Affordable Low-Cost Home-Made Skull Model for Interactive Neurosurgical workshops: Experience with Hands-on Intracranial Pressure Monitoring at 2 International Neurosurgical Conferences

***Mohammad Ashraf*[1,2] *and Naveed Ashraf*[2]**

■ BACKGROUND: **Undergraduate neurosurgery conferences are acknowledged to play an important role in bridging the gap between a limited exposure to neurosurgery within medical schools and a highly competitive application process. Hands-on workshops are attractive for any conference but can be prohibitively expensive, especially for student societies.**

■ METHODS: **We describe our method to manufacture a low-cost skull model, which we used for a hands-on intracranial pressure (ICP) monitoring workshop station at 2 international neurosurgical conferences. We describe the workflow for our ICP monitoring workshop using these models.**

■ RESULTS: **Our model acts as an appropriate substitute for more professional simulators while adequately mimicking the sensation of skull drilling, dural puncture, and intraparenchymal ICP bolt and probe insertion. All tools and resources are accessible from local markets and can be sourced online. A total of GB£100 was spent making 5 skull models and took 2 hours to manufacture by 3 individuals. The ICP monitoring workshop was carried out 3 times over 40 minutes, with each session accommodating 18 or 19 delegates ($N = 55$).**

■ CONCLUSIONS: **These workshop models have been praised by medical students for increasing exposure and awareness toward neurosurgical procedures and the sophistication of investigations used by the specialty. Consultant neurosurgeons have praised the simulation provided by these models as closely mimicking the procedure in reality.**

INTRODUCTION

In the United Kingdom, entrance to neurosurgery specialty training is by national selection. It represents one of the most competitive training programs, requiring extensive extracurricular achievements to be eligible for an interview.[1] Medical schools have extremely limited exposure to neurosurgery, so naturally, the opportunities available to build one's curriculum vitae for national selection are scarce. Undergraduate conferences, however, in the United Kingdom are recognized to inspire students toward neurosurgery and provide opportunities and guidance toward relevant resources for improving their curriculum vitae for national selection.[2]

Naturally, as undergraduate conferences are student run, the resources, funding, and scope are extremely varied between societies and depend heavily on support from sponsors, the involvement of the neurosurgery department affiliated with one's medical school, and support from an individual's university/medical school itself. Hands-on workshops are recognized as an integral part of teaching and have been demonstrated to increase exposure, improve confidence, and provoke interest.[3] Due to increasing regulations, hands-on procedural experience in developed countries is limited, especially at the medical school level; thus a specialty like neurosurgery, which is highly procedure heavy, naturally allows the least exposure to students for hands-on activity. Postgraduate societies have addressed this world over with hands-on workshops to supplement training,

Key words
- Hands-on
- Intracranial pressure monitoring
- Low-cost
- Neurosurgery
- Undergraduate neuro conference
- Workshop

Abbreviations and Acronyms
ICP: Intracranial pressure

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such as cadaveric dissection courses. Technologic advances have led to expensive simulators that closely mimic surgery, even providing haptic feedback. If provided early at medical school, such exposure can empower individuals to make important professional decisions. However, as previously stated, not every medical school neurosociety is in a position to provide hands-on workshops. One reason for this is the lack of financial support to afford expensive simulators. This is even more of an issue in the developing world.

Neurosurgical training simulator "Rowena heads" are recognized as gold standard equipment providing hands-on simulation for various neurosurgical procedures. These heads are used worldwide by professional bodies for conferences and hands-on workshops but are expensive.[4] To facilitate the provision of a hands-on workshop, especially for student societies, the authors describe their method of manufacturing a low-cost skull model, which they have made using locally available materials and used at a clinical workshop on ICP monitoring, 14th Health Asia Conference Lahore 2018, and 2 international conferences: 1) International Conference on Recent Advances in Neurotraumatology (ICRAN) 2019, primarily attended by resident neurosurgeons and young international consultants and 2) Glasgow Neuro International Conference 2021, primarily attended by medical and neuroscience students and prespecialty training junior doctors in the United Kingdom.

MATERIALS AND METHODS

Materials required:

1. Calvarium model (preferably with cranial suture markings)
2. Children's play slime
3. Plaster of Paris
4. Plastic measuring jug and large plastic bowl
5. Small-sized plastic bin/trashcan bag
6. Plywood square board
7. Apron and hand gloves
8. Access to kitchen workspace and sink
9. Hammer and small thin screws
10. Standard drill

Figures 1 and 2 summarize, with illustrations, the process of assembling the skull models. A standard small-sized bin/trashcan plastic bag should be placed within the interior of the calvarium; this will mimic dura within the final model. Slime should be emptied into the bag while it is placed inside the calvarium, as this will partly lead to the slime adapting and distributing around the calvarium's geometric contours. We recommend that the bag be filled to 90%–95% of the calvarium's edge and closed and knotted. This is because, as seen in Figure 1E, when the slime-filled bin bag is initially placed in the calvarium, it will not uniformly adapt to the geometric contours and may be partly out with the calvarium; leaving some space within the bag will then mean one can use his or her hands to gently press down on the bag (and the contained slime) against the surface of the calvarium to ensure it levels off at the surface height and is adapted to the shape of the calvarium.

Plaster of Paris should be made into paste form per the manufacturer's instructions in a plastic bowl using water. Caution needs to be exercised, and manufacture instructions should be diligently followed. Initially, when water is first

Figure 1. Procedure for building a single skull model.

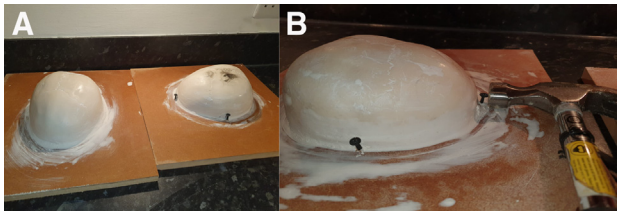

Figure 2. Skull models in their near-final form with screw placement. (**A**) The calvarium model was flipped on the plywood board with semi-solid plaster of Paris paste covering the underside and containing the slime within the plastic bag. As the paste hardens, it expands and pushes the bag cranially towards the roof of the cranial vault, holding it firmly in place. The edges/rim of the model in contact with the plywood board is strengthened by adding a layer of Plaster of Paris paste that hardens, forming a weak seal. (**B**) Uniformly drilled screws along the model's edges hold it in place firmly. In case of a gap between screw and model due to manual inaccuracy of the screw trajectory, this gap can be reduced with a hammer.

mixed, a liquid consistency is formed, tempting the fabricator to add more powder. However, this should be avoided as the mixture becomes a paste within a matter of minutes and a solid soon after; therefore adding too much powder will render the paste unusable.

While still in paste/semisolid form, as it is hardening, a layer should be generously spread above the plastic bag, on the underside and rim of the calvarium. **Figure 1G** shows a generous blob of plaster of Paris placed on top of the slime-containing bin bag. This paste is then spread evenly to ensure the entire plastic bag on the underside is covered, as shown in **Figure 1H**. The calvarium's underside is immediately flipped onto the plywood board. As the plaster of Paris paste changes from semisolid to solid consistency, the mixture expands and pushes the slime-containing plastic bag cranially to the roof of the cranial vault and holds it in place pressed up, preventing the bag from sagging caudally and therefore the need to make readjustments. A thin layer of paste is then added along the edges of the calvarium in a circular fashion where it touches the plywood board, as this forms the first seal to hold the calvarium in place. This is shown in **Figure 2A**. Two to 3 individuals are required to make a single skull comfortably. Unless more are present, the plaster of Paris mixture should be synthesized in small quantities to make the skull model serially, not simultaneously, as the plaster of Paris mixture rapidly turns from paste to solid; therefore it is likely that any excess Paris in the plastic bowel will turn solid while the first skull model is being made, preventing the remaining mixture from being used for subsequent skull models.

The initial seal made by the paste around the rim of the calvarium is weak and can be broken down by water. It is reinforced by screws that are drilled symmetrically along the edges of the calvarium to hold the skull firmly in place on the plywood board. Once drilled in, if any screw is inaccurate in that it is not in contact with the edge of the calvarium on the plywood board (as seen in **Figure 2B**), then a hammer should be used to reduce the gap. This is important as during an intracranial pressure monitoring workshop, which requires drilling into the model, the skull needs to be perfectly firm in its place. We recommend using between 4 and 6 screws per skull.

Any remaining thin layers of plaster of Paris on the plywood board or the exterior surface of the calvarium should be cleaned with a sponge soaked in warm water and dish cleaning liquid to facilitate removal for neatness's sake. Plastic aprons and gloves should be appropriately disposed of. Skulls should be manufactured at least 2 days before the event as this is the time to allow the plaster of Paris to harden fully. In our experience, they should be manufactured no more than 4 days in advance as the plaster of Paris seal around the edge of the calvarium can begin to brittle. This, however, may not be an issue as screws firmly hold the calvarium onto the plywood board. Constructing 5 calvarium models took 3 individuals 2 hours to make.

DISCUSSION

Individual calvariums were purchased from Pakistan and cost 2500 PKR or approximately US$14. A similar high-quality calvarium with anatomic landmarks including the coronal suture can be sourced within the United Kingdom for GB£30 or US$40. We purchased a large leftover plywood board from our local B&Q, which is a Do-It-Yourself Shop for a total of GB£5 (US$6.7) and cut this into 5 square boards. A 2.5-kg bag of plaster of Paris and excess slime were purchased for a total of GB£20 (US$26.6). However, these prices may vary locally, and cheaper items can be sourced online. As a society, we spent nearly GB£100 or US$134 to equip ourselves with 5 skull models and hence 5 stations for the Glasgow Neuro 2021 Conference held at the Royal College of Physicians and Surgeons of Glasgow. A 20-minute preworkshop lecture was delivered by Professor Naveed Ashraf, which touched not only the pathophysiology of raised ICP and its sequalae but also the theory behind ICP monitoring and described the technique of ICP catheter insertion with the help of sequential pictures and videos. The workshop accommodated 55 students and junior doctors. We divided delegates into 2 groups of 18 and 1 group of 19. The workshop was conducted over 2 hours with groups of 18 rotating between lectures and workshops of 40 minutes each. In a single 40-minute session, there were 18 delegates split into groups of 3 or 4 around each of the 5 skull models. All delegates had ample time to drill into our skull models, place the ICP bolt, inser the probe, and ask questions to facilitators. Consultant neurosurgeons or senior residents crewed each station. Delta Surgical kindly supported this event and provided cranial access kits, ICP bolt screws, and ICP catheters. **Figure 3** illustrates our setup on the day of the conference.

A similar setup was implemented at ICRAN 2019, with the main difference being that the majority of delegates were interns and junior neurosurgical residents. Spare ICP bolts and cranial access kits were acquired from our neurosurgery department for this workshop. On both occasions, the overwhelming feedback highlighted to conference organizers that our hands-on ICP monitoring workshop was of great help to students and junior doctors. Junior doctors going into neurosurgery expressed that the workshop had increased their

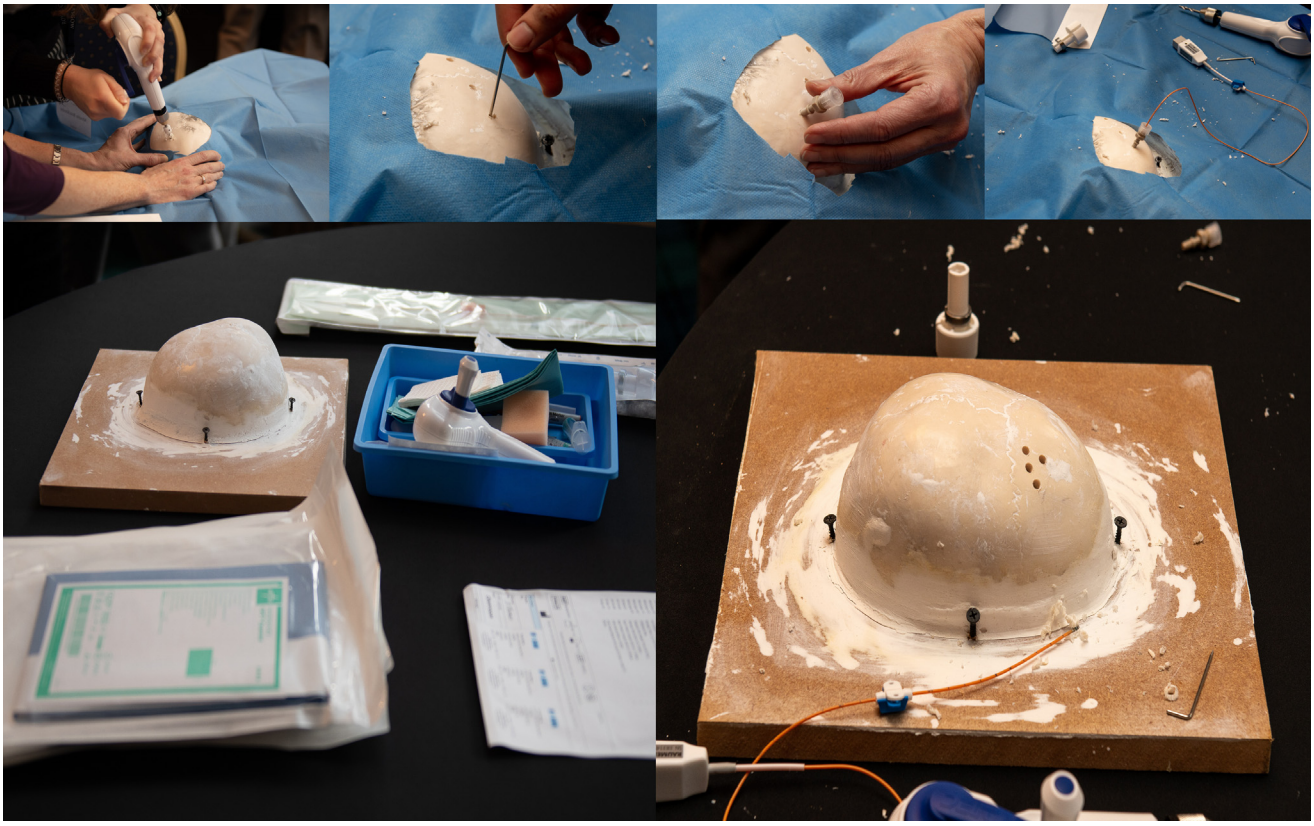

Figure 3. At the workshop, our skull models with intracranial pressure (ICP) monitoring in action. In the top row, for simulation purposes, the model was covered by leftover surgical drapes and a delegate is seeing using the dural puncture and placing ICP bolt and catheter. The bottom row shows the setup on the table itself.

exposure to the procedure and improved their confidence in performing it independently in person.

Similarly, in feedback, medical students, especially those without prior exposure to neurosurgery, indicated the hands-on workshop to be the highlight of the conference, stating it had improved their interest to further explore neurosurgery as a career option, citing the sophisticated parameters and detailed investigations such as ICP monitoring in neurosurgery as reasons for attraction. These participants were generally unaware of the vast, sophisticated investigations in the armamentarium of neurosurgeons. Consultant neurosurgeons and senior residents commented that the plastic bin bag closely mimicked dura and that slime served as adequate material to mimic brain tissue while carrying out the probe insertion.

CONCLUSION

Our model provides a cheap alternative that can easily be made by students/societies with limited resources but still simulate a high-quality, hands-on workshop. While the use of an expensive simulator can be obviated, however, support from one's local neurosurgery department to facilitate such a workshop is essential, and cranial access kits and ICP monitoring equipment is required, which can be from a relevant sponsor or spare equipment by a neurosurgical department.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Mohammad Ashraf: Made and conceptualised skull models and wrote the manuscript. **Naveed Ashraf:** Made and conceptualised skull models.

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Conflict of interest statement: Delta Surgical equipped each of the five stations with cranial access kits and their ICP bolt and probes. No monetary support was recieved.

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