Perfectly Imperfect: A Novel Hydrogel for Ultrasound-guided Procedure Training

A DIY gel using grocery items represents the next best thing to human tissue

By Aswin Bikkani, MD; Fiona Pudewa; Steven Johnson, DO, & Jamshid Mistry, DO

We set out to create an ideal material for simulating ultrasound-guided procedures. Several manufactured options are available, but they are expensive, and don't work all that well in our opinion.

Ideally, the perfect material would be cheap, easy to make, long-lasting, and as close to real tissue as possible. It would need to provide tactile feedback, mimic the ultrasonographic appearance of human tissue, and be compatible with various apparatuses for simulating anatomy.

Quite the wish list. Is it even possible to tick all these boxes?

We spent six months obsessively researching, creating, and testing different materials. The various materials available for this purpose are collectively known as tissue-mimicking materials (TMMs) molded into phantoms. (*Ultrasound Med Biol.* 2023;49[1]:18.)

The polymer-based TMMs sold are shelf-stable and replicate the feel of tissue. They can withstand hundreds of needle passes before becoming unusable, but the resulting artifact doesn't readily disappear.

DIY materials range from meat to hydrogels. (*J Am Soc Cytopathol.* 2023; 12[4]:275; https://tinyurl.com/2y2bfneb). Meat replicates human tissue but is unsanitary, perishable, and expensive. Hydrogels like gelatin or agar must be arduously mixed, boiled, and molded. Ballistics gel is shelf-stable but expensive. These gel-based materials fracture easily and leave needle-pass artifact like their more expensive counterparts.

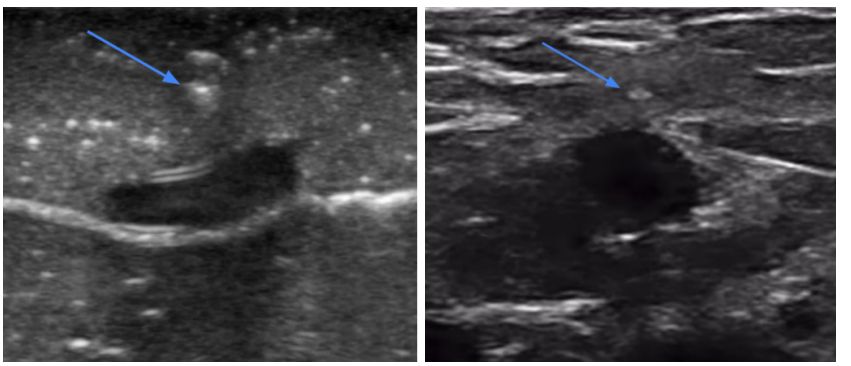


Figure 1. Comparison of echogenicity of SonoGuar (left) with real human tissue (right).

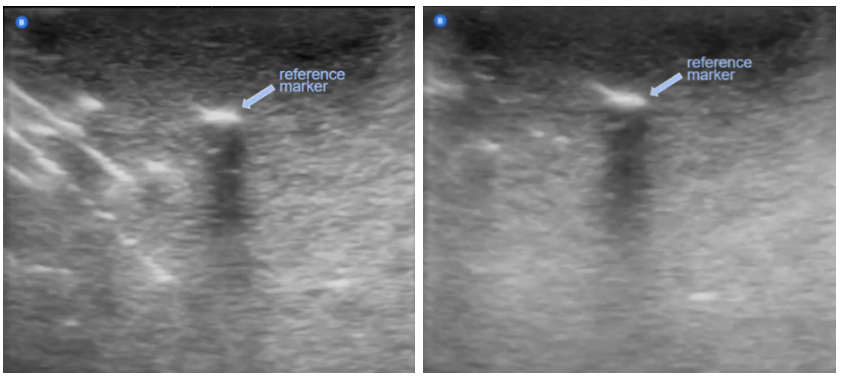


Figure 2. Repetitive needle tracts in SonoGuar after one minute (left) and after 24 hours (right).

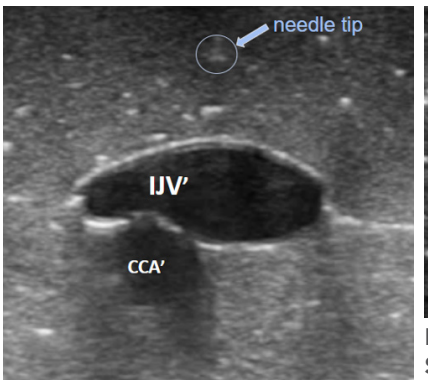


Figure 3. Simulated central venous catheterization with needle tip approaching the imitation internal jugular vein (IJV').

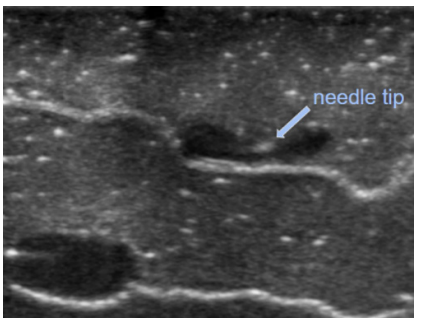


Figure 4. Example of tenting on the SonoGuar phantom.

Replicating the realism of ultrasound-guided vascular access is another shortcoming of existing options. DIY phantoms with embedded vessels must be entirely replaced to repair or modify the vessels. Most commercial phantoms for basic vascular access use empty channels, so certain features such as achieving a flash cannot be replicated. We also noticed that tenting (the indentation caused by vessel deformation prior to needle entry) is absent when using these models. This is a considerable limitation because this is a common visual landmark during real cannulation that trainees must learn to identify and interpret.

DIY and commercial phantoms also have an unrealistic homogenous appearance under ultrasound. This might make for a more carefree simulation session, but such simulations may give a false sense of competence. It turns out we want a little imperfection.

Different How?

This brings us to the exciting part. After all this time spent researching and testing, we think that we finally discovered an ultrasound training material that checks all our boxes. Most notably, it has a heterogeneous appearance that

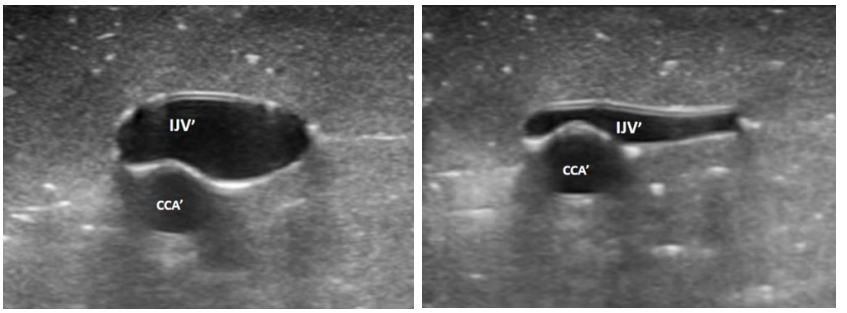


Figure 5. Graded compressibility of simulated IJ (IJV') in comparison with common carotid artery (CCA') in SonoGuar phantom. CCA' remains stiff while IJV' is compressed (right).

Do-It-Yourself Hydrogel

Ingredients	Cost
20 g guar gum powder	3.5 cents/g
20 g (0.73 fl oz) canola oil	8.2 cents/fl oz
340 g (10.3 fl oz) distilled water	1.1 cents/fl oz
20 g (0.54 fl oz) vegetable glycerin	83 cents/fl oz
0.5 tsp (~4.3 g) Borax in 81 g water	1.37 cents/g
Yield: ~14x9x4 cm (1.5 cups)	$1.38 per unit

Supplies needed: 8"x8" baking pan, measuring cups, utensil for hand-mixing, digital scale

The Recipe

Extensive testing led to our final recipe. We listed quantities that will yield a small, portable block with dimensions sufficient for practicing needle-tracking. The batch size is ideal for mixing quickly without clumping. Limit each batch to these quantities even when making more material.

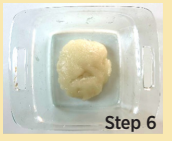
We first suspend the powder in a neutral oil before adding it to water and glycerol (added as a plasticizer). Finally, it is crosslinked with sodium tetraborate (Borax).

The Steps

1. Disperse 20 g of guar in 20 g of oil and mix to form a slurry. Set aside.
2. Thoroughly mix 20 g glycerin with 340 g distilled water.
3. Pour the slurry into the water/glycerin, mixing *gently* as you pour to avoid air bubbles. The mixture will thicken rapidly. Immediately pour into 8"x8" pan at the first sign of thickening.
4. **Pro tip:** Don't try to scrape out all the slurry. It is more important to pour the mixture into a pan as soon as it becomes a thick liquid than to use up all the guar.
5. Dissolve 0.5 tsp Borax powder in 81 g water. It can be heated to help it dissolve.
6. Crosslink by covering top and bottom surfaces with Borax solution by using a spray bottle or brush, then pressing in. Feel for any sticky areas and apply more Borax as needed. You don't need to use it all.
7. Cross linking finishes within minutes, then homogenizes with time. Place the hydrogel into a container, and it will conform. Store in the fridge.


Step 2


Step 4


Step 6


Step 7

allows the operator to practice the skill of distinguishing their needle from other hyperechoic structures (Figure 1), making it perfectly imperfect. We named our creation, SonoGuar.

Our formula is inspired by existing literature on guar-glycerol-Borax hydrogels but aims for a stiffer material than previously described to improve tactile feedback. (*ACS Biomater Sci Eng*. 2018;4[9]:3397.) The oil slurry is a novel technique that delays hydration to allow for hand mixing with minimal clumping and air artifact. The result is our ideal, self-healing, moldable, freezable hydrogel. It only takes 15 minutes to assemble at room temperature, and can be made with low-cost grocery store ingredients.

After manipulating the recipe during numerous attempts, we found the material would maintain its viscoelasticity if we sacrificed some stiffness, allowing it to readily heal after being poked, cut, or even dilated, so much so that needle tracts are virtually indiscernible after 24 hours. (Figure 2.)

Our material's ability to self-heal also makes it ideal for projects such as creating 3D-printed molds. The gel will coalesce within a short time to give the tissue a seamless appearance when you divide the material and place it over the mold. Take a look at our internal jugular central line model. (Figure 3.) Fascial planes and skin can be simulated using gauze.

We used oblong latex balloons of different diameters as our vessels to create a more realistic cannulation experience. Modulating the amount of fluid inserted simulates vessel tenting (Figure 4) and the difference in compressibility between arteries and veins (Figure 5).

Overall, we think that our gel represents the next best thing to human tissue when it comes to ultrasound procedural training. From our extensive research, it seems that no formulation to date has been able to avoid inaccurate echogenicity and prolonged needle tract artifact while simultaneously being low cost and long-lasting. The physical properties of our material also make it ideal for creating your own custom training models for specific purposes. Our material excels where existing TMMs fall short.

If you're not the type to shy away from a quick DIY project, you too can become a sim superstar at your residency with SonoGuar. EMN

DR. BIKKANI is a second-year emergency medicine resident at Arrowhead Regional Medical Center in Colton, CA, interested in clinical ultrasound, simulation, and medical education.

MS. PUDEWA is an MD candidate in her final year at the California University of Science and Medicine in Colton, CA. She is pursuing a career in emergency medicine with involvement in academics.

DR. JOHNSON is an emergency physician at Arrowhead Regional Medical Center in Colton, CA. He is fellowship trained in emergency ultrasound and anesthesia critical care and works as an ICU attending at Keck School of Medicine of USC.

DR. MISTRY is board certified in emergency medicine and critical care with a penchant for point-of-care ultrasound, acute resuscitation, and diseases pertaining to the brain and spine.