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Design and Manufacture of a Training System for Ventriculostomy

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***Abstract*— A neuroendoscopic training system was developed, consists of an algorithm, computer equipment, a pair of cameras and a head anatomical model. By applying well-known equations and using the necessary hardware and software. Images are obtained of the instruments used to always know its position inside the head and the coordinates of the 3-dimensional axes are calculated. The development of the project consists of two main stages: The identification of the instrument on the anatomical model by the implementation of passive markers on it and the registration of the coordinates of the path that the instrument will follow during the training for its subsequent analysis.**

***Keywords*— Ventriculostomy, algorithm, training station, metrics, markers.**

I. Introduction

A medical training system is used in the educational field to provide controlled environments of real situations. Surgical simulation plays an important role in the learning process as the required skill and ability can be obtained with fewer clinical cases [1]. Practicing with a simulator can improve performance by reducing risks due to an inexperienced technique, training can become a powerful educational tool [2], [3], [4]. Currently 70% of the learning centers have trainers or simulator [5].

Ventriculostomy is a neurosurgical procedure in which a catheter is placed into the cerebral ventricles, these ventricles are filled with cerebrospinal fluid, sometimes it is necessary to drain excess fluid to the outside because it can cause inflammation, this procedure is also known as external ventricular drainage (EVD). A tube (long, tunneled ventricular catheter, dipped in antibiotic to prevent infection) is usually placed connected to a collection device (Fluid Collection System) which can vary the amount of fluid that is drained. To perform the procedure, the patient's head must be shaved and placed in a supine position with the head tilted approximately 30 degrees. The Kocher point located in front of the coronal suture and 3 cm from the midline should be marked, it is at this point where the trepanation or Stoma will be performed using a manual drill with a drill bit larger than the diameter of the catheter, the catheter is then inserted into the frontal horn of lateral ventricle. The lower tip of the catheter should point to the Monro hole for successful placement, the catheter is inserted through the stoma to a depth of approximately 6 to 6.5 cm from the scalp. Once the catheter has been successfully placed, subcutaneous tunneling is performed to reduce the risks of infection.

Ventriculostomy is one of the first interventions that novices in neurosurgery must learn, during their training require several insertions to finally penetrate the ventricle with the catheter, this can increase the rate of complications. Complications from bleeding can occur in 30%-40% and complications from infection in 20%. 20% of the insertions performed fail to hit the ventricles [6]. The existing training systems for this intervention are based mainly on virtual reality systems which, thanks to virtual patient models and hardware with haptic purposes, the surgical intervention can be simulated using virtual instruments, this results in the acquisition of experience in that intervention [7], [8]. On the other hand, there are physical models [9], these models tend to look and feel very realistic from the anatomical point of view, on them we can make an intervention with more tactile feedback, because, unlike virtual reality-based trainers, tangible physical models are presented here. Virtual trainers offer a more realistic anatomy, while physicists are better at improving manual and technical skills [10], [11].

The proposed system consists of a physical part of anatomical model and a virtual part which will help the practitioner to know the position of the catheter on the physical model through passive markers using image processing.

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II. Material and Methods

The methodology used for the development of our proposal was to identify the needs for the simulation of the intervention by consulting a pair of expert neurosurgeons, the workstation and system software described below were subsequently designed. The training system proposal consists of two parts: Training station (Physical part) through which we intend to replicate the tactile feedback provided by the physical models, also includes a Software for the system (Virtual part), which will help us record various metrics and observe the performance of practitioners.

A. *Training Station*

The physical model of the trainer consists of a structure built in MDF (Medium Density Fibropanel); laser cutting was used to obtain panels.

To eliminate the greatest interference captured by the cameras from the environment in which the trainer was placed, the entire structure was painted matte black color, so the color that may interfere with the identification of the markers placed on the catheter is minimized.

Maintaining stable lighting becomes one of the key points for proper functioning of the system, this helps us to obtain better images and computational processing is simpler and more effective. A 30 w LED white light lamp was installed for this purpose.

A pair of c922 Logitech cameras are also implemented, these cameras are placed orthogonally at 43 cm from the center of the anatomical model and at a height of 25 cm, to capture images from two different perspectives, the images are acquired from a frontal plane and a sagittal plane, in this way a three-dimensional space can be reconstructed.

On the catheter are placed a pair of green passive markers, these were built by 3D printing, are hollow cylinders placed with a gap of 11 cm covered in green (Fig. 1).

It is necessary to recreate the training conditions as realistic as possible, a skull model with realistic dimensions and qualities will help the practitioner to develop his skills naturally and will be able to extrapolate these skills to real patients. A physical model formed by a skull, brain and replaceable modules is placed. The placement of the atomic model is in the supine position, the skull is in a neutral position and bent at 30 degrees as is normally done in a real intervention of this type, this is achieved thanks to an inclined base on which the anatomical model is placed.

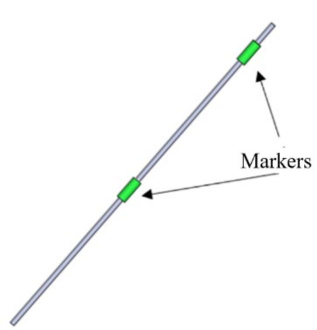

Fig. 1. Catheter used in the system.

For the construction of the skull a 3D model was obtained on the web GrabCAD, it was necessary to modify the model so that it formed 2 pieces to open and close the skull. A pair of markers are also added over the top of the skull, each will be detected by one of the cameras, so the exact position of the skull will be always known, also help us calculate the insertion of the catheter into the anatomical model from a frontal and sagittal view. A replacement stoma is placed that consists of a small oval that must be fixed on the skull, through which the catheter must be embedded to reach the ventricles. Stoma is placed in the Kocher point located in front of the coronal suture and 3 cm from the midline (Fig. 2). Fig. 3 shows all parts of the skull model.

Once through the Stoma, the catheter will have to be inserted into the brain, a realistic model of brain in 3D printing was implemented (Fig. 4.a), however, the material (PLA) is too

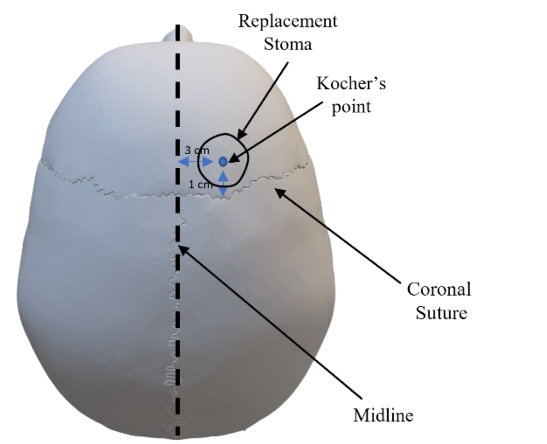

Fig. 2. Replacement stoma placement on the anatomical model.

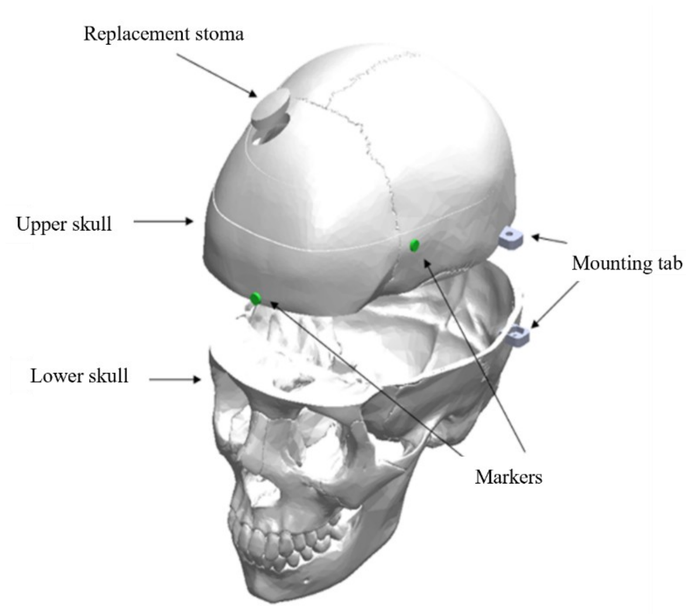

Fig. 3. Skull model and parts.

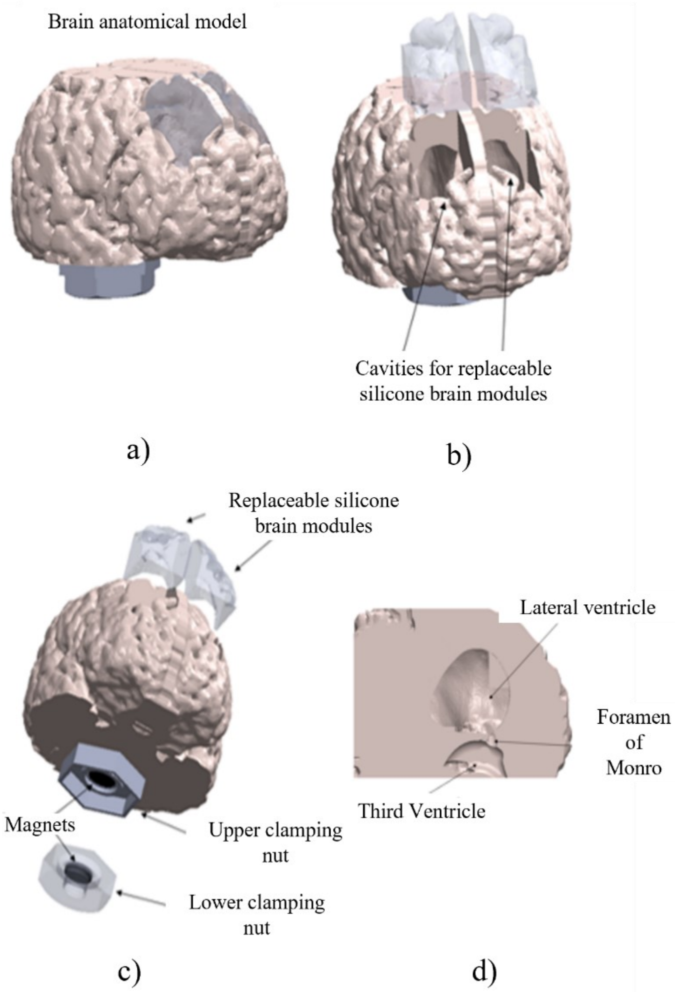

Fig. 4. Brain Model. a) Anatomical model of the full brain, b) placement of the replaceable silicone modules on the cavities, c) holding system of the brain model, d) Hollow ventricular system.

hard to pretend to be the brain, To perform a module similar to the texture and consistency of the human brain, tests were carried out with different composite materials, such as ballistic gel, grenetin, gelatin and finally 100% silicone, the latter being the choice for its durability and consistency.

The replaceable silicon modules (Fig. 4.b) are placed on the brain. To correctly place the brain model within the skull model, clamping nuts with magnets are implemented (Fig. 4.c) to avoid movements due to the placement of the catheter.

The objective of the training is to place the catheter inside the ventricles, in the brain model 3 areas of the ventricular system are replicated: the lateral ventricles, the foramen of Monro and the third ventricle. As can be seen in Fig. 4.d the whole area is hollow to perform the training properly. It is worth mentioning that the ventricular model used corresponds to a patient with hydrocephalus, one of the most common diseases for which a ventriculostomy is required.

B. Software for the System

It is necessary to record various metrics such as the training time, the angle the catheter takes, the insertion length and the linearity of the catheter. To do this, an algorithm was developed that acquires these metrics and records them for later analysis. Each part of this is described below. Python was used in conjunction with the OpenCV library for image processing, Tkinter library was also implemented for the generation of the user-friendly graphical interface (Fig. 5).

The algorithm starts with a graphical login interface, which helps us to have better control over each participant and record their metrics individually. Once the practitioner logs in, the main user interface is displayed.

Before starting the training, a calibration is performed so that the system works properly, this consists of choosing the position of the cameras and adjust the levels of HSV (H: Hue, S: Saturation, V: Value or Brightness) to make the identification of green markers easier.

Once the training process begins, images representing the position of the anatomical model will be uploaded, time counting will begin, finally the cameras will begin to acquire images.

The image processing algorithm consists in the identification of the markers placed in both the catheter and the anatomical model and in turn generate a straight line on the images of the sagittal view and the frontal view that always represents the position of the catheter even if it is immersed in the atomic model and is impossible for the practitioner to see.

First, a radial distortion calibration is performed. Then are identified the groups of pixels corresponding to the range in HSV previously established in the system calibration, by default the following levels are placed: H (70:95), S (90:255), V (155:255), these correspond to green. Once identified, they are eroded and subsequently dilated to maintain only the largest area and remove those that only represent interference from a source other than that of passive markers, an area range is also applied to remove these interfering sources. When the markers are identified the centroid of each is obtained and their coordinates are stored in different variables: x_a, y_a upper marker in the catheter, x_b, y_b lower marker in the catheter, x_c, y_c marker placed in the anatomical model.

For the calculation of the angle of the catheter the slope of this first must be calculated, for this we simply apply the

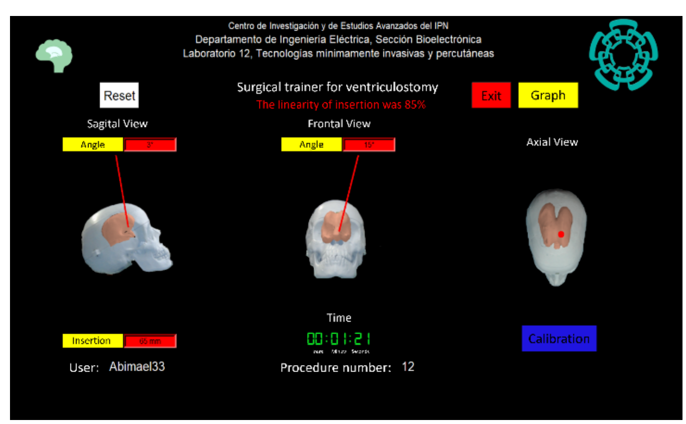

Fig. 5. Main graphical interface with various views of the anatomical model to strengthen visual feedback.

formula of the slope using the coordinates, then we must obtain the tangent arc of the slope to obtain the angle in radians, we must convert this measurement to sexagesimal angles for greater user convenience using (1).

$$\alpha = \left(arc\,tan\left(\frac{y_b - y_a}{x_b - x_a}\right)\right)\left(\frac{180}{\pi}\right) \quad (1)$$

To plot the straight line representing the catheter, we must find the bottom point of the line (x_{cc}, y_{cc}), where the top point is the centroid of the upper marker (x_a, y_a) and the midpoint the centroid of the lower marker (x_b, y_b). To find the bottom point we used the formulas to obtain the midpoint of a line, however, they were adapted to obtain the bottom point instead of the midpoint as shown in (2) and (3).

$$x_{cc} = 2x_b - x_a \quad (2)$$

$$y_{cc} = 2y_b - y_a \quad (3)$$

When the necessary points for graphing are obtained, the line is drawn from its upper to the lower point on the image representing the anatomical model (Fig. 6).

The calculation of the insertion (*I*) of the catheter is made by creating a circle in an independent image that represents the dimensions of the skull, taking as central point the marker placed on the anatomical model (x_c, y_c), on this image is also drawn the graph of the catheter, an analysis is performed and the point at which the two graphs are crossed is obtained, this point is called interception point and we store it as x_i, y_i. Calculate the distance from the bottom point of the line and the intercept point as shown in (4).

$$I = \sqrt{(x_i - x_{cc})^2 + (y_i - y_{cc})^2} \quad (4)$$

The software is also able to identify the area where the catheter is located using coordinates of central points of these zones, the distance between the lower end of the catheter and the zone reference point is measured and if the distance is less than the radius of the area covering the zone then the catheter is in that zone. These may be the lateral ventricle, the foramen of Monro and the third ventricle.

When the training is finished, we can graph the path of our catheter during the training.

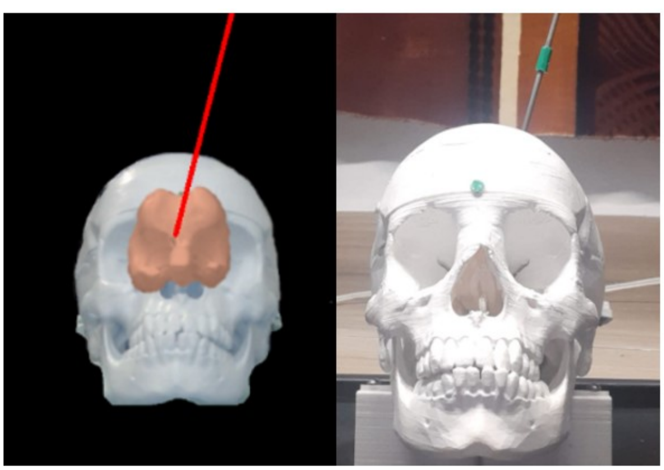

Fig. 6. Line representing the catheter on the preloaded image (left) and how it looks in reality (right).

III. Results

A proposal of trainer was developed, which consists of a training station and software (Fig. 7). The system is physical, not virtual.

Based on the design described above and the implementation of the training station in conjunction with the software, a system was achieved that responds to the needs of touch feedback using 3D printing, replicating areas of the ventricular system such as the lateral ventricles, the foramen of Monro and the third ventricle, in addition to having a visual feedback that allows us to know for all time *t* the position of the catheter, this helps to have greater accuracy during the placement of the catheter through images representing the position of the anatomical model. In addition, the software indicates through labels the area on which the catheter is placed (lateral ventricles, foramen of Monro or the third ventricle).

Thanks to this, users will have the opportunity to train on a controlled environment that does not represent any risk for patients.

The simulator is designed to provide a potential training tool for training professionals in the practice of this intervention.

At the end of the training, different metrics collected from the procedure are used and shown in a report, in this way the practitioner can observe its improvement in the procedure, as well as previous training, The metrics considered are reported in Table 1.

Other products that we obtain after a training are the graphs that represent the path of the catheter.

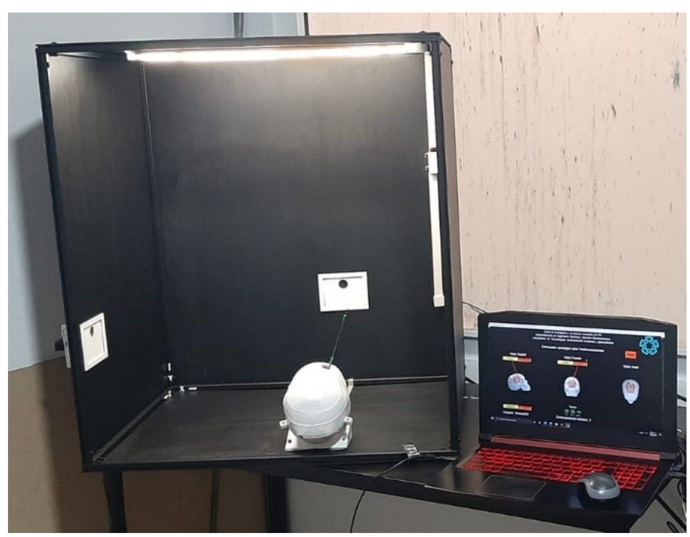

Fig. 7. Training system for ventriculostomy.

TABLE I. METRICS RECORDED BY THE SYSTEM

METRIC	DESCRIPTION	EQUATION
Total time	The total time from start to finish training.	$$T = \sum_{k=0}^{n-l} t \qquad (5)^{a}$$
Insertion length	It's the length that the catheter has been inserted into the head model.	$$I = \sqrt{(x_i - x_{cc})^2 + (y_i - y_{cc})^2} \qquad (6)^{b}$$
Angle	Determines the tilt of the catheter while in the head model.	$$\alpha = \left(\arctan\left(\frac{y_b - y_a}{x_b - x_a}\right)\right)\left(\frac{180}{\pi}\right) \qquad (7)^{c}$$
Linearity	Measure the variation of the angle of insertion.	$$L = \Delta\,\alpha \qquad (8)^{d}$$

[a] In (5) "T" represents the total time and "t" represents the current time. [b] In (6) "I" represents the insertion in millimeters, the insertion point is represented by x_i and y_i, x_{cc} and y_{cc} represent the lower tip of the catheter. [c] In (7) we calculate the angle of insertion. [d] In (8) we get the variation Δ of the angle of insertion where "L" represents the linearity.

An experimental test was conducted by two novices with no experience in ventriculostomy, test consisted of placing the ventricular catheter in the third ventricle, based on the views offered by the system and the graphic representation of the catheter to achieve the correct placement of this. First, the insertion area of the catheter on the anatomical model had to be in front of the coronal suture and 3 cm from the midline. The catheter is then inserted into the lateral ventricle through the skull and brain, once the catheter was in the lateral ventricle, the foramen of Monro had to be traversed and then reached the third ventricle, once this point had been reached, the task was considered completed. Fig. 8 shows how the training is done and the path the catheter follows (Red arrow) until it reaches its target. In addition to the metrics previously considered, graphs are also obtained (Fig. 9) that indicate the trajectory followed by the catheter in the 3 main views, as well as a 3D view that can be manipulated if a specific point is required to be observed.

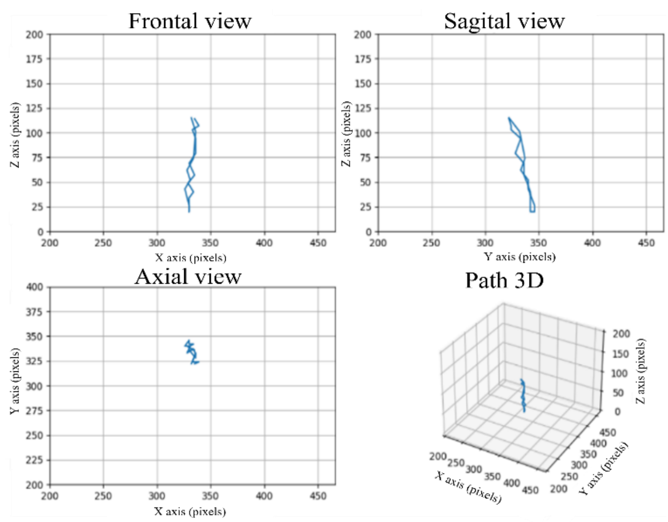

Fig. 9. Catheter path during training.

IV. DISCUSSION

Today there are various methods for surgical training such as direct training on corpses, models of physical simulation that often lack realism, there are also virtual simulators that lack haptic feedback, we compare our system with others in table 2.

The correct implementation of the intervention by novices in neurosurgery, as well as the reduction of times and errors, make it necessary to develop new training systems.

The developed system provides advantages as safe conditions for training in the placement of ventricular catheters, this could strongly benefit new professionals in neurosurgery. One of the conditions in which ventriculostomy is most used as a treatment is hydrocephalus, the model includes a ventricular system that simulates this condition.

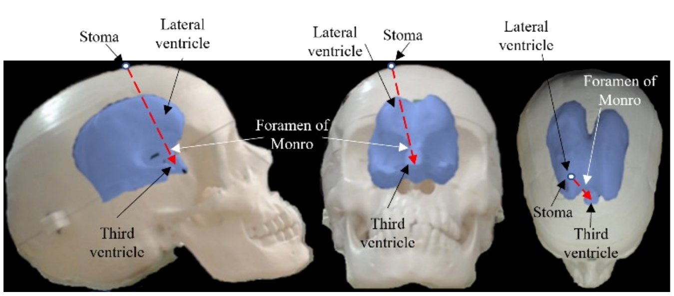

Fig. 8. Path to follow to perform the procedure

The active markers are those that require an energy consumption, are easy to identify and are less susceptible to environmental interference, however, in the implementation they limit the free movement of the instruments, being able to alter the formative practice. Our proposal includes passive markers that have no power consumption and are wireless.

Other advantages of our proposal are that the model can be easily assembled and disassembled in case you need to move or transport, however, the current version it is not intended to be a portable system. It is possible to train in any room. In addition, the anatomical structures that will be crossed by the instruments are replaceable therefore several practices can be performed with the same system. This system always provides visual feedback for the observation of the catheter position and from 3 anatomical views, thanks to this the practitioner has a greater

TABLE II. COMPARISON BETWEEN EXISTING SYSTEMS AND OUR SYSTEM

System	Technology	Start-up	Instrument	Replaceable modules	Metrics	Intervention
Simulator for EVD [a] Tai et al [5].	Physical simulator with 3D printing.	7 min.	Catheter.	Scalp and Skull.	None.	EVD [a]
ImmersiveTouch [8].	Augmented reality and virtual reality.	2 min.	Optical pen.	None.	None.	ETV [b]
Neuro Touch ETV [b] [10].	Mixed reality with endoscopy view.	2 min.	Catheter.	None.	Time, angle, and insertion.	ETV [b]
University of Florida Ventriculostomy Simulator [12].	Augmented reality and physical anatomical model.	7 min.	Catheter.	Scalp and Skull.	None.	EVD [a]
Simulator for ETV [b] Weinstock P et al [13].	Hyper-realistic physical simulator with 3D printing and special effects.	7 min.	Catheter.	None.	None.	ETV [b]
Our System.	Physical simulator and visual support through software.	5 min.	Catheter with passive markers.	Scalp, stoma, and brain modules.	Time, angle, linearity of insertion and length of insertion.	EVD [a]

[a] EVD, External Ventricular Drain, [b] ETV, Endoscopy Third Ventriculostomy.

chance of success during training and can translate into an improvement of the spatial location of the catheter position.

Some limitations of the system are the level of realism on the part of the physical model, this lacks realistic textures, although it complies with an adequate anatomical structure. As mentioned above, it is important that the prototype works under certain conditions, such as calibrated cameras, constant lighting in the anatomical model, if the illumination is varied it is likely that the passive markers on the instrument will no longer be identified due to environmental interference. Also, the need for a system calibration every time you start a training session can be tedious but necessary for proper operation.

Not only are catheter trajectories indispensable when performing a ventriculostomy, the patient's brain anatomy must often be carefully studied through imaging studies such as tomography and MRI scans, this to know if the patient has anatomical abnormalities and therefore plan a different trajectory to the usual one.

The System could be used for the practice of interventions like ventriculostomy where a catheter is inserted into the cerebral ventricles to have a pathway to the cerebrospinal fluid as is the case with the Ommaya reservoir.

The system provides a risk-free environment for practitioners where they can improve their skills and observe their improvement by recording their previous training.

V. CONCLUSIONS

Surgical training is a very important point for the development of technical skills and abilities of practitioners. For the performance of ventriculostomies it is important to practice under controlled environments that do not represent any risk for patients. A novel training system was developed by combining techniques in image processing and 3D printing, said system allows the practitioner to always know the position of the catheter on the anatomical model and by recording the movement of this, metrics can be obtained that help the practitioner to know its performance. Training systems like ours offer opportunities for improvement to surgeons who wish to do so under safe conditions.

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