The Novel Use of Silicone Dielectric Gel for Central Nervous System Encapsulation and Preservation

Philip R. Persino[1]*, Daniel R. Olson[2], Moira Jenkins[2], Karen E. Samonds[2]

[1]Chicago Medical School, Rosalind Franklin University, 3333 Green Bay Road, North Chicago, IL 60064 USA

[2]Department of Biological Sciences, Northern Illinois University, DeKalb, IL 60115 USA

*Corresponding author

Abstract

Anatomical sciences education is currently at a crossroads. Cadaver dissection is widely considered an essential part of an anatomical sciences curriculum. However, facilities are often expensive, and with pressures to reduce cost and concentrate anatomy learning into fewer hours, there is a clear need for alternative teaching tools that preserve vital characteristics of cadaveric specimens. We report here on a new method for the encapsulation and preservation of the central nervous system (CNS). The encapsulation material is a high performance, silicone dielectric gel adhesive that provides a stable environment without any significant visual distortion. This method is cheaper and simpler than plastination, can be repaired or changed after initial encapsulation, preserves fine detail, and can clearly demonstrate anatomical variations. With the current need to balance the use of digital technologies with cadaveric specimens, these types of specimens can be a valuable addition to any anatomical sciences curriculum.

Key Words: Encapsulation, Anatomy, Cadaver, Silicone gel, Education

Introduction

Historically, the classic method of teaching human anatomy has focused on hands-on learning through human cadaver dissection, often recognized as providing better outcomes in student learning than either prosected cadavers (Winkelmann *et al*. 2007) or models only (Anyanwu and Ugochukwu 2010, Wright 2012, Preece *et al*. 2013). However, many anatomy departments have greatly reduced the amount of time students spend in the lab, often in part due to the lack of support from educational administrators. In general, cadaveric dissection has leveled off and lab hours have decreased as medical schools and undergraduate institutions move towards digital teaching and other alternatives in this technologically advanced era (Shaffer 2004, Drake *et al*. 2009). In some cases, cadaver dissection has been completely phased out of medical schools as they transition to a curriculum with computer simulations, synthetic cadavers, and plastic models (McLachlan *et al*. 2004, Nguyen *et al*. 2012). The effects of this shift in medical and anatomical education are still not clear, though recent studies suggest that students learning with digital teaching tools do not perform as well as those directly interacting with cadavers (Biasutto *et al*. 2006, Saltarelli *et al*. 2014, Mathiowetz *et al*. 2016). Some programs that discontinued anatomical dissection in favor of model-based teaching have later re-adopted it as an integral part of their program in response to a drop in student performance (Rizzolo and Stewart 2006). Whether or not computer-based anatomical software is more beneficial, or equal for student performance in traditional dissection courses remains a topic of considerable debate (Leung *et al*. 2006, Bergman *et al*. 2011, Johnson *et al*. 2012).

However, with the advent of more advanced computer imaging, synthetic models, and other alternatives, student interaction with real human tissue may begin to decline. With pressures on institutions to reduce cost, and often decrease the time-consuming hours dissecting (Shaffer 2004, Dissabandara *et al*. 2015), there is a clearly demonstrated need for alternative teaching tools that preserve as many qualities as possible of actual cadaveric specimens. Synthetic, high fidelity models are durable and give clear representation of three-dimensional relationships (Chan and Cheng 2011) but lack the detail of real tissue. These models also demonstrate "normal" structures of the human body while overlooking variations or pathology, an important aspect for students pursuing a future in health sciences. One solution to this problem is the use of plastinated cadaveric tissue, where water and fats are replaced by plastic, yielding specimens that retain more "lifelike" properties than a traditional model (Tamura *et al*. 2014, Stancu *et al*. 2015).

Plastination, invented by Gunther von Hagens in 1977, has produced spectacular models both for education and display (von Hagens and Tiedeman 1987, Baker *et al*. 2013, Stancu *et al*. 2015). Often considered the gold standard in human

continued on next page

anatomical model creation from cadaveric tissue, plastinated models have been demonstrated as more beneficial for student learning in anatomical sciences as compared to computer-based models (Fruhstorfer *et al*. 2011, Riederer 2014, Tamura *et al*. 2014). While this technique produces high-quality specimens, it is often a laborious, time consuming, and expensive process to perform, frequently requiring special lab facilities that may not be accessible or affordable (Cornwall 2011, Stancu *et al*. 2012, Riederer 2014). While some specimens may last for many years, handling of these specimens can also lead to damage, making them potentially less cost effective. Additionally, plastinated nervous tissue shrinks considerably and becomes more prone to breaking (Riederer 2014).

In this paper, we present a material and novel method for the encapsulation and preservation of the central nervous system (CNS) of a single cadaveric specimen; an additional tool for teaching anatomy to a broad range of students from diverse backgrounds, including both undergraduate and post-graduate students. This method is cheaper and simpler than plastination, shows greater detail than plastic models, and provides students a physical object to view. Additionally, this method has great potential to reclaim and restore older specimens preserved in formaldehyde, as often this fluid darkens with age, and the teaching value of these specimens is diminished.

Materials and Methods

Body donation program

Northern Illinois University (NIU) offers a body donation program that supplies cadavers to courses at both the undergraduate and graduate levels. This program works in conjunction with a local funeral home where initial cadaver preparation is completed. Cadavers are perfused with a solution of Dodge Chromatech Pink-21.5 index, Metasyn-20 index, Metaflow arterial conditioner, and Rectifiant pH stabilizer equaling 2.5-3 quarts of final solution. Perfusion fluids are administered through a cannula in the right common carotid artery as a closed system. Cadavers are then transported to NIU and again perfused for storage. The cannula from initial embalming is used to perfuse with a solution containing 4L phenol, 4L 95% ethanol, 1L formaldehyde. This solution is introduced into the cadaver by a gravity-driven system and takes 1-2 days.

Cadaver dissection

The CNS (brain and spinal cord) were removed from the cadaver as a single unit and transferred to a solution of 1:8 formaldehyde:H_2O. It should be noted that the complete dissection and removal of an intact human CNS can be a complicated and time-consuming endeavor which should be undertaken by an experienced dissector. As part of this project, a comprehensive digital atlas of the central nervous system and excision manual was compiled (Persino 2014). Storage of the nervous tissue consisted of six washings and re-fillings of the holding solution to ensure no additional particles or fluids would be introduced into the encapsulation.

Materials used in the encapsulation

The encapsulant for this project was from Noelle Industries, Inc. Noelle 810-47 is a low viscosity, soft, transparent, two component (1:1 mixing ratio), high performance, silicone dielectric gel adhesive. It was designed for use in applications that require a highly flexible, shock resistant material, to cushion coat sensitive or fragile components/fine electrical wires. The material has a specific gravity of 0.88 with an operating temperature of -45˚C to +150˚C. Working time for this material is 3 hours with a cure time of 16 hours at 25˚C, according to the manufacturer (Noelle Industries 2004). This product was purchased directly from the manufacturer at a price of $25/lb.

Encapsulation process

Prior to the encapsulating the finished product, a test CNS specimen was used to determine the proper steps to be taken during the final encapsulation. The vacuum apparatus and test specimen are diagrammed at the end of this section (Figure 1, Figure 2).

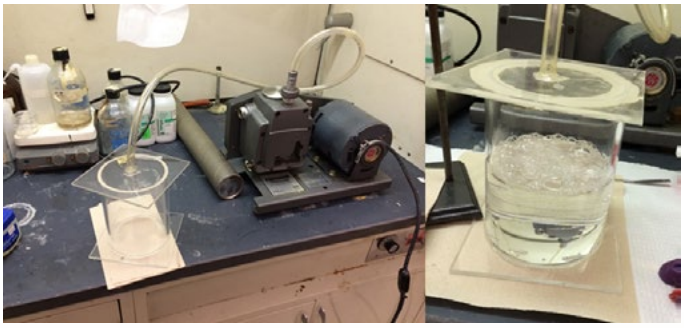

Figure 1: Encapsulation and vacuum apparatus for test specimen. Acrylic tubing and plexi-glass plates to hold test specimen were bonded with a two-part epoxy. This adhesion method was unable to withstand regular handling of the specimen. Notice the dissolution of gas from the encapsulant due to the pull of the vacuum (right). Note that this is a rudimentary, unfinished vessel that was not to be used for display purposes.

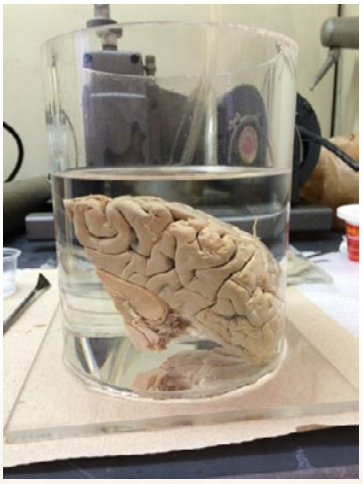

Figure 2: Test specimen completed one year before full-scale CNS encapsulation. Used to monitor system changes that may affect the full-scale completed system.

continued on next page

Encapsulation was completed within a cast acrylic tube suitable in size to contain the entire CNS. This tube was first closed off at one end with machined sheet acrylic and sealed with adhesive to ensure no leak of encapsulation material. A two-inch diameter circular hole was machined in the center of this piece for a cap and pressure-release system. Three inches of encapsulant was then poured on this end with a temporary plug coated with a silicone cast releasing agent in the two-inch hole; it was then allowed to set for 25 minutes to act as a cushion for the CNS as it was lowered in. Immediately following the pour, a vacuum was pulled on the system for five minutes to encourage dissolution of any trapped air in the encapsulant. The specimen was lowered in brain first with a clear monofilament secured to the cauda equina to maintain the spinal cord in the central position of the display. A second pour was done to cover the base of the brain up to the pons. At this point, a custom-designed acrylic-sheet support was lowered and secured at the new level of encapsulant. A second vacuum was then pulled on the system. Three final pours with subsequent vacuuming were then performed until the entire specimen was within the encapsulant (Figures 1 and 2).

Curing and finishing

This system was allowed to settle for several months to observe changes before the final pour and sealing of the tube was complete. The tube was then sealed at the end of the cauda equina with a machined acrylic sheet. The entire specimen was then turned right-side up for a final filling before sealing. A steel cap with a hole (<1mm) was machined as a pressure release for the top of the encapsulation to replace the temporary plug used during the encapsulation procedure. In the event the specimen was ever in a high temperature situation, this cap allows for pressure equilibration between the system and its surroundings.

Results

Upon completion, the encapsulation revealed a crystal-clear specimen without any distortion of structures, by gross visual inspection. During the process, we also demonstrated that the material was repairable with freshly mixed encapsulant, allowing for the repair of any mistakes or gas inclusions. Repairs were easily accomplished with a Pasteur pipette and freshly mixed encapsulant. It should also be noted that within the first week nearly all of the gas inclusions, which were unable to be removed, had vanished. This was the case for nearly all of the inclusions under one centimeter. A few larger inclusions remained in the encapsulation, but did not affect the overall quality and visibility of the specimen. It is important to note that this material does not set solid, but rather to a stable gel-like consistency. Though the working time of this material is listed as 3 hours at 25˚C, we found that for our application, the reasonable working time was only approximately 30-45 minutes. However, though the working time was significantly reduced, we found it to be more than adequate for this type of application.

This medium was found to be superior to both liquid systems and solid systems. In our experience, liquid systems allow for too much diffusion and exchange between the specimen and its surroundings, which creates cloudiness and discoloration to the system. On the other hand, solid systems (e.g., epoxy) have a significant exothermic reaction, only allowing small pours to be done at a time; this allows any larger specimen to potentially desiccate before encapsulation is complete. Another issue with solid encapsulants in acrylic tubes is distortion, as structures cannot be visualized without distortion in a larger epoxy-based system. While acrylics may be useful with smaller plastinated systems, it may not be feasible for larger specimens, as distortion produces a model that is not an accurate representation. Noelle's dielectric gel did not produce any significant distortion in the display. Structures covered by several inches of encapsulant are still clear and non-distorted during visual inspection. The equilibrium of the system, as compared to holding solution, does not allow for diffusion of discolored perfusion fluid beyond the confines of the tissue; unlike exclusively fluid systems.

Since the primary pour and encapsulation of this specimen, it has been over two years. There has been no observable change in either the specimen or surrounding encapsulant. While the total lifetime of the specimen cannot be determined at this point, the lack of change is a promising indicator that this method may produce a stable specimen for the long term. However, as this is the first time that this material has ever been used for this specific application, it will be several years before the complete efficacy of this dielectric gel as an encapsulant will be established.

Discussion

This method of CNS encapsulation is both simpler and cheaper than traditional plastination methods. The total cost of encapsulant for this application was < $700. Considering the large amount of encapsulant used to complete this project, it is still significantly cheaper than plastination. Fast pouring and setting of the two-component silicone based dielectric gel can prove to be a valuable addition to labs that do not have plastination capabilities. As large anatomical sciences courses pose a barrier to students direct contact with cadaver dissection (Simpson 2014), or ideal prosected specimens, these types of models for both teaching and examination purposes may help eliminate the need of prosections that have a limited lifetime. Older anatomical specimens in storage may also have renewed teaching value by removing them from darkened formaldehyde and encapsulating them. Additionally, as body donation waxes and wanes at our institution, this method also offers labs a way to retain parts of cadavers in an easy, cost-effective manner. This may prove to be especially important in the preservation of pathologic features for teaching purposes in both undergraduate and medical institutions alike.

continued on next page

One drawback of this method as compared to plastinated specimens is the lack of "direct" physical interaction with the specimen, as our method encapsulates the material in a cast acrylic tube; which may be a possible source of hindrance to student retention of information (Preece *et al*. 2013). However, we argue that different anatomical regions may be more or less suited for this type of model. Our encapsulation of the entire CNS allowed for detailed examination of the superficial surface of the brain, cranial nerves, and the spinal cord. However, the encapsulation of something very small (e.g., the middle ear) or something very complex (e.g., infratemporal fossa) may be challenging for this type of model without the benefit of close "in-hand" inspection.

Though it was not done for this project, these types of models can be tagged and labeled before encapsulation, allowing them to be used with guides to structures or as specimens for laboratory examination questions. Additionally, the use of red laser pens for instruction could also be utilized to highlight untagged structures or to draw attention to larger areas of the encapsulated specimen. Future work should experiment with other ways to maximize the potential of encapsulated specimens for student learning and assessment.

The authors acknowledge that this encapsulation specimen and its precursors are the only of their kind, but recognize the potential of using this material as an encapsulant for a variety of anatomical specimens. The size and construction of this specimen is clearly not meant to be handled extensively by students, but is a starting-point for future encapsulations. More efficient use of space within a display can dramatically decrease the cost, size and weight of the completed product; making it more maneuverable and convenient for students. This material should not be limited to CNS structures, but should be experimented with and tested on all tissues. Though the efficacy of the silicone dielectric has not been tested with other anatomical specimens, it is our opinion that it will also provide highly detailed encapsulations of a variety of tissues.

Conclusions

Anatomical sciences education has been moving away from costly and time-consuming cadaver dissection to cheaper and more technology-based approaches (Nguyen *et al*. 2012). When implemented properly, computer based models and other educational tools that do not require a wet laboratory can certainly be beneficial to student learning (Wright 2012, Hochman *et al*. 2015). However, it has been shown that three-dimensional analysis of anatomical specimens is an advantage to learning outcomes of students, specifically those that retain qualities that make cadavers or high-fidelity models unique and valuable learning tools (e.g., variation, pathologies; Preece *et al*. 2013). Obtaining structurally detailed and long-lasting specimens is vital to the success of students' structural understanding of the human body.

This new method of encapsulation is a cheaper and more accessible alternative to traditional plastination techniques, and may provide a longer-lasting teaching tool. Though this model required a great deal of encapsulant, its production was significantly cheaper than that of traditional plastination methods. Future encapsulations can maximize specimen space while minimizing the amount of encapsulant required. As the multimodal approach is demonstrated to enhance student learning (Drake and Pawlina 2014, Fasel *et al*. 2015), this technique offers an additional tool that, when combined with other methods (e.g., digital models, small-group learning, integration of clinical correlates) may help to enhance and enrich the student experience; though this investigation has yet to be initiated. While encapsulated specimens lack the ease of handling and manipulation of in-hand models, we believe that with the current need to balance the use of digital technologies with cadaveric specimens in a cost-effective way, these types of specimens can be an important addition to any classroom or laboratory. It is not the authors' intention to replace any traditional or new tools for teaching anatomical sciences, but rather to introduce an adjunct to the lab or classroom to enhance student learning (Figure 3).

Figure 3: Encapsulated brain and spinal cord in the Northern Illinois University Human Gross Anatomy Laboratory. Specimen is mounted in a cast acrylic tube filled with silicone dielectric gel (Noelle Industries; #810-47).

continued on next page

Acknowledgements

The authors wish to acknowledge the Department of Biological Sciences and the College of Engineering and Engineering Technology at Northern Illinois University for supporting this project throughout its entirety. They also wish to thank Dr. Mary McGinn for her assistance, Jim Doherty (president and founder of Noelle Industries) for facilitating the use of 810-47 encapsulant material, and Mike Reynolds for his machinist expertise and work on this project. Special thanks to Dr. Vincent McGinn for his dedication to the engineering, design, and problem solving needed to successfully execute this project. The authors would also like to thank Sam Finch, funeral director of Finch Funeral Home, for his embalming work. The use of this cadaver was approved by the Northern Illinois University Body Donor program in full accord with their policies and procedures. Thank you to Christina Cline for photographing the finished specimen. The authors are solely responsible for the content and writing of this article, and would like to recognize those who graciously donated their bodies to enable this research.

About the Authors

Philip Persino MS, is a medical student at Chicago Medical School, North Chicago, Illinois. He received his M.S. in Anatomical Sciences at NIU.

Daniel Olson MS, EdD, is an Assistant Professor in the Department of Biological Sciences at Northern Illinois University, and Director of the Anatomical Sciences Cadaver Laboratory at NIU.

Moira Jenkins MS, DC, is an Anatomy Instructor in the Department of Biological Sciences at Northern Illinois University.

Karen Samonds MS, M Phil, PhD, is an Associate Professor in the Department of Biological Sciences at Northern Illinois University, and the Program Director of the Masters Program in Anatomical Sciences.

Literature Cited

Anyanwu GE, Ugochukwu AI (2010) Impact of the use of cadaver on student's ability to pass anatomy examination. *Anatomy: International Journal of Experimental & Clinical Anatomy* 4:28-34.

Baker E, Slott P, Terracio L, Cunningham E (2013) An innovative method for teaching anatomy in the predoctoral dental curriculum. *Journal of Dental Education* 77:1498-1507.

Bergman EM, van der Vleuten CP, Scherpbier AJ (2011) Why don't they know enough about anatomy?? A narrative review. *Medical Teacher* 33:403-409.

Biasutto SN, Ignacio Caussa L, Esteban Criado del Río L (2006) Teaching anatomy: Cadavers vs. computers? *Annals of Anatomy* 188:187-190.

Chan LK, Cheng MM (2011) An analysis of the educational value of low-fidelity anatomy models as external representations. *Anatomical Sciences Education* 4:256-263.

Cornwall J (2011). The diverse utility of wet prosections and plastinated specimens in teaching gross anatomy in New Zealand. *Anatomical Sciences Education* 4:269-274.

Dissabandara LO, Nirthanan SN, Khoo TK, Tedman R (2015) Role of cadaveric dissections in modern medical curricula: A study on student perceptions. *Anatomy & Cell Biology* 48:205-212.

Drake RL, McBride JM, Lachman N, Pawlina W (2009) Medical education in the anatomical sciences: The winds of change continue to blow. *Anatomical Sciences Education* 2:253-259.

Drake RL, Pawlina W (2014) Multimodal education in anatomy: The perfect opportunity. *Anatomical Sciences Education* 7:1-2.

Fasel JHD, Aguiar D, Kiss-Bodolay D, Montet X, Kalangos A, Stimec BV, Ratib O (2015) Adapting anatomy teaching to surgical trends: A combination of classical dissection, medical imaging, and 3D-printing technologies. *Surgical and Radiologic Anatomy* 38(3):361-367.

Fruhstorfer BH, Palmer J, Brydges S, Abrahams PH (2011) The use of plastinated prosections for teaching anatomy--the view of medical students on the value of this learning resource. *Clinical Anatomy* 24:246-252.

Hochman JB, Rhodes C, Wong D, Kraut J, Pisa J, Unger B (2015) Comparison of cadaveric and isomorphic three-dimensional printed models in temporal bone education. *The Laryngoscope* 125:2353-2357.

Johnson EO, Charchanti AV, Troupis TG (2012) Modernization of an anatomy class: From conceptualization to implementation. A case for integrated multimodal–multidisciplinary teaching. *Anatomical Sciences Education* 5:354-366.

Leung K-K, Lu K-S, Huang T-S, Hsieh B-S (2006) Anatomy instruction in medical schools: Connecting the past and the future. *Advances in Health Sciences Education: Theory and Practice* 11:209-215.

Mathiowetz V, Yu C-H, Quake-Rapp C (2016) Comparison of a gross anatomy laboratory to online anatomy software for teaching anatomy. *Anatomical Sciences Education* 9:52-59.

McLachlan JC, Bligh J, Bradley P, Searle J (2004). Teaching anatomy without cadavers. *Medical Education* 38:418-424.

Nguyen N, Nelson AJ, Wilson TD (2012) Computer visualizations: Factors that influence spatial anatomy comprehension. *Anatomical Sciences Education* 5:98-108.

Noelle Industries (2004) Noelle 810-47; A two component transparent silicone dielectric gel. In: Noelle Industries, Inc.

continued on next page

Persino PR (2014) Central Nervous System Excision Manual. In: Biological Sciences. Unpublished Masters Thesis: Northern Illinois University. p 41.

Preece D, Williams SB, Lam R, Weller R (2013) "Let's Get Physical": Advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. *Anatomical Sciences Education* 6:216-224.

Riederer BM (2014) Plastination and its importance in teaching anatomy. Critical points for long-term preservation of human tissue. *Journal of Anatomy* 224:309-315.

Rizzolo LJ, Stewart WB (2006) Should we continue teaching anatomy by dissection when ...? *The Anatomical Record (Part B: New Anatomy)* 289:215-218.

Saltarelli AJ, Roseth CJ, Saltarelli WA (2014) Human cadavers Vs. multimedia simulation: A study of student learning in anatomy. *Anatomical Sciences Education* 7:331-339.

Shaffer K (2004) Teaching anatomy in the digital world. *New England Journal of Medicine* 351:1279-1281.

Simpson JS (2014) An economical approach to teaching cadaver anatomy: A 10-year retrospective. *American Biology Teacher* 76:42-46.

Stancu G, Bacean O, Bacean A (2015) Biodur S10 method in plastination of the central nervous system structures. Romanian Journal of Functional & Clinical, Macro- & Microscopical *Anatomy & of Anthropology* 14:228-230.

Stancu G, Motoc A, Stancu G, Halga A (2012) Plastination. The sustainable method of preserving anatomical preparations. *Romanian Journal of Functional & Clinical, Macro- & Microscopical Anatomy & of Anthropology* 11:296-299.

Tamura K, Stickley CD, Labrash SJ, Lozanoff S (2014) Effectiveness of plastinated anatomical specimens depicting common sports injuries to enhance musculoskeletal injury evaluation education. *Athletic Training Education Journal* 9:174.

von Hagens G, Tiedeman K (1987) The current potential of plastination. *Anatomy & Embryology* 175(4):411-421.

Winkelmann A, Hendrix S, Kiessling C (2007) What do students actually do during a dissection course? First steps towards understanding a complex learning experience. *Academic Medicine* 82:989-995.

Wright SJ (2012) Student perceptions of an upper-level, undergraduate human anatomy laboratory course without cadavers. *Anatomical Sciences Education* 5:146-157.

■

Back to TOC