

Simulation of Postpartum Hemorrhage Maneuvers Using an Educational Biomodel for Low-income Countries

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Abstract: A key challenge in clinical teaching is to create alternative environments due to restricted access to rare emergency practice settings, such as postpartum hemorrhage (PPH). Similarly, difficulties have emerged not only in representing biomodels but also in ensuring maneuver performance, considering components and their ability to replicate sensations akin to those felt by the affected tissues. A research initiative was launched to improve the training of healthcare personnel in low-level care facilities and educational institutions on the management of PPH, given that it remains a significant cause of maternal mortality globally. Consequently, doctors must develop proficiency in handling such emergencies. Hence, the research was conducted to create solutions tailored to local resources, minimizing the reliance on external technology through a collaborative approach between medicine and industrial design. The investigators focus on creating experiences and perceptions through three key components: first, aligning student skills and situations with emergency protocols and the medical curriculum; second, incorporating convergence technologies for emergency procedures; and third, employing a phantom model of a female body segment to facilitate maneuvers related to PPH, named 4T (tone, tissue, trauma, and thrombin). Methodological research conducted in the early stages of creating an intermediate-fidelity clinical simulator highlights the importance of input from a multidisciplinary team. Initially, the review of the literature identified various materials and feasible biomodels suitable for training exercises. Subsequently, the authors outlined the essential requirements for the physical element. Following this, they developed biomodels that integrate diverse shapes and materials to replicate the conditions encountered in obstetric interventions. Employing an iterative approach in conjunction with digital and hybrid manufacturing technologies from our institutional laboratories, the prototype was refined to mimic material perceptions. The next study phase will explore whether the model can enhance teaching and learning in various applications. Due to the high cost of detailed anatomical models, the research proposes an affordable, mid-level fidelity biomodel using digital manufacturing with elastomeric materials. However, our PPH biomodel needs to be improved for testing with medical students at the Universidad Industrial de Santander, to validate their skills safely.

Keywords. Postpartum Hemorrhage, Clinical Simulation-based Education, Additive Manufacturing, Biomodel.

1. Introduction

Simulation-based medical education (SBME) is critical for safe and effective training in obstetric emergencies, where error-free practice is essential (Carriel & Ramírez, 2011). In low and middle-income countries, PPH accounts for up to 19.7% of maternal deaths (López-García *et al.*, 2017; Montañez *et al.*, 2022). Although codes like Colombia's "código rojo" systematize response (Navarro & Castillo, 2010), hands-on training remains limited by resource constraints.

Commercial simulators (e.g., SimMom by Laerdal®, Noelle by Gaumard®) are costly and complex to maintain (Riaz, 2019). Low-cost creative models using animal tissues, fruit, or textiles improve affordability but fall short in realism, hygiene, repeatability, or anatomical accuracy (Lunardhi *et al.*, 2024; Ramseyer & Lutgendorf, 2019; Knobel *et al.*, 2020). In clinical practice at the UIS, mannequin elastomeric components degrade easily, and textile substitutes fail to emulate tissue properties effectively.

To address these limitations, this study develops a conceptual framework to improve the training of healthcare based on aligning student skills and situations with emergency protocols and updating the medical curriculum; second, incorporating convergence technologies for emergency procedures; and third, employing a modular biomodel built with an accessible digital and hybrid manufacturing approach. The model aims to simulate tactile responses of human tissues, enable repeatable maneuvers aligned with the 4Ts (tone, trauma, tissue, thrombin), and support teaching in resource-limited educational settings, thereby enhancing preparedness in obstetric emergencies.

2. Methodology

An interdisciplinary team from design and medicine at UIS applied Design Thinking across five phases (Liedtka, 2015):

2.1 Phase 1: Empathize

Researchers observed simulation-based training sessions and conducted semi-structured interviews with medical students and health professionals (e.g., poor tactile realism and component fragility). In this phase, the researchers could recognize types of models for training simulation practices at the faculty, identifying deficiencies in existing models.

2.2 Phase 2: Define

A systematic review using the PRISMA guidelines on WoS and Scopus identified 353 articles (45 selected) on low-cost clinical simulators utilizing digital or elastomeric technologies, none of which specifically targeted PPH. CES EduPack-guided material selection compared tissue-like properties: human skin, muscle, and bone tensile strength and elasticity informed choices (Ashby, 2008). Anthropometric measures for anatomical realism were sourced (Clerico *et al.*, 2017; Kreklau *et al.*, 2018). PPH response protocols guided functional requirements (Fescina *et al.*, 2012; FIGO, 2022).

2.3 Phase 3: Ideate

According to the last phases, we develop a conceptual map based on the integration of products into the learning experience. Then CAD models were configured, representing the organs of the reproductive system, such as the components. The approach of this research included digital design for manufacturing CAD RP technologies, integrating molds of polymeric materials. In fact, in parallel, the experiment with elastomeric materials like latex and silicon was made.

2.4 Phase 4: Prototype

Using Rhinoceros®, prototypes were CAD-modeled and fabricated at I+3DLAB using FDM (ABS/TPU), SLA, and SLS machines (Molitch-Hou, 2018). Elastomeric material trials included alginate-gelatin composites, natural latex, Ecoflex 00-30 silicone, and reinforced screws for modular assembly. Material properties (σ_{ts} and $\% \epsilon$) matched tissue ranges for skin, muscle, and bone (Ashby, 2008): latex (0.5–3.5 KSI, 700–750 %), Ecoflex (0.2 KSI, 900 %), elastic 80A resin (1.291 KSI, 100–120 %), TPU (1.41 KSI, 327 %).

2.5 Phase 5: Evaluate

While full validation is pending, early iterations underwent informal clinical simulation feedback to assess realism, assembly, and tactile response.

3. Results

Observations revealed low-fidelity assemblages; we found that textile vulvas and uteruses allowed only generic maneuvers, suffered tears, lacked penetration resistance, and failed to mimic tone. Fiberglass torsos improved portability but compromised anatomical detail. Figure 1 shows the different models used to make the practice for PPH. On the left, a high-resolution mannequin combined with a low-resolution model made of fabric with low tactile and anatomical fidelity, adapted to represent the vagina and vaginal canal; on the right, it is a simulation-based training session with a medium and low-resolution mannequin made of fiberglass, involved with a dress to simulate the skin. The current models have low anatomical, tactile, and dimensional fidelity.



Figure 1: Examples of mannequin models for PPH practices are used in medicine.

Literature review confirmed scarcity of PPH-specific low-cost models, though other specialties used FDM plus silicone (Comeau *et al.*, 2020), hybrid manufacturing (Gillis *et al.*, 2020). Material criteria were quantitatively aligned with human tissue benchmarks; analogues were selected successfully with CES Edupack®. The material selection criteria (Ashby, 2008) were made, see Figure 2. Among the properties consulted to select tissues similar to muscles, in relation to the which is the ratio between the tensile capacity tensile strength (σ_{ts}) and the degree of stretching percentage of elongation ($\% \epsilon$) before breaking ($\sigma_{ts} / \% \epsilon$). Human skin has been emulated with silicone, while muscle has a represented with polyurethane or polyethylene foams. The manufacturing of polymers was shaped by moulding to catalytic mixtures, temperature control, or vacuum. As for human bone, it is emulated with similar polymeric filament materials such as PLA, ABS, and PEEK to be printed in FDM.

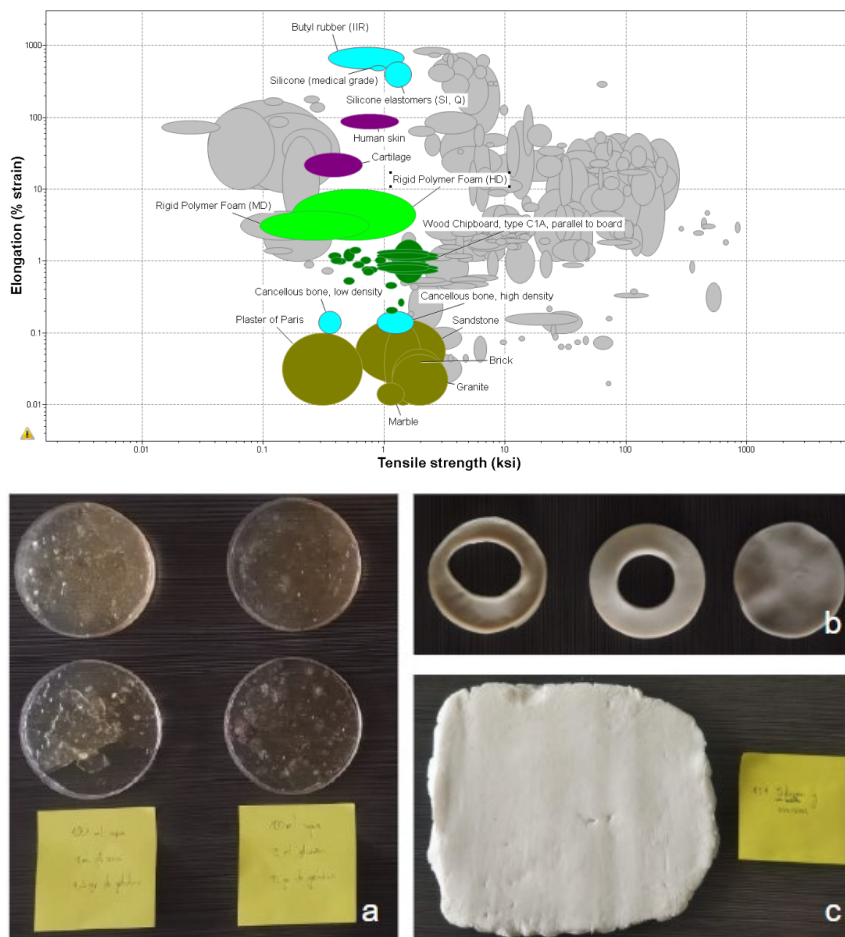


Figure 2: Preselection material by CES Edupack analysis and materials testing.

3.1 Development of the Biomodel

Develop a conceptual map based on the integration of products into the learning experience, composed of three moments configured with the key moments of the simulation strategy. 1-Prebriefing, involving the introduction and orientation before the simulation experience. 2-Briefing is a relevant scenario information just before the scenario begins. 3. Debriefing represented post-simulation analysis and post-simulation dialogue. The framework integrates two moments: The first one is a low-medium fidelity scenario, including a Hybrid Simulation configured with a Patient mannequin/simulator, a biomodel, and an Extended Reality Virtual and Augmented. The second one, high fidelity scenario, conformed to Product Hybrid Simulation by Patient mannequin/simulator biomodel.

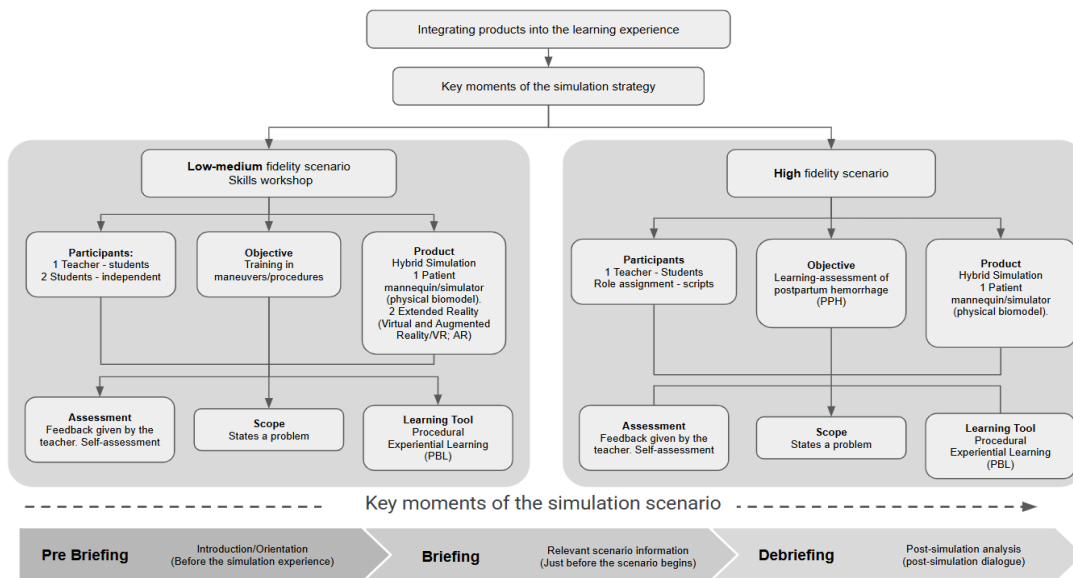


Figure 3: A framework of learning experience developed for teaching-based simulation.

Considering the process of design through the insights, CAD models of the reproductive system, such as the vagina and their canal, the cervix, and the uterus, were modeled. These design components featured a rigid PLA body with flexible elastomeric. CAD-printed rigid torso with layered latex overlays achieved realistic tactile behavior and modularity. Repeated maneuvers were feasible, with user feedback citing improved realism and durability over handcrafted versions durability see Figure 4.

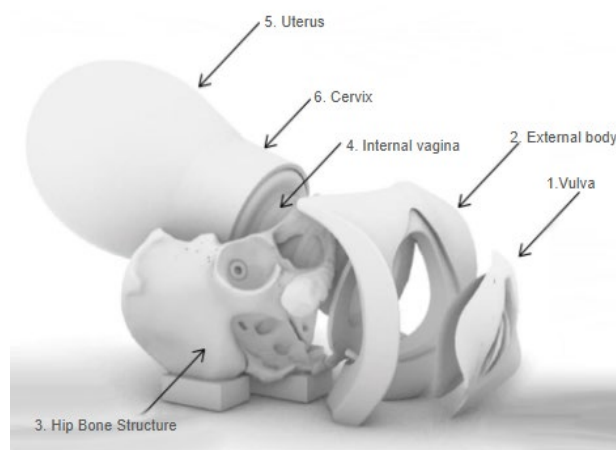




Figure 4: CAD and 3D printed model components, biomodels.

The material tests showed that alginate materials lacked stability. Natural latex and Ecoflex offered superior elasticity. Silicone molding introduced air bubbles and curing issues. ABS and TPU provided structural support.

Finally, early iterations by students in a clinical simulation scenario were made, and the feedback was oriented to assess realism perception by interaction, assembly, and tactile response, see figure 5.



Figure 5: First iteration of testing biomodel.

4. Discussion and Conclusion

This biomodel offers several advantages over low-cost artisan models: according to the initial feedback in testing, it provides more realistic tactile simulation, modular replaceability, and durability, all created with accessible materials and institutional manufacturing capabilities. Compared to commercial simulators, it is cost-effective and adaptable, making it ideal for low-resource contexts.

Material selection grounded and manufacturing synergies between additive and elastomeric molding (Goudie *et al.*, 2019; Koh *et al.*, 2021) demonstrated feasibility for complex, anatomically coherent models. The modular design supports simulation of the 4Ts sequence (Fescina *et al.*, 2012) with tailored replacement options, advancing over handcrafted or static designs.

Limitations include challenges in achieving homogeneous elastomer curing and mold integrity, and the absence of formal validation data. Future research must involve controlled trials comparing skill acquisition outcomes between this biomodel and commercial simulators, and explore sensor integration for objective feedback.

In conclusion, the proposed modular biomodel presents a **suitable**, **scalable**, and **contextually adapted** tool for PPH training. By leveraging digital manufacturing and material science aligned with user-driven design, it addresses limitations in existing educational tools and supports enhanced competency development in maternal emergency care.

Ethics Declaration

Ethical clearance was not required for this study, as no patient data or vulnerable populations were involved.

AI Declaration

AI tools were not used in the creation of this manuscript.

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