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# Preliminary evaluation of a multi modal simulator for freehand ventriculostomy

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## INTRODUCTION

Ventriculostomy is one of the most frequent procedures in neurosurgery [1]. It involves puncturing the ventricle to drain cerebrospinal fluid. In Freehand Ventriculostomy (FV), neurosurgeons first palpate external anatomical landmarks before blindly inserting the catheter. Their trajectory is guided by their mental projection of the needle path and internal anatomy from pre-op MRI scans. During the insertion, surgeons heavily rely on haptic feedback to control their gestures. This technique is still preferred over existing image-assisted procedures due to the extra effort the latter requires [2]. Despite its prevalence, the accuracy of FV is a controversial topic. Insufficient training has been linked to additional risks for the patients [2] and surveys have demonstrated that junior residents needed more passes (2.4) than senior ones (1.4) to puncture the ventricle, with a success rate between 72% and 84% [3].

To address the limitations of current training and due to the limitations of purely virtual simulators [4], haptic training simulators have been considered. They are broadly classified into three categories [5]: Physical Simulators (PS), Virtual Reality Simulators (VRS), and Mixed Reality Simulators (MRS). PS and MRS permit palpation; however, they suffer from low reusability and low diversity. VRS combine visual and Active Haptic Feedback (AHF) but are costly and lack physical anatomical landmarks. According to the expert neurosurgeons taking part in this preliminary evaluation, these limitations prevent the adoption of such technologies in the training curriculum.

Therefore, a multi-modal training simulator for FV was introduced in 2023 [6], providing visual and force feedback associated with tangible anatomical landmarks (as required in clinical practice) while improving the reusability and diversity of PS and MRS. This paper introduces a preliminary subjective evaluation of this simulator by 17 international expert neurosurgeons.

## MATERIALS AND METHODS

The simulator conveys three types of information. Users evaluate the geometry of internal anatomy on displayed MRI slices (see (I) in Fig. 1-a). As an educational feature, the position of the needle tip can be displayed on the MRIs. During simulation, the user interacts with virtual anatomy constructed through MRI segmentation (see (II) in Fig. 1-a), using a commercial haptic interface (see (III) in Fig. 1-b). It provides force feedback and connects the

tangible parts of the simulator to the virtual anatomy and MRIs. The 3D-printed skull (see (IV) in Fig. 1-b), designed according to MRI scans, displays relevant anatomical landmarks, the nasion, the coronal suture, and the top of the ear. It is essential for the realism of the simulation that all these elements are well collocated to provide consistent visual, haptic, and proprioceptive information. During the simulated insertion, tip forces and friction forces are rendered to the user. Tip forces due to the deformation and rupture of the meninges (1) and the cutting of the parenchyma (2) are illustrated in Fig. 1-c. The puncture (3) is marked by a sudden drop in forces.

The simulator was tested by 17 expert neurosurgeons at the 2024 Consensus Conference and 6th Refresher Course of the European Society for Pediatric Neurosurgery (ESPN). Participants, who gave their informed consent had performed more than 20 FV and still practiced regularly (monthly or weekly). Out of the 17 experts, 12 (70.6%) had never practiced on simulators during training, 3 (17.6%) had trained on cadavers or mannequins, and only 2 (11.8%) had prior experience with simulators. They were asked to perform the FV on our multi-modal simulator. To do so, surgeons could browse the MRI scans, palpate anatomical landmarks, and measure reference points both on scans and on the printed skull.

After completing their FV trial, experts were asked to fill out a survey consisting of seven questions (summarized in Table I) that were answered on a 5-level Likert Scale. The survey focused on the novelty of this simulator in the context of FV training, i.e. the combination of AHF and tangible anatomy. First, three questions concerned the relevance of the simulator's design (see *About this simulator* in Table I) regarding the potential benefits in the training and evaluation of FV and the appropriateness of tangible anatomical landmarks. Then four questions concerned the realism of force feedback (see *Do you feel that the force feedback is realistic* in Table I).

## RESULTS

It is clear from the answers (summarized in Table I) that expert surgeons believe our multi-modal simulator could have a positive impact on training. According to 82.4% of the experts this simulator could be beneficial to the current training curriculum and 76.5% agree that it could allow for a precise evaluation of students. Although experts

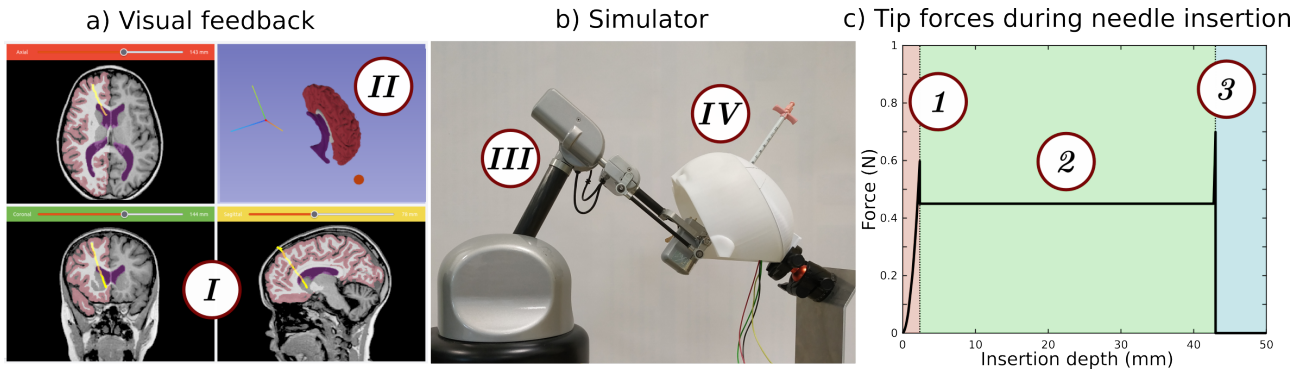


Fig. 1: Overview of the multi-modal simulator.

	Agree	Slightly agree	Without opinion	Slightly disagree	Disagree
<b>About this simulator</b>					
Its integration into the training curriculum can be of real benefit in learning how to perform the freehand ventriculostomy	14 (82.4%)	3 (17.6%)	0 (0%)	0 (0%)	0 (0%)
Its use could allow for a precise evaluation of the student during freehand ventriculostomy training	13 (76.5%)	3 (17.6%)	1 (5.9%)	0 (0%)	0 (0%)
The skull and anatomical landmarks are sufficient in their current form	6 (35.3%)	7 (41.2%)	1 (5.9%)	3 (17.6%)	0 (0%)
<b>Do you feel that the force feedback is realistic</b>					
As a whole	12 (70.6%)	2 (11.8%)	1 (5.9%)	1 (5.9%)	1 (5.9%)
Across the meninges	7 (41.2%)	6 (35.3%)	1 (5.9%)	2 (11.8%)	1 (5.9%)
Across the parenchyma	11 (64.7%)	4 (23.5%)	0 (0%)	1 (5.9%)	1 (5.9%)
When puncturing the ventricle	12 (70.6%)	3 (17.6%)	0 (0%)	1 (5.9%)	1 (5.9%)

TABLE I: Results of the subjective evaluation of the multi-modal simulator.

concluded on the potential benefits of the simulator, opinions were more divided regarding anatomical landmarks according to the results. In complementary comments and during interviews, some experts suggested that having the complete nose and ears could be useful.

Force feedback was overall well received. 70.6% of expert neurosurgeons agreed that insertion forces were rendered realistically throughout the insertion. Although the cutting of the parenchyma and the puncture of the ventricle were found realistic (64.7% and 70.6% agreed respectively), the rupture of the meninges was less convincing to the experts. Indeed, 41.2% agreed and 35.3% slightly agreed on the realism of the force feedback for the meninges. Only very few experts rated the realism of the simulator negatively. It is worth noting that only one expert completely disagreed on the realism of the force feedback. Still, this expert slightly agreed on the positive impact of the simulator in the training curriculum.

## CONCLUSIONS AND DISCUSSION

In this paper, a first subjective evaluation of the multi-modal simulator for FV training was introduced. This preliminary evaluation was conducted by 17 international expert neurosurgeons who still practice FV on a regular basis. It aimed to validate the overall design of the simulator and relied on surveys regarding the anticipated benefits of integrating simulation into training. Although encouraging, these results are not yet definitive and will need to be generalized with more participants, including

novice surgeons as well. Still, these preliminary tests confirmed the value of designing a multi-modal simulator for FV training. Future work will be organized in two parts. First, several improvements will be brought to the simulator regarding anatomical landmarks and force feedback. One of the benefits of AHF is the ability to simulate a wide variety of patients, tending towards patient-specific simulations. In the near future, ways to enable multi-patient simulation despite the presence of tangible anatomy (which constrains eligible patient anatomy) will be addressed. Second, the simulator will need to be further validated by comparing performance between experts and novices during tests on various simulated patients.

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