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ORIGINAL ARTICLE

# A study of the surface characteristics of homemade ultrasound phantoms

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**Abstract**
*Objectives* Expertise in the utilization of procedure-guided ultrasonography has become increasingly important within the field of Emergency Medicine. Consequently, ultrasound phantoms have been implemented as simulation tools in introductory courses. This study of the surface behavior of gelatin blocks was performed to describe the behaviors of phantoms for ultrasound training.
*Methods* Gelatin blocks of varying preparation techniques and component concentrations were tested on exposed and latex-coated surfaces to determine the variation in surface disruption and force–displacement characteristics of each of the surfaces tested.
*Results* Gelatin blocks made at a cooler temperature than current recommendations have a more durable surface. Latex-coated blocks have the most durable surface.
*Conclusions* Gelatin blocks made at a lower temperature than current recommendations result in a more desirable phantom. A re-usable latex coating can add to the durability of the phantom.

**Keywords** Phantoms · Ultrasound · Training · Durability

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## Introduction

Expertise in the utilization of procedure-guided ultrasonography has become increasingly important within the field of Emergency Medicine. Consequently, ultrasound phantoms have been implemented as simulation tools in introductory courses. Table 1 lists most of the applications used for gelatin-based simulators within the authors' curriculum. Standard recommendations [1] for preparation of ultrasound phantoms using over-the-counter gelatin produce a phantom with inadequate surface strength and deflection characteristics that result in surface disruption by novice users. The optimal phantom would include image fidelity between the phantom and the tissue simulated, would provide tactile feedback to the trainee that is similar to tissue, would have a durable surface that would not be disrupted by pressure from the ultrasound probe, and would have a durable surface that would not be visibly disrupted by repeated needle punctures.

The goal of this project was to understand the surface behavior of different gelatin preparations that predicts the likelihood of surface disruption by the ultrasound probe. A latex-coated gelatin block was studied because this coating was observed to obscure needle punctures. In fact, after 100 needle sticks (19 g needle) within a 4 mm diameter circle, no puncture holes were visible. This property was felt to be important when trying to minimize bias among learners trying to identify proper needle placement.

## Methods

Blocks of gelatin were made in order to study the surface strength and force displacement characteristics of the blocks. Gelatin was poured into bread pans in order to

**Table 1** Gelatin-based simulators used in the authors' curriculum for procedure training for emergency medicine residents

| |
|---|
| Ultrasound-guided central venous catheterization |
| Ultrasound-guided lumbar puncture |
| Ultrasound-guided pericardiocentesis |
| Ultrasound-guided abscess identification and drainage |
| Ultrasound-guided thoracentesis |
| Radial artery puncture |

minimize edge effects on surface response by ensuring that block depth and width substantially exceeded the compression depth of the tests and the diameter of the testing device. The resulting gelatin blocks were 5 cm deep, 10 cm wide and 21.5 cm long on the bottom and 12 cm wide and 23 cm long on the top surface. The test matrix (Table 2) was designed to study the difference in preparation technique, the presence of psyllium added for ultrasound contrast, the type of gelatin used and the effect of gelatin concentration.

Hot water gelatin was prepared according to the method suggested by Bailey [2]. Gelatin (and psyllium) was added to boiling water. This was stirred until the gelatin and psyllium were visibly dissolved. The solution was poured into a plastic wrap (Glad Products Co, Oakland, CA)-coated bread pan, covered with plastic wrap (not in contact with gelatin surface), cooled briefly at room temperature (20 min) and then cooled for at least 24 h in a 4°C refrigerator (but not more than 36 h prior to testing).

Cool water gelatin was prepared similar to the method suggested by Jussila for the preparation of ballistic gelatin [3]. Forty-five percent of the water was at 20°C. Fifty-five percent of the water was heated to 70°C. The gelatin was added to the cool water and mixed by hand until achieving the consistency of mashed potatoes. This was allowed to sit for approximately 5 min. References suggest that allowing the gelatin particles to sit for a few minutes is necessary for 250 Å particles to swell [3]. Next, the warmer water was poured into the gelatin mixture, the psyllium was added and the mixture was stirred for 8 min using a paint stirrer on a handheld electric drill. After pouring into the mold, the mixture was covered with plastic wrap and allowed to cool at room temperature for 20 min. Any foam was then scraped off prior to setting of the gelatin, and the pan was covered with plastic wrap (not in contact with gelatin surface). The bread pan was then placed into the 4°C refrigerator for at least 24 h (but not more than 36 h) prior to testing.

One block was created with a latex coating. Liquid latex (Castin' Craft Mold Builder) was painted onto the inside of an aluminum foil bread pan of similar size to the other molds. Five coats of latex were applied to ensure a thick coating. The coating was allowed to dry completely in between coats (up to 2 days to dry between coats). Cool water gelatin was poured according to the technique described above. For testing, the aluminum foil pan was cut away to allow access to the free standing block of gelatin. Testing was performed on the latex-coated bottom of the block only.

Two types of gelatin were tested. One block was made from 250 Bloom ballistic gelatin (Kind & Knox) ("ballistic gel"), while all others were Knox gelatin. Gelatin concentrations were either 7.4% by weight [2] or 10%, which is the concentration recommend for ballistic gel [3]. The 7.4% gelatin included 80 g gelatin per liter of water, while 10% gelatin included 110 g gelatin per liter of water. Psyllium used was generic psyllium powder (The Kroger Company, Cincinnati, OH) that weighs 25 g per 30 ml volume. Bailey recommends 10 g psyllium per 250 ml water. For the tests with psyllium, 21 ml of psyllium powder was added per liter of water.

For each test, the block was removed from the mold and allowed to warm to room temperature for at least 4 h but less than 7 h. Indentation testing was performed using a custom built test rig. (Fig. 1) Indentation was applied using a 12.5 mm diameter rod without rounded edges applied

**Table 2** Test matrix for gelatin testing

| Test number | Top or bottom | Gelatin concentration (%) | Gelatin | Preparation temperature | Psyllium |
|---|---|---|---|---|---|
| T10KCNO | Top | 10 | Knox | Cool | No |
| T7KCP | Top | 7.4 | Knox | Cool | Yes |
| T10KCP | Top | 10 | Knox | Cool | Yes |
| T7KHP | Top | 7.4 | Knox | Hot | Yes |
| T10BCP | Top | 10 | Ballistic gel | Cool | Yes |
| B7KLCP | Bottom | 7.4 | Knox with latex coat | Cool | Yes |
| B7KHP | Bottom | 7.4 | Knox | Hot | Yes |
| B10KCP | Bottom | 10 | Knox | Cool | Yes |
| B7KCP | Bottom | 7.4 | Knox | Cool | Yes |
| B10KCNO | Bottom | 10 | Knox | Cool | No |

perpendicularly to the testing surface. This flat faced, circular indenter was chosen to remain consistent with the Bloom method of testing gelatin surface strength. Bloom technique actually implies the testing of a 112 g sample of 6.67% gelatin indented with a constant rate of application of weight until the surface is indented 4 mm [4]. This test series was conducted using the same size indenter; however, the gradual application of 30 or 60 g of water was applied. Depth of indentation was measured immediately after each application of extra weight, and then re-examined at 30 s—prior to the application of additional weight. There was no variation between initial and follow-up examination. Three trials were performed on the exposed (or top) surface of the blocks or the latex-coated (block bottom) surface. Two trials were performed on the bottom of the blocks without a latex coat. The maximum gelatin compression prior to a visible crack in the gelatin was recorded for each trial. Tests were always at least 2.5 cm away from any other test site and at least 3 cm from the block edge. See Fig. 1 for a schematic of the test design.

With the sequential application of weight, the indentation depth was measured after each increase in weight applied. The initial load from the test apparatus was 238 g. Weight was added until one of the predefined endpoints was reached: the surface cracked visibly or a total of 1.3 kg of weight was applied to the surface.

Deflection results were entered into Microsoft Excel (Microsoft Corp, Redmond, WA). Data analysis was performed using SPSS (SPSS Inc, Chicago, IL) for linear regression calculations. A linear regression curve was fit through the data in the form of a linear force–displacement equation:

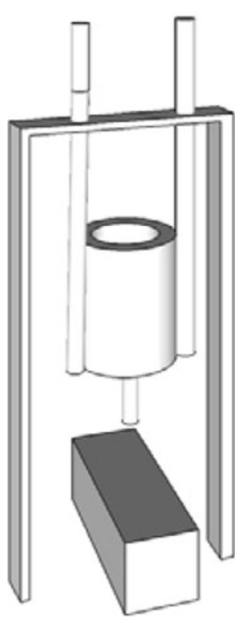

**Fig. 1** Custom-designed test rig for indentation testing. A 12.5-mm circular faced indenter was used on gelatin blocks 5 cm deep. Water is added to the cylindrical container illustrated

$$\text{Force} = \text{Stiffness coefficient} \times \text{Displacement} + \text{Constant}.$$

The stiffness coefficient reflects the stiffness of the gelatin surface (measured in g/mm) at working compression depths, while the constant reflects the variation in stiffness at lower depths of compression.

## Results

The data are presented in Table 3. The latex-coated surface did not crack at 1.3 kg of weight, and thus, no results on fracture depth are included in Table 3. While the gelatin blocks had linear force–displacement characteristics at the weights tested, the constant being non-zero implies there is a non-linear portion of the curve at lower weights. As a representative example of the performance of various gelatin blocks, Fig. 2 demonstrates the force–displacement results for three of the ten test conditions.

Testing of the various blocks resulted in several qualitative observations. First, the cool temperature blocks, while a bit more complicated to prepare, resulted in easier cleanup and less unpleasant odor from the psyllium additives. Second, the surface strength on the air exposed side of the gelatin was much greater than on the sides of the block with plastic wrap. Finally, the gelatin surface appeared to 'soften' during warming to room temperature prior to testing. Other authors have noted that mechanical properties change with gelatin block temperature [3]. The cost of construction for each block was less than $10.

Results from this study demonstrate that while the slope of the force displacement curve is similar between gelatin preparations, the offset varies between the hot gelatin and the cooler gelatin and the exposed surface and the unexposed surface. The slope of the curve describes the tangent modulus, while the offset (the constant in the equation fitted to the data) is a function of the secant modulus. The more negative the offset, the flatter the secant modulus. If the test apparatus could measure the displacement down to very low applied weights it would demonstrate that those with the flatter secant modulus would have more displacement with less applied force. A deeper displacement with a particular applied force would allow for more shear force to be applied to the gelatin as the user tries to manipulate the probe across the surface.

Qualitatively, the cool preparation, with its stiffer secant modulus and flatter surface (compared to the undulating surface of the hot preparation) would result in a more durable phantom than the hot preparations. While gelatin concentration only varied between 7.4 and 10% by weight, this variation did not result in any significant variation in the surface performance.

**Table 3** Experimental results and regression results for force–displacement curve

| | Test condition | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | T10KCNO | T7KCP | T10KCP | T7KHP | T10BCP | B7KLCP | B7KHP | B10KCP | B7KCP | B10KCNO |
| Avg. max compression depth (mm) | 14.3 | 12.7 | 10 | 14.7 | 12.7 | NA | 19 | 22.5 | 13 | 10.5 |
| St. deviation (mm) | 3.8 | 0.6 | 1 | 3.1 | 0.6 | NA | 0 | 0.7 | 1.4 | 2.1 |
| Stiffness coefficient (g/mm) | 48.9 | 45.8 | 52.1 | 48.9 | 52.2 | 53.8 | 32.8 | 16.5 | 37.6 | 46.1 |
| SE stiffness coefficient | 2.9 | 1.6 | 2.9 | 1.0 | 1.3 | 1.3 | 2.4 | 1.3 | 1.2 | 1.4 |
| Constant (g) | 51.4 | 47.3 | 69.1 | −42.1 | 41.7 | −210 | 25.1 | 134 | 45.2 | 49.8 |
| SE constant | 30.8 | 14.5 | 20.3 | 10.7 | 11.0 | 25.2 | 32.7 | 18.9 | 11.0 | 11.0 |
| Model fit ($R^2$) | 0.91 | 0.95 | 0.90 | 0.98 | 0.97 | 0.96 | 0.87 | 0.91 | 0.98 | 0.98 |

See Table 2 for the description of the nomenclature for the test condition

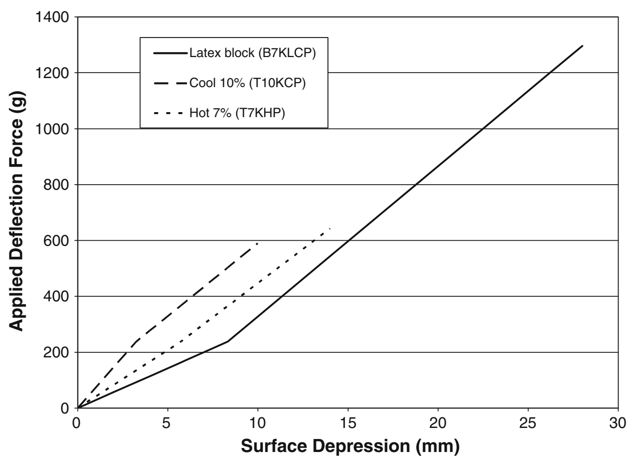


**Fig. 2** Force displacement curves of the three most significant of the ten test conditions

## Discussion

Emergency medicine resident training involves teaching many procedures (Table 1). Through the use of simulators residents can become facile with the equipment and techniques prior to use on patients. Unfortunately, as a commercial simulator is used repeatedly it begins to degrade, and the novice user can identify appropriate puncture sites by the holes visible in the disrupted simulator surface. Two solutions to this problem are to purchase a steady stream of commercial simulators or to fabricate low cost disposable simulators.

Industries that have significant experience with gelatin molding include the ballistics industry and the special effects industry in movies and entertainment. ‘Ballistic gelatin’ is typically used in the ballistics industry. By carefully manufacturing blocks of gelatin ballistics experts can quantify projectile velocity and momentum [3]. Special effects experts have various recipes for gelatin preparation in order to manufacture casts of flesh appearing gelatin molds. Previous recommendations in the medical literature for low cost phantoms have recommended a preparation method differing from ballistic gelatin in concentration and preparation temperature [1, 5]. The previously recommended phantoms often have an undulating surface with low enough surface strength that the phantom surface is disrupted when the ultrasound probe is vigorously maneuvered by novice users. This study was undertaken to quantitatively measure the impact of variations in preparation method and components on the surface strength and the force displacement characteristics of gelatin blocks.

Accurate measurement of the visco-elastic properties of compressible solids is extremely complex. This test was neither designed nor intended to define the properties of gelatin. The interested reader should review the works of Mattice [6] and Humphrey [7] for further discussion of the topic. Gelatin is particularly difficult to work with as the density and modulus of elasticity vary throughout the block [8]. The gelatin farther from the edge and deeper in the block is more densely compressed (by overlying and neighboring gelatin) than that on a top edge. Additionally, visual inspection of the gelatin blocks used in this study revealed that while the psyllium appeared uniformly distributed horizontally, it was not uniformly distributed vertically in some blocks due to apparent settling of the psyllium prior to solidification of the gelatin. Thus, this work cannot be considered a definitive quantitative solution. However, using careful experimental technique and understanding the limitations of the testing methods, these results can provide some quantitative information of the variation in surface strength of the gelatin blocks.

Typical testing of deformable materials would be done using a spherical tip or wedge tip indenter in order to minimize the effect of stress concentrations. The most durable surface of a gelatin block (without latex coating) would not support a 4 mm spherical tip indenter with 250 g of applied load. The results from a spherical tip indenter were felt not to be as functional as those from an indenter that would tolerate greater applied loads so a spherical indenter was not used. ASTM D695 describes a standard for the compression testing of uniform plastics [9]. Gelatin is not firm enough or uniform enough to test in this fashion, thus ASTM D695 methods were not applied. In the compression testing of foam plastics it is recommended to use a compression foot with a large diameter to limit penetration [10]. Extending this to gelatin, initial testing using a 1 in. square faced indenter (that would mimic the face of Sonosite P series probes) caused inconsistent surface cracking. Flat tipped circular indenters have been used historically to determine the surface characteristics of gelatin, and this shape was chosen for this test series after unsuccessful results with other geometries. Further inconsistent results were obtained with attempts at non-perpendicular application of the indenter and steady application of weight, as was described by Bloom testing [4]. We were unable to fashion a test rig that would apply force perpendicular to the surface and tangentially along the surface to measure the disruption properties of the surface that would typically occur during probe use during resident education. Deflection tests were performed at least 3 cm from the edge of the block in order to minimize edge effects. Additionally, no tests were repeated within at least 2.5 cm of the testing rod in order to minimize any preconditioning of the gelatin during prior tests. No visible or measurable deflection of the gelatin surface occurred more than 1 cm from the indenter edge in any test. Gelatin blocks were at least 5 cm deep so that block depth was at least an order of magnitude greater than maximum depression.

There is no clear reason for the large offset in the linear force–displacement equation for the latex-coated phantom. Possibly there was a small air pocket introduced between the latex and gelatin when the block was turned upside down for testing. Possibly the gelatin in contact with the irregular surface of the coated latex mold had different mechanical properties than the smooth surface of the underside of the gelatin blocks tested without latex (tests B7KHP, B10KCP, B7KCP and B10KCNO). Anecdotally, we were unable to apply the latex to a formed gelatin block in a fashion that would maintain gelatin integrity while allowing for adequate drying of the latex molding compound. The ammonia-based latex material required a warmer surface to cure. Thus, we formed the latex mold then filled the mold with the gelatin after the latex dried.

Gelatin is a desirable compound for phantom construction as it is can be poured into any mold. It is a low cost, readily available material. We were unable to identify another low cost, readily available material that could be poured as well as have the required ultrasound scatter pattern achieved with the psyllium [4, 5, 11].

## Conclusions

The training of emergency medicine physicians in procedural ultrasound requires ready access to ultrasound phantoms. Currently, recommended ultrasound phantoms were easily constructed but lacked durability. This paper tested the surface strength of various preparations and produced a phantom that is easily constructed, inexpensive, and extremely durable.

**Conflict of interest** None.

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