DEVELOPMENT OF A REPAIRABLE DERMAL LAYER FOR VENIPUNCTURE PHANTOMS

ANDRÉS MINTE VALDERRAMA
DESIGN PROGRAM, FACULTY OF ARCHITECTURE AND URBANISM, UNIVERSIDAD DE CHILE

ANDREA WECHSLER PIZARRO
FACULTY OF DESIGN, UNIVERSIDAD DEL DESARROLLO, CHILE
CENTRE FOR INNOVATION IN TECHNOLOGY AND DESIGN OF MATERIALS FOR THE BUILT ENVIRONMENT – CIMAC_ANID CTI250005

PABLO DOMÍNGUEZ GONZÁLEZ
DESIGN DEPARTMENT, FACULTY OF ARCHITECTURE AND URBANISM, UNIVERSIDAD DE CHILE
CENTRE FOR INNOVATION IN TECHNOLOGY AND DESIGN OF MATERIALS FOR THE BUILT ENVIRONMENT – CIMAC_ANID CTI250005

RECEIVED: OCTOBER 15, 2025 // **ACCEPTED:** JANUARY 13, 2026

THIS ARTICLE PRESENTS THE RESULTS OF AN INTERDISCIPLINARY PROJECT FROM THE UNIVERSITY OF CHILE, INVOLVING ITS SCHOOLS OF DESIGN AND NURSING. THE PROJECT AIMED TO DEVELOP A BIODEGRADABLE, REPAIRABLE SKIN LAYER THAT MIMICS HUMAN SKIN FOR USE IN VENIPUNCTURE TRAINING PHANTOMS. A SKIN-LIKE MATERIAL WAS DEVELOPED USING A HYDROCOLLOID MATRIX RICH IN CALCIUM CARBONATE. FOUR FORMULATIONS WITH THIS BINDER WERE DEFINED BY VARYING THE PERCENTAGE OF EACH COMPONENT AND THE ORGANIC LOAD. THESE MATERIALS WERE THEN CHARACTERIZED BY EVALUATING THEIR DENSITY, MOISTURE CONTENT, AND REPAIRABILITY. THE USER PERCEPTION OF THE MATERIAL WAS THEN VERIFIED BY NURSING STUDENTS AND TEACHERS. THIS VERIFICATION TOOK PLACE DURING A REAL TEACHING EXPERIENCE INVOLVING SIMULATED VENIPUNCTURE ROTATIONS, USING THE PHANTOM DEVELOPED FOR THE UNIVERSITY OF CHILE SCHOOL OF NURSING. THE TEST RESULTS SHOWED THAT THE NEW DERMAL LAYER IS MORE SIMILAR TO HUMAN SKIN THAN THE CURRENTLY USED RUBBER SILICONE. IT ALSO PROVED TO BE REPAIRABLE THROUGH DILUTION WITH WATER AND IS BIODEGRADABLE.

KEYWORDS: CLINICAL SIMULATION, VENIPUNCTURE, SKIN SIMULATOR, REPARABILITY, HYDROCOLLOIDS

INTRODUCTION

In a context where clinical simulation through repeated practice in a safe environment is an essential learning method for training healthcare professionals, the use of manikins is essential. Phantom models are devices that simulate human morphology for practicing various clinical procedures, increasing safety, and acquiring clinical skills before interacting with real patients (Armijo-Rivera et al., 2021; Contreras et al., 2021; Dagnino, 2025; Sambuceti Núñez, 2016). Simulation provides a space in which students can be taught various procedural scenarios, offering the possibility of active feedback in practice.

Venipuncture phantoms and simulators are usually composed of three main layers: dermis, veins, and hypodermis. Each of these layers has unique characteristics that are complex to simulate. This particular article will focus on the analysis of the dermis.

Among the most suitable materials for manufacturing phantoms are elastomers, such as silicone rubber, due to their mechanical and rheological properties (elasticity, viscoelasticity, flexibility), their resistance to high temperatures, chemical agents, and other external agents, along with their similarity to human skin when manipulated in basic clinical-surgical procedures such as punctures, sutures, and incisions.

Similarly, certain substances such as gels, gelatins, collagen, ballistic soaps, and polyvinyl alcohol (PVA) have been identified as suitable for replicating various physical and mechanical properties of human tissue due to their ability to interact with water and other components (Dabrowska et al., 2016); however, these materials tend to have less structural stability than silicone rubber, tending to break and crack, which limits their potential use in phantoms (Read et al., 2024).

When silicone rubber is repeatedly subjected to puncture procedures, it shows damage that significantly reduces its useful life. The accumulation of punctures in the device without replacement causes total deterioration of the dermal layer to the point of material failure, as shown in Figure 1. It should be noted that the two-component manufacturing process used for these materials makes them difficult to repair, recover through recycling, and degrade over the long term.

On the other hand, the deterioration of the dermal layer not only affects economic areas but also affects the quality of student learning. The visible damage accumulated on the surface of the device allows previously made punctures to be identified, as shown in Figure 2, and the trajectory of the venous simulators under the skin surface to be easily located, thus reducing the complexity of training in venipuncture techniques and palpation of blood vessels. The current method for avoiding these situations is to replace the entire part every one or two years, due to the complexity of disassembly. In addition to being costly, these parts have to be imported from abroad (Zúñiga, 2024).

The above clearly highlights the need to identify the most suitable materials for creating a biodegradable, repairable, locally manufactured, low-cost skin layer for a disassemblable venipuncture phantom, in order to extend the phantom's useful life compared to current practice.

This study is part of a collaborative and interdisciplinary project between academics and students from the BioLab FAU Biobased Materials Laboratory and the School of Nursing, both at the University of Chile, with whom low-cost, disassemblable, and repairable manikins were developed for basic and intermediate venipuncture practice. Currently, the phantom and, consequently, the skin developed during this project are in the process of intellectual property protection.

This study was conducted within the framework of a bachelor's degree design research seminar, which imposed limited time periods. The research, therefore, focused primarily on testing functionality through direct user trials.

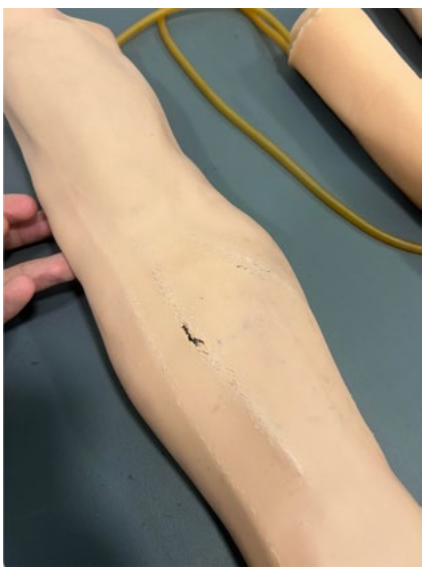

FIGURE 1. Breakage of the dermal layer due to accumulated punctures in phantoms used in practical exercises in nursing schools (own work).

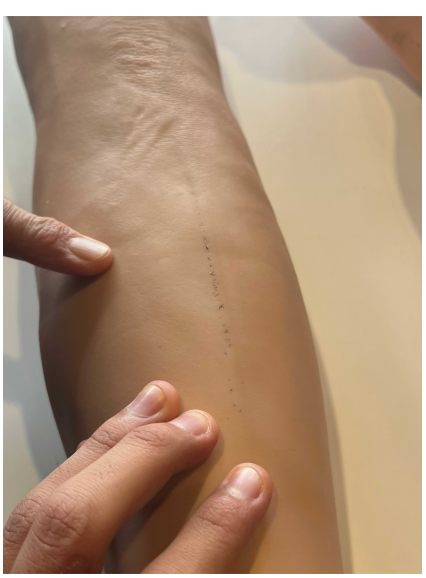

FIGURE 2. Puncture damage in phantoms used in practical exercises in nursing schools (own work).

METHODS

This project is approached from a user-centered design perspective. This approach seeks to identify the characteristics of who will use the product, how they will use it, and what needs this product should meet, to create more relevant and effective solutions. However, in situations where it is designed for a specific discipline, such as clinical simulation, interdisciplinary work is enriched by the experience of expert nursing users and technical design knowledge.

For the development of a repairable dermal layer simulator, the research is structured in two main stages. During the first stage, information was gathered on the properties of human skin needed for simulation; with this information, a material was selected, its density and moisture content were evaluated, and its repairability was determined. The material developed was validated in use by nursing students and teachers. After testing the material in isolation, its use was evaluated when installed in venipuncture phantoms developed in conjunction with the BioLab FAU team in simulation rotations with first-year nursing students.

MATERIAL SELECTION AND CHARACTERIZATION

To begin with, a selection of potential materials was made to be used as skin layer simulants. Through an exhaustive literature review, various factors were considered for the exploration of materials. First, information was gathered on the characteristics and physical properties of human skin, specifically the first layers of the dermis (epidermis, dermis, and hypodermis), in order to narrow down the search in material banks and compare the results with the properties of previously explored materials.

A base material was selected whose main component is a water-activated hydrocolloid hydrogel, due to its ability to form semi-solid matrices that effectively replicate the strength, elasticity, and tactile response of human dermis. This hydrocolloid was chosen specifically for its repairability, ease of manufacture, potential for local production, and low environmental impact. These characteristics are particularly relevant in the context of developing sustainable, low-cost medical simulators. Several studies have demonstrated the technical feasibility and experimental viability of working with this type of material, highlighting its versatility in the design of soft composites of biological origin (Barros Milla, 2021; Inostroza Muñoz, 2021). The use of natural binders such as alginate, in combination with organic or mineral waste reinforcements, has been widely explored as a functional alternative to synthetic materials, both for its mechanical properties and for its aesthetics and sustainability (Cantuarias Brañes, 2021; Núñez Herrera, 2021). Furthermore, research such as that conducted by Canales (2020) has validated the potential of reinforced plant compounds for applications that require flexibility, strength, and an appearance similar to natural tissues, reinforcing their relevance in the development of skin layers for medical phantoms.

The base formulation used in this study was adapted from an open-source development proposed by Canales (2020), whose objective was to create bio-based materials with an appearance and behavior similar to natural leather. This formulation uses sodium alginate as the main binder, glycerin as a plasticizer with softening properties, olive oil as a secondary plasticizer and preservative, and purified water as a diluent to promote the formation of hydrogels. In addition, it incorporates an organic filler in the form of pulverized tomato peel, intended to add texture, body, and aesthetic properties to the material.

For the specific purposes of this study, the original formulation was adapted and coded as G1AC, maintaining the relative proportions of the components but replacing the tomato peel filler with powdered eggshell. This change is not only due to the local availability of the waste, but also to its mineral content, especially calcium carbonate, which acts as a natural gelling agent for alginate, eliminating the need to add external calcium. Additionally, eggshell provides a light color and texture that favors the visual and tactile simulation of human skin in clinical training contexts.

Based on this basic formulation, three experimental variants were designed with the aim of analyzing the mechanical, sensory, and aesthetic properties of the material, as well as its comparability with commercial skin simulators. In total, four formulations were tested: two without organic filler (G and GA) and two with eggshell filler (G1AC and G2AC). Formulation G contains no oil or filler, enabling evaluation of the binder's basic response when combined with glycerin and water. For its part, the GA variant introduces olive oil as a second plasticizer, without organic filler, to analyze its effect on the elasticity and preservation of the material.

As for the formulations with filler, G1AC maintains the original balance of proportions with 4% filler, while G2AC slightly increases the levels of glycerin and filler and reduces the water content to evaluate its effect on the density, strength, and tactile response of the material. These variations allow us to establish the individual and combined impact of the components on the performance of the simulator material. To ensure replicability and experimental consistency, all percentages were normalized to a total of 100%, as shown in Table 1.

The mixtures were prepared at room temperature, with variations between 15°C and 30°C. First, the components were weighed separately on a Kern FKB 6K0.02 precision scale. The liquid components were mixed first, followed by the gradual addition of the dry components to form a homogeneous, lump-free mixture. The mixtures were left to dry in an open rectangular mold under infrared light for 24 hours. After drying the samples and removing them from the molds, a layer of sealant was added to the underside of the material by rubbing a bar of beeswax diluted in almond oil, as can be seen in Figure 3. The sealant applied to the material studied was based on the open-source formulation for treating kombucha sheets (Bogers, 2020). After sealing the material, it was left to dry for 20 hours under an infrared lamp.

TABLE 1. FORMULATIONS DEVELOPED (OWN WORK, BASED ON *CANALES, 2020)

FORMULATION	SODIUM ALGINATE (%)	GLYCERIN (%)	OLIVE OIL (%)	PURIFIED WATER (%)	LOAD (%)
G	6	14	0	80	0
GA	6	12	2	80	2
*G1AC	5	11	5	75	5
G2AC	6	15	5	70	5

After preparing the specimens, the density and moisture content were measured according to ASTM D1037. The physical properties were compared with those of human skin (Agache & Humbert, 2004) and those of EcoflexTM Supersoft, an elastomer currently used for the development of phantoms (Smooth-on Inc., 2024). Physical tests were carried out on the four formulations, with five repetitions per formulation, using a digital foot gauge, a Kern FKB 6K0.02 precision balance, and a Binder ED115 drying oven.

The density of the developed materials was determined as follows: for each formulation, five specimens measuring 50 x 50 mm were prepared. Thickness measurements were taken at four points per specimen using a digital caliper; the mean value was used to compute the volume. Following mass determination, density was calculated according to the formula:

$$p = m/v \quad \text{p: Densidad (g/cm}^3\text{) m: Masa (g) v: Volumen (cm}^3\text{)}$$

The moisture content was calculated by placing the five 50 mm x 50 mm replicates per formulation, as shown in Figures 8a and 8b, in a drying oven for 24 hours at 100°C, documenting the initial mass of the sample and the final mass after drying. It was calculated using the following formula:

$$\%\ de\ c.de\ humedad = \left(\frac{(w_1 - w_2)}{w_2}\right)$$

w_1: Masa inicial presecado.
w_2: Masa final postsecado por 24 hrs.

FIGURE 3. Sealing of material (own elaboration).

REPAIRABILITY

Experimental methods were defined and applied to evaluate its repairability, understood as the material's ability to recover its visual and functional integrity after an intervention. The selection of these methods was based both on a literature review of previous experiences with hydrocolloid materials and on consultations with specialists in soft biomaterial design. The criteria considered for establishing a valid repair method included: the removal of visible marks, ease of execution for non-expert users, and affordability of the process in low-tech contexts.

The available literature in the field of sustainable biomaterial design indicates that hydrocolloid-based materials can be partially reactivated through hydration and the application of gentle heat (Barros Milla, 2021; Inostroza Muñoz, 2021). Along these lines, Cantuarias Brañes (2021) argues that reversibility is a key feature of what he calls soft architectures, in which reparable biogels play a central role. Furthermore, Canales (2020) highlights that the inclusion of organic waste as reinforcement in soft composites does not necessarily compromise the possibility of repair, provided that a cohesive and stable matrix is maintained.

Based on this background, experimental tests were designed with the formulations developed, using conditions that simulate typical damage in a clinical context. Two methods of applying purified water were tested: localized pouring (20 ml on the damaged area using a syringe) and submersion (10 seconds of complete immersion of the sample). Subsequently, the specimens were dried at room temperature and subjected to three levels of heat treatment using a domestic iron: no heat, minimum heat (100 ˚C), and medium heat (150 ˚C), to observe the effect of heat on the cohesion of the matrix and the possible reactivation of the binder. To systematize the experimental results, we applied a qualitative evaluation rubric. Each combination of water and heat application methods received a score between 0 and 1. A score of 0 was given to cases in which there was no removal of puncture marks or recomposition of the material; a score of 0.5 was given when partial repair of the damage was noted, even though visible scars remained on the surface; and a score of 1 was given in cases of complete repair, with no traces or perceptible evidence of the initial damage. This rubric made it possible to establish reproducible criteria for evaluating the effectiveness of different restoration methods, based on direct and objective observation of the treated sample.

VERIFICATION BY NURSING STUDENTS

To validate the developed material in use, 24 nursing students in their eighth to tenth semesters participated in the study. This approach provided accurate, contextualized assessments of the simulator's educational usefulness, realism, and performance in teaching environments (Armijo-Rivera et al., 2021).

Participants in this study signed an informed consent form for the collection of personal data, their responses, and the use of photographs for research purposes.

During the procedure shown in Figure 4, each student received a #22 and #18 gauge peripheral intravenous catheter, as well as a pair of nitrile gloves, and was instructed to perform a puncture procedure on two specimens made from the four formulated materials, simulating training conditions with a commercial phantom. This strategy of direct comparison between developed prototypes and commercial models meets the performance evaluation criteria proposed by Read et al. (2024). The attributes evaluated were texture, elasticity, palpability, and puncture of the material, dimensions considered fundamental for approximating the biomechanics of human skin. These properties have been extensively documented by Agache and Humbert (2004) as determinants in the sensory perception of the skin and its behavior in response to mechanical stimuli, and are essential for ensuring the realism of simulators. In this regard, Dabrowska et al. (2016) emphasize that the success of a simulator material lies not only in its objective physical properties, but also in its ability to generate subjective responses consistent with real clinical experience.

For data collection, a Likert scale questionnaire from 1 to 5 was used, where 1 represented the least similarity to human skin, and 5 represented the greatest similarity. The number 3 was considered the cutoff value, interpreted as a performance equivalence threshold, i.e., when the performance of the developed simulator does not present relevant functional differences with respect to the commercial standard (Read et al., 2024). In this case, Ecoflex™ Smooth-On Inc. (n.d., 2024) was chosen, a silicone elastomer recognized for its flexibility, resistance, and similarity to human soft tissue.

A statistical analysis of the results was performed using Graphpad's Prism software, in which the responses were analyzed by evaluation variable, in contrast to the constant response 3, which could mean that the variable to be evaluated does not differ from the commercial phantom.

VERIFICATION BY NURSING TEACHERS

According to Armijo-Rivera et al. (2021), the integration of specialized teaching teams in the validation processes helps to ensure that simulators are aligned with training objectives and international quality standards. The validation of the material by nursing teachers was carried out using the qualitative focus group technique. The focus group methodology is widely used in applied health research, as it enables the collection of rich qualitative information from interaction and discussion among participants with expert knowledge (Agache & Humbert, 2004). In this case, the application of two instances allowed for the incorporation of different teaching profiles: in the first, the head of the nursing school and a teacher specializing in adult patient simulation; and in the second, a larger group consisting of ten teachers, seven from the adult area and three from the pediatric area. This strategy allowed perceptions to be triangulated among professionals from different clinical areas, increasing the internal validity of the results (Dabrowska et al., 2016).

During both sessions, participants were asked to handle the four formulations and perform punctures with #22-gauge peripheral intravenous catheters, recording their comments audiovisually and through field notes. The choice of an observational and participatory method is in line with the recommendations of Read et al. (2024), who emphasize that direct qualitative assessment by experts provides more detailed information on the behavior of materials than purely quantitative analyses.

Subsequently, the records were analyzed using a thematic categorization process, complemented by a descriptive analysis of the scores obtained for each variable (texture, elasticity, palpability, and puncture) using GraphPad Prism software. The assessments were compared with a reference response 3, which represented the performance equivalence with the commercial phantom.

DERMAL LAYER VERIFICATION IN A PHANTOM

After evaluating the developed dermal layer in use, it was installed in the disassemblable puncture phantom developed by BioLab FAU, to be delivered to the School of Nursing at the University of Chile. Molding methods were explored in order to include vascular grooves or adapt to the three-dimensional shape of a phantom prototype; however, hydrocolloid material, being a material that dries through water evaporation, complicates molding with double curvatures. For this reason, for this study, the laminar dermal layer was manufactured and installed in the disassemblable phantom using a fitting system.

Twenty basic intravenous puncture simulation phantoms were manufactured (Figure 5). These phantoms are modular and feature a bio-based skin layer. They were tested in simulation rotations with first-year nursing students. During these rotations, the performance of both the developed material and the complete phantom was observed, and feedback was collected from students and teachers.

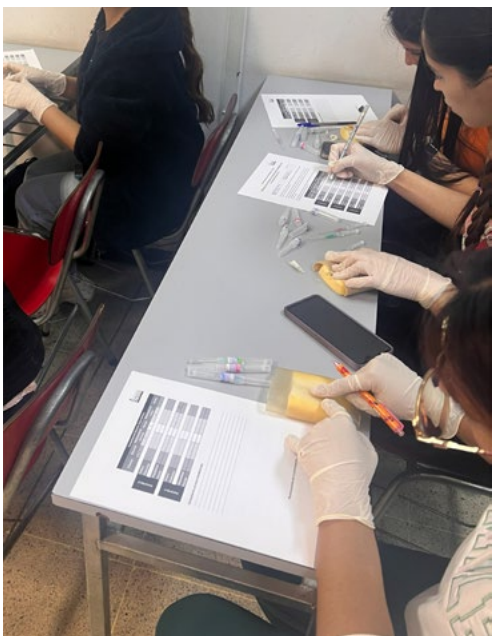

FIGURE 4. Dermal layer check with 7th and 8th semester nursing students (own work).

FIGURE 5. Phantom with a developed skin layer used during student rotations (own work).

RESULTS AND DISCUSSION

MATERIAL SELECTION AND CHARACTERIZATION

The results of the physical tests performed were compared with data on the characteristics of human skin taken from the research by Agache & Humbert (2004) and silicone rubber used in dermal layer simulation, EcoflexTM Supersoft from the US brand Smooth-on Inc., as can be seen in Table 2, Fig. 6, and Fig. 7.

In the density test, the formulations developed are approximately 24.8% denser than human skin, in contrast to Ecoflex, which is 11.2% less dense than human skin, as can be seen in Figure 6.

The moisture content analysis performed based on the procedure described in the test methods showed moderate variations between the formulations, mainly attributable to differences in the proportion of the binder base, as shown in Figure 7. Specimens with a higher presence of plasticizers tended to retain more water, while formulations with higher oil content and organic load presented lower percentages. In addition, Figures 8a and 8b show the optical differences between the samples before and after drying.

TABLE 2. SUMMARY OF PHYSICAL TESTS (OWN WORK)

FORMULATION	DENSITY (G/CM^3)	MOISTURE CONTENT (%)
G	1,4	21
GA	1,5	24
*G1AC	1,55	17
G2AC	1,58	23
Piel Humana1	1,2	-
EcoflexTM 2	1,1	-

Note:
[1] Human skin (Agache & Humbert, 2004)
[2] Ecoflex (Smooth-on Inc., n.d.)

DENSITY

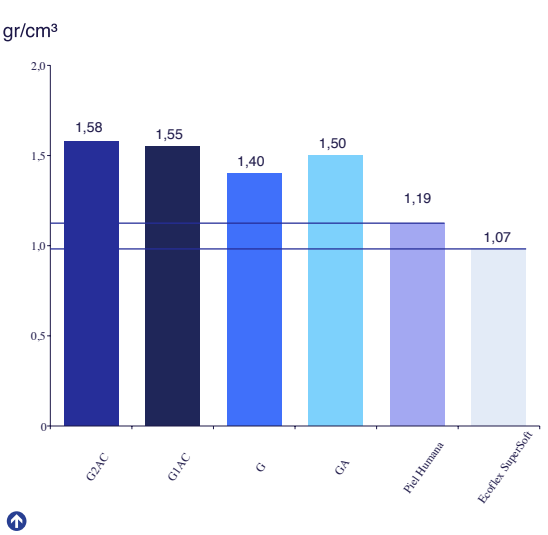

FIGURE 6. Comparative graph of formulation densities (own elaboration based on: Human skin 1, Ecoflex 2).

Note:

- *1 Human skin (Agache & Humbert, 2004)*
- *2 Ecoflex (Smooth-on Inc., n.d.)*

MOISTURE CONTENT

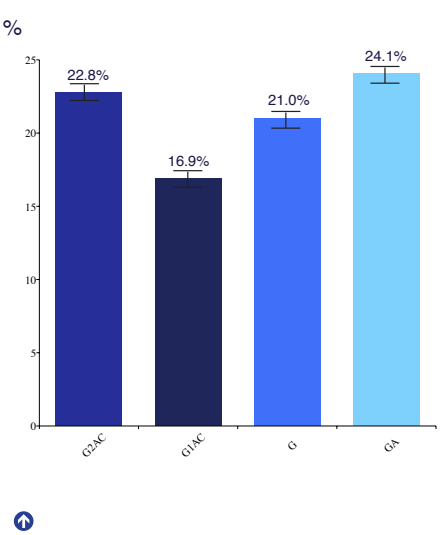

FIGURE 7. Comparative graph of the moisture content of the formulations (own elaboration).

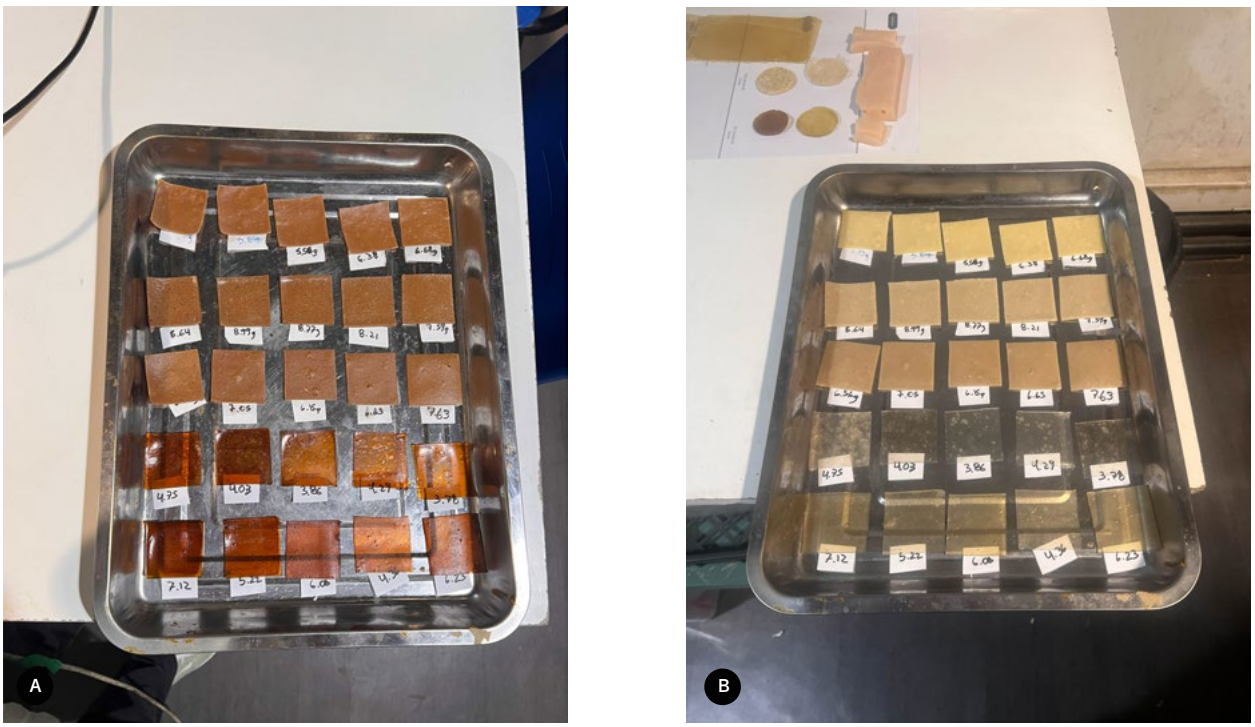

FIGURE 8A. Samples mixed for moisture content testing (own work), Figure 8B. Samples after moisture content measurement (own work).

REPAIRABILITY

The results of the repairability experiment are presented in Table 3.

The results obtained show that the 10-second immersion method allowed for a higher degree of repair compared to the localized pouring method, regardless of the type of formulation evaluated. This trend suggests that immersion, which provides uniform and intense hydration, optimally activates the sodium alginate binder, allowing it to reconstitute its structure.

In particular, formulation G1AC, which contains eggshell as an organic calcium filler, performed best under high temperature conditions (150 °C), achieving a rating of 1 (complete repair) under both hydration methods. This behavior could be explained by the presence of calcium carbonate in the eggshell, which acts as a natural cross-linking agent for alginate, allowing the material to maintain its integrity even after thermal stress (Cantuarias Brañes, 2021; Canales, 2020). The unfilled formulations (G and GA), on the other hand, showed greater dependence on the type of hydration: the pouring method was less effective in both cases, achieving only scores of 0 (no repair) in G, while the immersion method allowed for complete (1) or partial (0.5) repair depending on the temperature applied.

A common trend observed across all formulations was that applying heat at 150°C, in combination with the immersion method, was less effective than at 100°C, decreasing the repair score from 1 to 0.5. This suggests that excessive temperature can cause accelerated surface drying, preventing complete reactivation of the binder before the cohesion of the material is restored. This phenomenon has been described by Barros Milla (2021) and Núñez Herrera (2021), who warn that in hydrocolloid-based materials, heat application must be moderate to avoid surface crystallization or premature stiffness.

Another relevant finding is that formulations with fillers (G1AC and G2AC) maintained better overall performance in the heat, which could be due to the filler's ability to retain moisture and act as a thermal mediator. In contrast, formulation G, which contains neither oil nor filler, showed the most limited performance, being unable to repair itself under the pouring method even at controlled temperatures. This reinforces the importance of the multicomponent matrix in achieving stability, elasticity, and repairability in soft simulation materials, as also pointed out by Inostroza Muñoz (2021) and Cantuarias Brañes (2021).

In summary, these findings indicate that repair capacity is directly influenced by the combined effect of material composition, hydration method, and temperature. The data allow us to conclude that immersion followed by drying at a moderate temperature (100 °C) is the most efficient and replicable method for functional recovery of the material in simulated clinical use scenarios. This type of response favors its use in educational settings where frequent reuse and easy maintenance are required, as proposed in the design principles for sustainable bio-based materials (Canales, 2020; Núñez Herrera, 2021).

TABLE 3. REPAIRABILITY EXPERIMENT RESULTS (OWN ELABORATION)

	HYDRATION BY POURING DRYING TEMPERATURE			HYDRATION BY IMMERSION DRYING TEMPERATURE		
MIXTURE CODE	AMBIENT TEMPERATURE, NO PRESSURE	100°	150°	AMBIENT TEMPERATURE, NO PRESSURE	100°	150°
G	0	0	0	1	1	0,5
GA	0,5	0,5	0	1	1	0,5
G1AC	0,5	0,5	1	1	1	0,5
G2AC	0,5	0,5	0	1	1	0,5

Note:
0: No puncture marks were removed, and no material was recomposed.
0.5: Puncture repair was achieved; however, repair scars are visible on the material.
1: Complete repair of damage without scars is achieved.

USER TESTING WITH NURSING STUDENTS

For the verification instance with students, as can be seen in Figure 9, the evaluations of each variable yielded different results with a high standard deviation.

The results obtained during user validation with nursing students indicate that the formulations developed generally perform comparably to a commercial phantom, especially in terms of texture, elasticity, palpability, and puncture capacity. The dispersion observed in the responses, reflected in a high standard deviation, may be influenced by subjective variability in tactile perception among participants, a phenomenon widely documented in simulation studies (Dabrowska et al., 2016).

The fact that no statistically significant differences were observed in most of the variables evaluated suggests that the formulations achieved an adequate level of realism for educational purposes, which is consistent with the proposals of Read et al. (2024), who state that a simulator can be considered equivalent from a pedagogical point of view when it meets the minimum sensory perception required to perform procedures without compromising learning.

The exception found in the GA formulation, which was evaluated as having less similarity in the texture variable, may be due to the surface properties of the material, which are possibly less rough or more uniform compared to real human skin or the commercial phantom. According to Agache and Humbert (2004), the texture of human skin is influenced by multiple microstructural factors such as the thickness of the stratum corneum and the presence of dermal folds, which are complex to replicate in synthetic materials if not properly considered in the formulation process.

On the other hand, formulation G was rated as more similar to the commercial phantom in terms of palpability, which is a particularly relevant finding. This variable is related to the ability to perceive simulated internal structures (such as veins or vascular pathways), a critical feature in teaching venipuncture. This result could be linked to an appropriate combination of surface rigidity and material compressibility, as suggested by Dabrowska et al. (2016) in their analysis of the relationship between the multilayer structure of the skin and its response to pressure.

Furthermore, the use of Ecoflex™ as the base for the formulations evaluated may have contributed positively to the overall performance of the prototypes. This material has been widely used in the medical simulation industry due to its elongation capacity, low modulus of elasticity, and good tactile response (Smooth-On Inc., 2024). Their choice, therefore, aligns with technical and pedagogical recommendations for the development of realistic simulators.

USER VERIFICATION RESULTS

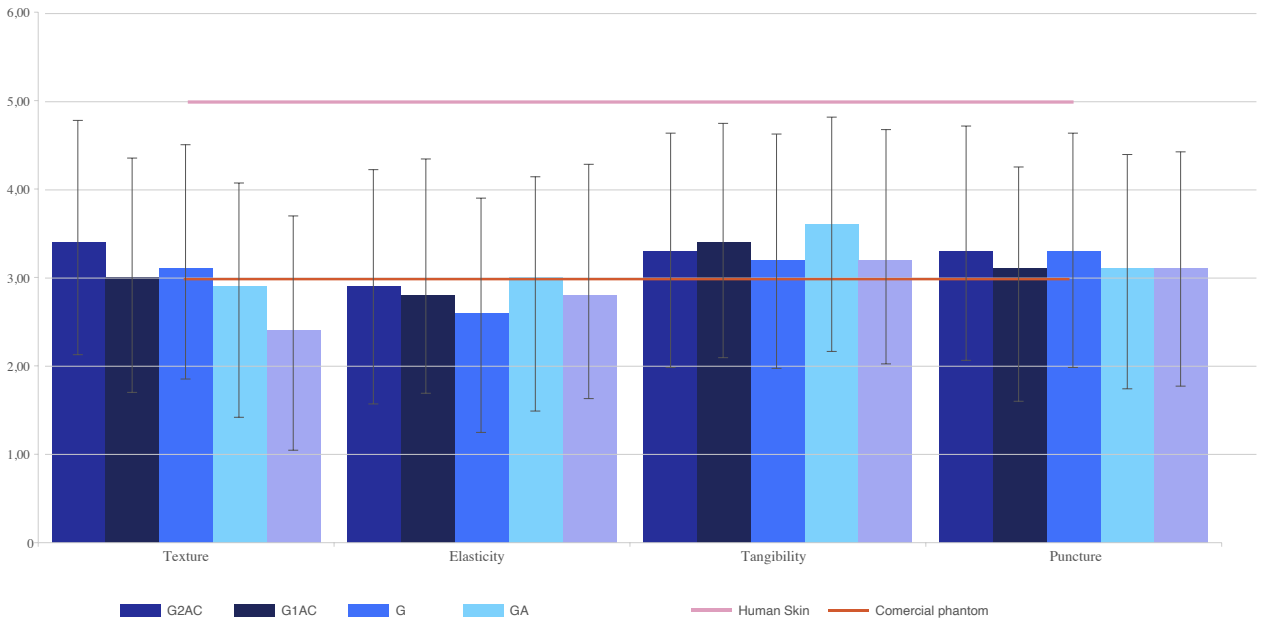

FIGURE 9. Summary of test results with students (own work).

VERIFICATION WITH NURSING TEACHERS

The comments obtained revealed clear perceptual differences between the formulations. The teachers agreed that the samples without organic filler (G and G1AC) felt "more plastic", while the formulations with organic filler offered resistance more similar to human skin during puncture. In particular, the G1AC formulation was identified as the most balanced in terms of texture, palpability, and mechanical response, a finding consistent with that reported by Smooth-On Inc. (2024) regarding the performance of silicone elastomers with additives that improve tactile sensation and pressure response.

DERMAL LAYER VERIFICATION IN A PHANTOM

During the verification rotations, it was observed that after puncturing the blood simulators, the artificial blood leaked to the surface, as can be seen in Figure 10.

Being an aqueous substance dyed with artificial colorants, the developed material turned red, rendering this dermal layer unusable at the end of the rotation. However, the course instructors continued to highlight the similarity of the material and its behavior to human skin.

FIGURE 10. Staining of post-puncture samples shows damage to the dermal layer when checked for use (own elaboration).

CONCLUSIONS

The research succeeded in developing a bio-based, repairable, and biodegradable skin layer designed to be integrated into a removable venipuncture phantom, to extend its useful life and reduce costs in educational settings. Through validation with nursing students and teachers, it was verified that the formulations achieved levels of tactile and functional realism comparable to commercial simulators such as those made of silicone rubber. The material in current development is in the process of being patented, demonstrating that it is highly innovative and differs from other phantoms on the market.

The results obtained confirm that the repairability of the developed material depends both on its formulation and on the activation method applied. Formulations with organic calcium fillers (such as G1AC and G2AC) demonstrated greater stability and recovery capacity, especially when immersion and drying methods were used at moderate temperatures (100 °C). These findings support the viability of using bio-based, repairable, and low-cost materials as functional alternatives to commercial phantoms in clinical simulation contexts.

In pedagogical terms, the research confirms that the joint participation of students and teachers in the validation processes favors a more comprehensive evaluation of the simulator. This mixed methodology can be replicated in future developments of biomedical simulation devices, constituting a robust validation tool to guarantee the quality and educational effectiveness of the materials.

Unlike traditional simulators, the material developed can be repaired using basic resources available in nursing schools, without requiring industrial equipment, and is part of a modular and reusable system, making it more sustainable and economical. This approach not only proposes an effective technical solution but also introduces an ecological and pedagogical perspective to the design of medical simulation devices. Due to its repairable, biodegradable, and locally manufactured properties, the material represents an innovative and replicable contribution to simulation-based clinical teaching.

ACKNOWLEDGMENTS

To Cristian Pérez and Paola Sepúlveda from the School of Nursing at the University of Chile for their willingness and efforts in conducting the checks for this study.

To the BioLab FAU team for their contribution and integration of this research into the service provision project.

This work was partially funded by CIMAC_ANID CTI250005.

This work was partially supported by Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED) (through Red BioRed Iberoamérica, 324RT0155)

To Professor Francisco Zúñiga of the Austral University of Chile for providing an important opportunity for the development of this research.

REFERENCES

Agache, P., & Humbert, P. (Eds.). (2004). *Measuring the skin.* Springer-Verlag.

Armijo-Rivera, S., Machuca-Contreras, F., Raul, N., de Oliveira, S. N., Mendoza, I. B., Miyasato, H. S., & Díaz-Guio, D. A. (2021). Characterization of simulation centers and programs in Latin America according to the ASPIRE and SSH quality criteria. *Advances in Simulation, 6*(1). https://doi.org/10.1186/s41077-021-00188-8

Barros Milla, D. (2021). *Desarrollo de un método DIY (hazlo tú mismo) que sistematice la fabricación de materiales que se cocinan a partir de hidrocoloides y residuos orgánicos: Casos de estudio bagazo de té y cáscara de naranja* [Tesis de pregrado, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/180632

Bogers, L. (2020, 20 de Marzo). *Kombucha Foil/Leather*. Textile Academy – Fabricademy Class Archive. https://class.textile-academy.org/2020/loes.bogers/files/recipes/kombuchapaper/

Canales, C. (2020). *Tonato materia vegetal: Propuesta de refuerzo para compuesto estéticamente símil al cuero natural* [Tesis de pregrado, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/180620

Cantuarias Brañes, S. (2021). *Arquitectura blanda: Geles y biogeles como materiales de diseño arquitectónico* [Tesis de pregrado, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/186417

Contreras, V. A. Y., Ríos, G. A. S., & Palma, F. A. S. (2021). Importancia de la simulación clínica en el desarrollo de personal y desempeño del estudiante de enfermería. *Ciencia y Enfermería, 27*. https://doi.org/10.29393/ce27-39isvf30039

Dabrowska, A. K., Rotaru, G. M., Derler, S., Spano, F., Camenzind, M., Annaheim, S., Stämpfli, R., Schmid, M., & Rossi, R. M. (2016). Materials used to simulate physical properties of human skin. *Skin Research and Technology, 22*(1), 3–14. https://doi.org/10.1111/srt.12235

Dagnino, F. (2025, April 30). La consolidación de la simulación clínica en las carreras de la salud. La Tercera. https://www.latercera.com/educacion/noticia/la-consolidacion-de-la-simulacion-clinica-en-las-carreras-de-la-salud/

Inostroza Muñoz, M. (2021). *Desarrollo de un método DIY (hazlo tú mismo) que sistematice la fabricación de materiales que se cocinan a partir de hidrocoloides y residuos orgánicos: Caso de estudio residuo de concha de mejillón y cáscara de huevo* [Tesis de pregrado, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/180636

Núñez Herrera, S. (2021). *Hacia nuevas materialidades sostenibles: Exploración del residuo cítrico como materia prima para la elaboración de un material compuesto biobasado* [Tesis de pregrado, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/183763

Read, J., McNaught, K., Hazael, R., & Critchley, R. (2024). Evaluation of soft tissue simulant performance against economic and environmental impact. *Environmental Science: Advances, 3*(4), 585–602. https://doi.org/10.1039/d3va00403a

Sambuceti Núñez, C. (2016). *Simulación clínica con práctica deliberada en el proceso de aprendizaje en estudiantes de enfermería* [Tesis de Magíster, Universidad de Chile]. Repositorio Académico. https://repositorio.uchile.cl/handle/2250/170944

Smooth-On, Inc. (s. f.). *Ecoflex™ Series technical information* [Archivo PDF]. https://www.smooth-on.com/documents/?doc=all#ecoflex-00-10

Smooth-on Inc. (2024). *Smooth-on Medical Simulation & Orthotics/Prosthetics*. https://www.smooth-on.com/applications/medical-simulation/

Zúñiga, F. (2024, 29 de abril). Entrevista a Francisco Zúñiga responsable de Laboratorio de simulación clínica Universidad Austral de Chile (UACH) sede Puerto Montt.

ANDRÉS MINTE VALDERRAMA
andres.minte2@gmail.com
UNIVERSIDAD DE CHILE
ORCID ID: 0009-0004-6307-2930

DESIGNER WITH A MINOR IN INDUSTRIES ANO SERVICES (UCH), BACHELOR´S DEGREE IN DESIGN (UCH). DURING HIS STUDIES, HE DEVELOPED A DEEP INTEREST IN USER-CENTERED DESIGN AND SUSTAINABLE DEVELOPMENT. IN HIS LAST TWO YEARS OF STUDY, HE INTEGRATED HIS KNOWLEDGE OF DIGITAL PROTOTYPING TOOLS WITH MATERIAL DEVELOPMENT TOOLS FOR SERVICE DELIVERY ANO DESIGN PROJECT MANAGEMENT.

ANDREA WECHSLER PIZARRO
awechsler@udd.cl
UNIVERSIDAD DEL DESARROLLO
ORCID ID: 0000-0002-3787-0777

PHD IN BUILT ENVIRONMENT (UNSW) ANO INDUSTRIAL DESIGNER (UBB). RESEARCH PROFESSOR AND COORDINATOR OF BIORED IBEROAMERICA OF THE CYTED PROGRAM. PRINCIPAL INVESTIGATOR OF CENTRE FOR INNOVATION IN TECHNOLOGY AND DESIGN OF MATERIALS FOR THE BUILT ENVIRONMENT – CIMAC_ANID CTI250005. LECTURER IN RESEARCH COURSES IN DESIGN, MATERIALS DESIGN, SUSTAINABLE DESIGN, AND UNDERGRADUATE AND GRADUATE PROJECTS, BOTH NATIONALLY ANO INTERNATIONALLY. SHE HAS RAISED NATIONAL AND INTERNATIONAL FUNDING FOR APPLIED RESEARCH. HER AREAS OF WORK INCLUDE SUSTAINABLE DESIGN AND NEW BIO-BASED MATERIALS.

PABLO DOMÍNGUEZ GONZÁLEZ
pdominguez@uchile.cl
UNIVERSIDAD DE CHILE
ORCID ID: 0000-0001-5269-0080

MECHANICAL ENGINEER (UTEM) AND MASTERS DEGREE IN DESIGN TECHNOLOGIES (UAB). ASSISTANT PROFESSOR TEACHING OF THE DESIGN DEPARTMENT, FACULTAD DE ARQUITECTURA Y URBANISMO DE LA UNIVERSIDAD DE CHILE. PRINCIPAL INVESTIGATOR OF CENTRE FOR INNOVATION IN TECHNOLOGY AND DESIGN OF MATERIALS FOR THE BUILT ENVIRONMENT – CIMAC_ANID CTI250005. RESEARCHER AT BIORED IBEROAMERICA, PART OF THE CYTED PROGRAM. MEMBER OF BIOLAB FAU AND NEUROLAB 3D (INCA). LECTURER AND TUTOR FOR COURSES AND PROJECTS IN DESIGN AND ENGINEERING, RESEARCH, MATERIALS DESIGN, AND SUSTAINABLE DESIGN, AND PROJECTS, AMONG OTHERS. PROJECT ADVISOR IN COMPOSITE MATERIALS, PARAMETRIC MODELING, DIGITAL SIMULATION, AND RAPID PROTOTYPING.