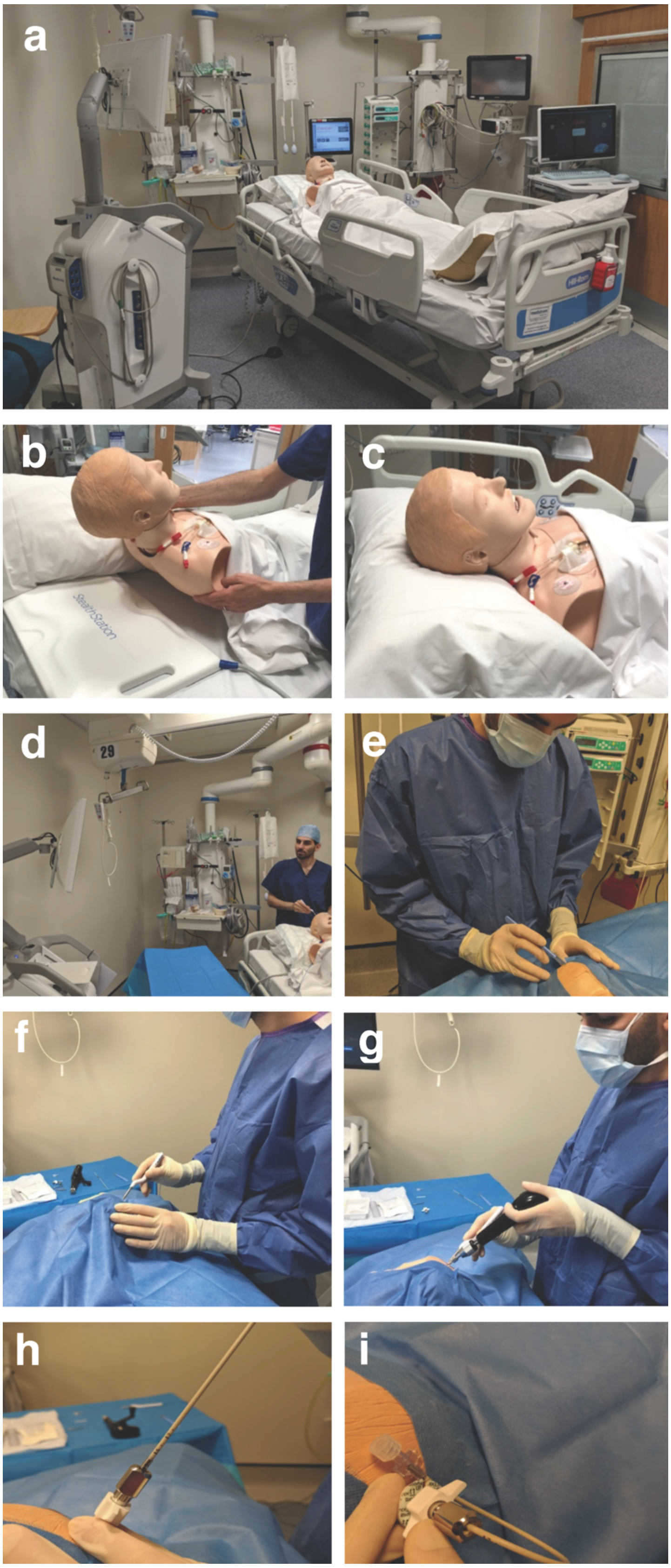

Figure 2

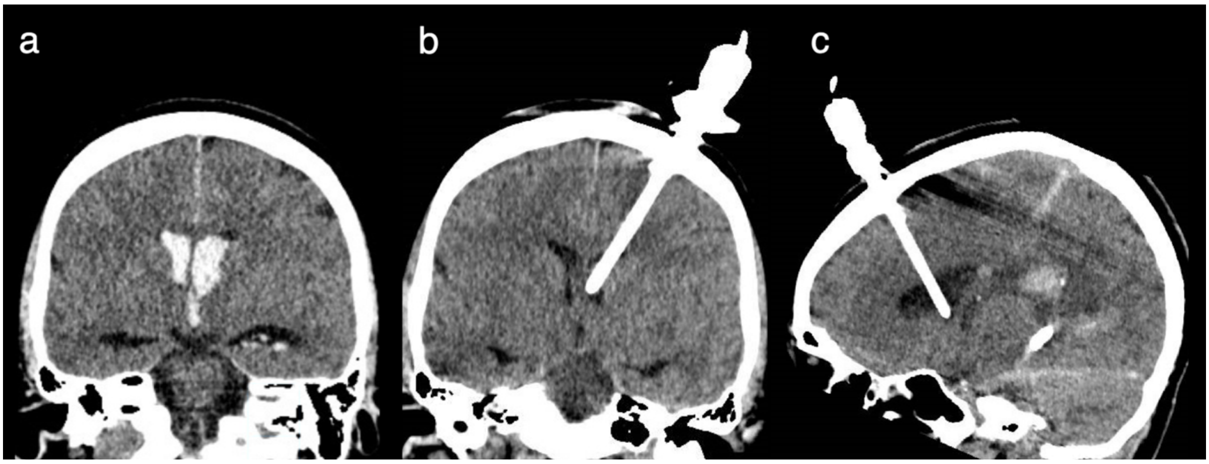

Figure 3