Advancing Biomimetic Skin Patch for Realistic IV Insertion Simulations: Mechanical Characterization andPerformance Evaluation

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Abstract. This research addresses the challenge of training intravenous (IV) insertion skills in Pakistan, where reliance on expensive silicone-based arm simulators or less realistic plastic manikins' limits access. It introduces a cost-effective artificial skin patch made from gelatin, gel wax, glycerin, a small amount ofsilicone gel, and pigment, designed to replicate the mechanical and physical properties of human skin. The patch is versatile in shape and size, and its mechanical performance was validated through tensile and puncture testing, demonstrating its ability to withstand forces similar to human skin. The patch showed minimal swelling (4.66%) and maintained structural stability under simulated conditions. Its hydrophobicity, with a mean contact angle of 95.66°, further supports its resistance to moisture. While the patch's tensile strength (0.04 MPa) is lower than that of silicone (0.12 MPa), it performed well in IV puncture simulations, withstanding 37 punctures compared to silicone's 50, achieving a 74% accuracy rate. This innovation represents a significant advancement in bio-simulation technology, providing a realistic and cost-effective alternative for medical training.

Keywords: Artificial Skin, Gelatin-Based Skin Patch, Biomaterials, IV Insertion, Cost Effective, Mechanical Characterization, Simulation-Based Education.

1 Introduction

1.1 Background

Approximately 30% of hospitalized patients receive intravenous (IV) therapy [1], but in Pakistan, there's a 20% infection rate due to improper IV insertions [2]. The success of IV insertion depends on the healthcare provider's skill, vein condition, and equipment quality. A major challenge is the lack of realistic training simulators [3]. Currentsimulators technologies have revolutionized the ways of teaching but often use costly, fragile artificial skin [4], which can result in unavailability leading to inadequate training and higher rates of failed insertions and complications. There's a critical need for cost-effective, durable artificial skin for simulators to enhance training, improve provider skills, and reduce patient complications and healthcare costs [5].

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1.2 Literature Review

The literature review focuses on the development of realistic artificial skin for medical simulation. Daly et al. (2017) explores gel wax for medical simulators, noting its limitations in durability and realism [6]. Dsouza et al. (2018) investigates smartphone technology to create realistic skin models, using elastomer polydimethylsiloxane [7]. Teyssier et al. (2019) develops a silicone-based artificial skin for on-skin interactions, emphasizing its realistic texture but noting high costs [8]. Gao et al. (2022) presents a synthetic skin model with self-nourishing and self-healing properties, using biocompatible materials, though it has limitations in water interaction and cost [9]. Sabak et al. (2022) and Hadidi et al. (2021) suggests homemade ultrasound phantoms for IV insertion training, using gelatin and psyllium, with limited realism and durability [10, 11]. Kim et al. (2023) develops a haptic-mixed reality system providing realistic tactile feedback for IV needle insertion, which is beneficial for nursing education [12]. Avkins' wearable simulator replicates a human arm for IV insertion practice, offering durability and realism [13]. The University of Florida's CSSALT (2023) creates a mixed-reality IV access simulator using 3D-printed materials, emphasizing portability and user friendliness [14]. Tian et al. (2024) developed an artificial skin model by converting elastomers into tough hydrogels via radiation-induced penetrating polymerization method, replicating the structural and mechanical properties of human skin [15]. This highlights the need for further research on cost-effective materials and techniques to create realistic artificial skin specifically for IV insertion training.

2 Material and Method

The synthetic skin patch is composed of gelatin, gel wax, glycerin, silicone elastomers, and color pigment. Gelatin provides structure and mimics the tactile feel of human skin, while gel wax enhances pliability and elasticity, allowing for realistic bending and stretching during simulations. Glycerin maintains moisture, and silicone gel improves the patch's mechanical stability. Color pigment is added to replicate natural skin tones for authenticity. The fabrication process involves mixing gelatin and gel wax, microwaving the mixture, adding glycerin for flexibility, and then incorporating silicone gel for stability. After adding skin color pigment, the mixture is poured into molds and left to solidify for 24 hours to ensure structural integrity (see Fig. 1).

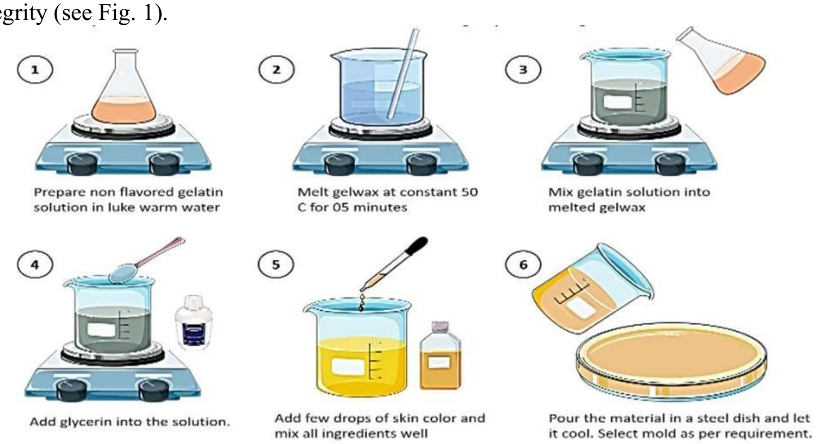

Fig. 1. Figure shows the whole fabrication process of the artificial skin patch.

3 Material Testing

The artificial skin was evaluated through several tests to ensure its effectiveness and durability **(see Fig. 2)**. In the swelling test, 5-gram samples were immersed in PBS solution, with mass recorded every 20 minutes to measure swelling and verify structural integrity. The contact angle test used "Image J" software to assess the hydrophobicity and wettability of the skin patches, measuring fluid repellency or absorption. The puncture test examined the skin's resistance to deformation under pressure with IV insertion syringes, comparing it to a silicone-based skin used in P50/1 by 3B Scientific simulator. Lastly, the tensile test measured the skin's elasticity and tensile strength using a tensile machine WDW-2M to evaluate its ability to stretch and withstand pulling forces without tearing, in comparison to silicone-based skin.

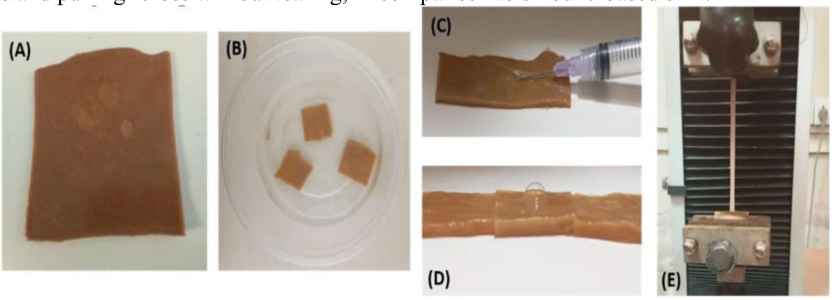

Fig. 2. (A) Formulated skin patch (B) Swelling test on three samples (C) Puncture test (D) Contact angle test (E) Tensile test

4 Results and Discussion

In the **Swelling Test**, the patch swelled by an average of 4.66% over 120 minutes, demonstrating minimal fluid interaction and structural stability (see Fig.3A). The **Contact Angle Test** showed an average angle of 95.67°, confirming its hydrophobic nature, which helps maintain material integrity by preventing excessive fluid absorption (see Fig. 3B). The **Puncture Test** revealed that the patch could withstand 37 punctures compared to 50 for silicone-based skin, yielding a 74% accuracy rate relative to the commercial product, making it durable and cost-effective for training. Lastly, the **Tensile Test** indicated that while the patch had a lower tensile strength (0.04 MPa) (see Fig. 4A) than silicone skin (0.12 MPa) (see Fig. 4B). Despite its lower tensile strength, our skin patch shows promise for IV insertion simulation due to several factors. The gelatin's softness and flexibility closely mimic human skin's texture and pliability, crucial for realistic training. The lower tensile strength allows the material to deform and accommodate the needle’s entry, improving the simulation’s accuracy. The gelatinbased skin meets essential simulation requirements, such as needle handling and catheter placement, providing a realistic surface and adapting well to insertion forces.

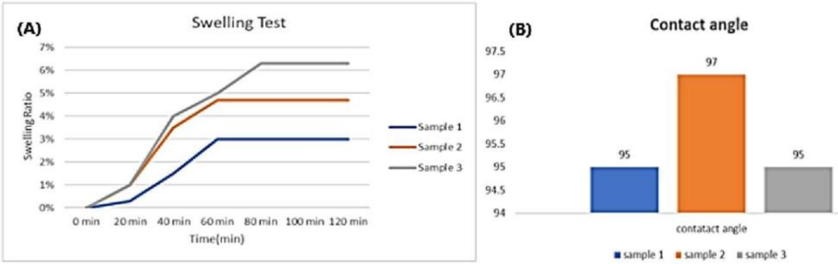

Fig. 3. (A). The Swelling Test result graph showing samples swelled by 3%, 4.7%, and 6.3% respectively **(B)** The contact angle result showing samples with 95°, 97° and 95° of contact angles

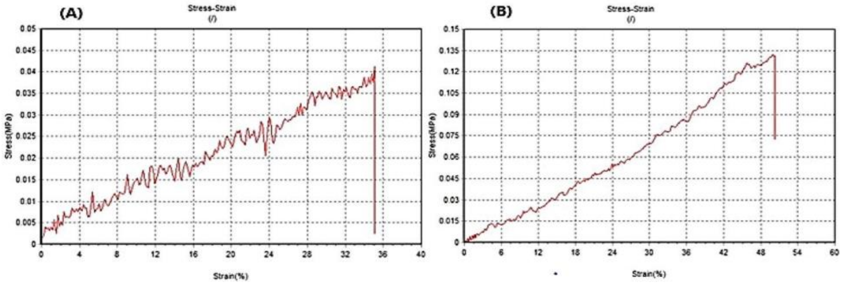

Fig. 4. (A) Tensile test result of our skin patch**. (B)** Tensile test result of silicon skin patch.

4.1 Cost Analysis

The cost-effectiveness of the gelatin-based skin patch is emphasized through a cost comparison with commercial silicone-based patch [16], as shown in Table 1. Both patches have an area of 69.44 square inches, with the gelatin-based patch reducing costs by 97.7%, showcasing its economic advantage while maintaining realistic performance in IV insertion simulations. Table 2 compares the test results of the synthetic gelatinbased skin patch and the silicone-based skin of P50/1 IV injection arm simulators by 3B Scientific, confirming that the primary goal of creating an affordable patch has beenachieved. While the gelatin-based patch may not perfectly replicate all properties of a silicone-based patch, it provides a cost-effective balance that meets training needs.

Table 1. Cost Comparison between formulated skin patch and existing silicon-based patch

Gelatin-Based Patch	
Total cost of ingredients	PKR 1,620 (approx. $5.81)
Cost per gelatin-based patch	PKR 540 (approx. $1.94)
Cost per square inch	PKR 7.77 (approx. $0.028)
Silicon-Based Patch	
Cost per silicone-based patch	$60
Cost per square inch	$0.864

Table 2. Results comparison between formulated skin and silicon-based skin

	Gelatin-based Patch	Silicon-based Patch
Punctures	37	50
Contact angle	95.67º	101.65º
Swelling ratio	4.66%	2.25%
Ductility	35%	49.5%
Tensile Strength	0.042 MPa	0.125 MPa
Strain	35	49.5
Load Bearing	2.91 MPa-in^2	8.66 MPa-in^2
Youngs Modulus	0.001 MPa	0.002 MPa

5 Conclusion

The study aimed to develop a cost-effective and realistic artificial skin for IV insertion training, showing significant potential for medical applications. Although commercial products outperform fabricated skin, the synthetic material offers sufficient durability and cost-effectiveness for training. The tensile test results confirm the material's ability to stretch and withstand pulling forces, mimicking human skin's elasticity and mechanical behavior. This research could enhance healthcare providers' training, leading to better patient outcomes and reduced complications. However, to meet training standards, qualitative feedback from medical professionals is needed through surveys with participants from various medical and nursing institutes. Future research should focus on improving the fabrication process for better durability and cost reduction, exploring alternative materials and methods, and conducting long-term studies to ensure the synthetic skin's reliability and effectiveness in different training conditions.

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Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Nosocomial Bacteremias Associated with Intravenous Fluid Therapy -USA. www.cdc.gov.
2. Ahmed, B., Khan, I., Beg, M.: Frequency of Central Venous Catheter Related Infections and their Culture and Sensitivity Pattern. 2012.
3. Lateef, F.: Simulation-based learning: Just like the real thing. Journal of Emergencies, Trauma, and Shock 3(4), 348 (2010).
4. Işık, B., Kaya, H.: The Effect of Simulation Software on Learning of Psychomotor Skills and Anxiety Level in Nursing Education. Procedia Social and Behavioral Sciences 116, 3864–3868 (2014).
5. Ravik, M., Bjørk, I.T.: Influence of simulation and clinical settings on peripheral vein cannulation skill learning in nursing education: A qualitative study. International Journal of Nursing Studies Advances 5, 100123 (2023).
6. Daly, R., Planas, J., Edens, M.: Adapting Gel Wax into an Ultrasound-Guided Pericardiocentesis Model at Low Cost. Western Journal of Emergency Medicine 18(1), (2017).
7. Dsouza, R., Spillman, D.R., Barrows, S., Golemon, T., Boppart, S.A.: Development of a

Smartphone-Based Skin Simulation Model for Medical Education. Simulation in Healthcare 16(6), 414–419 (2020).

8. Teyssier, M., Bailly, G., Pelachaud, C., Lecolinet, E., Conn, A., Roudaut, A.: Skin-On Interfaces. Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (2019).
9. Gao, X., Su, J.-F., Wang, S., Yang, P.: Smart Self-Nourishing and Self-Healing Artificial Skin Composite Using Bionic Microvascular Containing Liquid Agent. Polymers 14(19), 3941 (2022).
10. Sabak, M.: Homemade Phantoms Improve Ultrasound-Guided Vein Cannulation Confidence and Procedural Performance on Patients. Turkish Journal of Trauma and Emergency Surgery (2022).
11. 20. AI-Hadidi, A.I., Amine, M., Batman, A., Hakmeh, W.: Homemade Cardiac and Vein Cannulation Ultrasound Phantoms for Trauma Management Training in Resource-Limited Settings. Avicenna Journal of Medicine 11(1), 42–45 (2021).
12. J. W. Kim, J. Jarzembak, and K. Kim, "Bimanual intravenous needle insertion simulation using nonhomogeneous haptic device integrated into mixed reality," *Sensors*, vol. 23, no. 15, p. 6697, 2023.
13. Wearable IV Simulator | IV Simulation for Nurses Avstick. (n.d.). Avkin.
14. “IV access simulator,” *University of Florida Health*. Available: https://simulation.health.ufl.edu/technology-development/augmented-reality-mixed-simulation/iv-access-simulator/.
15. Y. Tian et al., "Connective tissue inspired elastomer-based hydrogel for artificial skin via radiation-induced penetrating polymerization," *Nature Communications*, vol. 15, no. 1, pp. 1–10, 2024.
16. “Anatomy Lab Venipuncture Pad,” Anatomy Warehouse.