Jurnal Ilmu Fisika
Vol. 15, No. 1, March 2023, pp. 22–29
ISSN: 1979-4657 (Print); 2614-7386 (Online)
https://doi.org/10.25077/jif.15.1.22-29.2023

Jurnal Ilmu Fisika
Open Access

Development of Slice Test Device for Testing Natural Rubber Composites Similarity with Incision Cadaver on Surgical Process

Riri Murniati[1*], Muhammad Nuraliffudin Saputra[1], Arini Fitria Gunawan[1], Nanda Novita[2]

[1] Department of Physics, Republic Indonesia Defense University, IPSC Sentul, Bogor, 16810, Indonesia
[2] Department of Educational Physics, Universitas Malikussaleh, Reulet, Aceh, 24351, Indonesia

---

Article Info

Article History:

Received August 01, 2022
Revised October 24, 2022
Accepted November 10, 2022
Published online November 16, 2022

Keywords:

natural rubber
alternative filler
mechanical characteristic
nanosilica

Corresponding Author:

Riri Murniati
Email: ririmurniati90@gmail.com

ABSTRACT

This research has developed the slice test device for testing natural rubber composites that made of magnetically-modified natural zeolite on nanosilica-reinforced natural rubber composites. We tested the sample similarity with incision cadaver used in surgical practice that has a mechanical characteristic like human tissue. Natural rubber is now being used as a primary component in the production of synthetic human tissue. The natural rubber had been blended with magnetic particle nanosilica, an alternative filler made of a mixture of nanosilica, natural zeolite, and magnetite. This project uses several formulas to give synthetic human tissue the desired mechanical qualities and incision test characteristics. We use technical specifications rubber (TSR) SIR 20 with nanosilica reinforced fillers and Titanate coupling agent (TCA) as filler and elastomer binders. Samples were characterized using Universal Testing Machine and then tested with the specially designed home-made incision test equipment. Mechanical characteristics of different human body part tissue were compared to the control samples having similar mechanical characteristics with internal human tissue. Based on these results, nanosilica fillers combined with magnetically-modified zeolites and titanate coupling agent are potential for application as synthetic muscle replacement cadavers with a customized formula.

---

1. INTRODUCTION

Massive cadaver (preserved human body) usage has been made in medic as a teaching and research tool, particularly for educating medical and surgical students. Cadaver usage in medical training, although controversial, has persisted over centuries. In veterinary education various methods have been proposed to either improve cadaver preservation, reduce cadaver use, or to replace cadavers entirely, but to date few have gained popularity (Varner et al., 2021). The use of cadavers as a teaching tool will help to effectively impart learning experiences about the introduction of human body parts, patient care, and the provision of specific medical procedures (Souza et al., 2020). Without a doubt, this is better than letting untrained students practice on actual patients, who could endanger them. there remains little evidence on the educational impact of teaching with or without cadavers (McLachlan et al., 2004). Without putting the patient at risk, non-human interactive technologies and systems can be utilized to educate the students abilities required to accurately detect and treat a range of health diseases (Lowe, 2015).

Medical students saw cadaver dissection as vital to their success in learning anatomy and were excited to perform their first dissection with guidance from an instructor (Rajeh et al., 2017). Other studies in medical education found both students and faculty to be in favor of access to cadaveric specimens and supportive of more traditional methods of small group teaching for anatomy based learning (Codd & Choudhury, 2011; Davis et al., 2014; Sheikh et al., 2016). Studies from the veterinary literature demonstrate similar findings (Da Silva et al., 2004; Little et al., 2018). Ghosh (2017) found that Turkish veterinary students thought the use of cadavers was absolutely necessary in their anatomy education. Before performing surgery on patients, surgeons must be trained and get familiar with the complexities of surgical operations. To be proficient in surgical operations, students, doctors, and surgeons must directly practice clinical surgical methods. Making incisions, reaching venous systems beneath the epidermis, and suturing body parts are common clinical surgical methods. This is very risky to let untrained students practice on actual patients, who could endanger them. Both digital and physical 3-D models are used to enhance education as a lower cost comparison to cadavers (Fredieu et al., 2015). When comparing 3-D printed models to cadavers directly, a meta-analysis found that test results from students using 3-D models were higher than students using traditional cadaver specimens to learn (Ye et al., 2020). It is necessary to find other ways to practice these surgical methods that are more like the nature of the human body. This tools must offer similarity of body surface tissue that is physically identical to the actual body tissue. As a result, it is essential to create material replicas based on real experimental data for surgical simulations, specifically for synthetic muscles. Tissue-slicing training is crucial to give surgeons precise feedback on routine surgical operations like grasping, cutting, and dissection, . An organ-slicing approach that is either geometry-based or physics-based.

The deformation in the geometry-based technique is only dependent on geometric manipulation, without taking into account the dynamics of internal interactions. In contrast, physics-based theories consider the dynamics of interactions between things, including how they behave physically when subjected to both internal and external pressures. The length of the resulting material slice is determined by the strength of the force applied to the scalpel. A scalpel is a tissue-cutting instrument made up of a scalpel and a blade. Compressive pressures and tensile forces playing important role during the slicing process. By measuring the slice length and cutting time while applying the same force, compared to the control material, the properties of a material can be determined. In this work, we made an effort to create synthetic cadavers using alternative materials. Clinical simulators that enable doctors to practice medical operations and researchers to examine the efficacy of medical equipment frequently employ silicone-based tissue simulating phantoms as tissue replacements.

Natural rubber is being used as a primary component in the production of synthetic human tissue (Murniati et al., 2022). The natural rubber blended with nanosilica fillers combine with magnetically modified zeolites and titanate coupling agents, potentially as an alternative filler to replace carbon black, and are applicable for synthetic muscle replacement cadavers with a customized formula. This project employ several material formula to give synthetic human tissue the desired mechanical properties and incision test characteristics. We used three different types of filler materials: kaolin, calcium carbonate, and nanosilica to achieve cadaveric properties. This is done as an additional variable in the search for natural rubber-based synthetic human tissue fillers that behave like the actual as good as possible. The volume fraction of the filler fraction will then be varied to determine the optimum filler dose.

The values of a material Young's modulus can be used to describe the material mechanical characteristics. One of the materials that can have its mechanical properties measured and observed in human tissue. The following information was gathered from sources that discuss the mechanical properties of the human body. The mechanical properties of human muscles influenced by gender, age, and body part have a significant impact which leads to variations in the physical properties of muscle depending on their functions. Therefore, based on the references found, the data in Table 1 shows the mechanical characteristics of particular areas of the human body. Mechanical characteristics may be measured by contrasting the value of Young's modulus in synthetic human tissue with data on Young's modulus for individual human body parts. This showed how closely synthetic human tissue made from natural rubber resembles actual human tissue.

2. METHOD

This experiment was divided into many phases, including: 1) the design and production of hotpress molds and slice test equipment, 2) material characterization and data gathering, and 3) data analysis. Stainless steel is utilized as a material for creating molds in the design and production of hotpress molds. The length, thickness, and the height of the mold are 10 cm, 7 cm, and 3 cm, respectively. To ensure the mechanical properties of the item to be inspected, a slice test instrument is created specifically.

Natural rubber is the primary component used in the production of synthetic muscle samples, and the processing aids are then added. The composition of the processing aids in phr (per hundreds rubber) includes 100 phr rubber, 8 phr oil, 5 phr ZnO, 2 phr stearic acid, 7.5 phr paraffin, 0.5 phr CMC, 1 phr TCA, and 2.25 phr sulfur. According to the function of each composition, each ingredient will activate the characteristics of natural rubber composites. To create a material with high tensile strength and elongation at break, cross-linking must occur. Sulfur was employed as a curing agent to start this process. ZnO (stearic acid) was an activator, while MBT (mercaptobenzothiazole) was an accelerator, both shorten the time it takes to reach the vulcanization process. In order to avoid effects that may alter the properties of polymer materials, such as oxidation, recombination, and cross-linking brought on by the oxidation of the polymer, paraffin wax was utilized as a stabilizer. Meanwhile, a softening component (oil processing) was added to aid processing so that proper mixing occurs by the mastication softening process. Then, TCA was utilized for effective chemical flow, effective cross-linking, and effective filler dispersion.

The addition of filler is a technique that may be utilized to improve the physical characteristics and lower processing costs by increasing the filler volume fraction. Except for control samples, 7.5 phr of filler per type of filler was applied to samples of synthetic muscle. Kaolin, CaCO3, and nanosilica were utilized as fillers. Additionally, modifications in the number of fillers in nanosilica were made in order to determine the necessary quantity of filler to get identical mechanical characteristics in synthetic muscle samples. The samples, which were made up of 6 pieces, varied in filler content by 2.5 phr, ranging from 0 to 12.5 phr.

The mechanical properties of samples were tested using the Universal Testing Machine (UTM). The material was then evaluated using an slice test device that had already been designed and created. Additionally, we analyzed the control samples slice test, and the results were compared to the synthetic muscle samples. The material similarity to the genuine cadaver mechanical and morphological properties was evaluated, and the existing data were compared to the control samples. Using the ISO 37:2011 standard as a guide, the sample was formed into a type 2 dumbbell shape at the time of data collection for mechanical parameters using UTM. To speed up the data processing procedure, the sample length is homogenized. Additionally, the sample material must be in a solid phase. The test results in a stress curve, which may be used to calculate the Young modulus of the composite. To complete the study data, it is important to examine the material viscoelastic properties in addition to its tensile strength. However, because of the difficulty in accessing rheology test equipment, viscoelastic qualities have not been tested in this research.

Figure 1 Molded synthetic muscle samples

Table 1 Mechanical Characteristic of Human Body (Murniati, 2018)

Part of Body	Gender	Age (Year)	Modulus Young (Mpa)
Bicep muscle	Man	65	49.02
Bicep muscle	Man	85	59.15
Bicep muscle	Man	75	48.74
Leather back	-	30	200
Leather back	-	9	0.42
Cartilage in the knee	Man	16	0.13
Cartilage in the knee	Woman	65	1.91
Shoulder muscle (anterior)	-	-	16,5
Shoulder muscle (middle)	-	-	6
Shoulder muscle (posterior)	-	-	4.1
Esophagus	-	-	0.077
Gut	-	-	0.0356
Gut	-	-	0.0359
Pericardium	-	-	2.51
Achilles tendon	-	-	819
Patellar tendon	-	-	643
Ligament (cruciate ligament)	-	-	345
Semitendinosus tendon	-	26	362.2
Ligament (ligamentum flavum)	-	Young	98
Ligament (ligamentum flavum)	-	Old	20
Ankle ligament (anterior talobifular ligament)	Woman	27	86
Cartilage (HWA of femoral condyle, superficial zone)	-	-	5
Cartilage (HWA of femoral condyle, middle zone)	-	-	3.1
Cartilage (LWA of femoral condyle, superficial zone)	-	-	10.1
Cartilage (LWA of femoral condyle, middle zone)	-	-	5.4

3. RESULTS AND DISCUSSION

3.1 Slice Test Device Preparations

It is predicted that the mechanical properties of the synthetic muscle samples that studied match the various of human body components, as indicated in Table 1. The sample must thus be tested before slicing it in order to create a composite texture that is comparable to actual human muscle. This project done so that when learning surgical methods using synthetic muscles, the medical students would have an identical interactive slicing experience like using cadavers. The mechanical properties of the synthetic muscle material may be used to test its quality. Utilizing the Universal Testing Machine tool and making reference to the international standard ISO37:2011 is one of the test methodologies that was used. The synthetic muscle sample have been shaped into a type 2 dumbbell in accordance with the ISO37:2011 testing standard (ISO, 2005).

We developed a technique that can assess the comparability of composite samples with human flesh in addition to utilizing UTM (in this test, beef is used as a control material). The scalpel on this instrument is drawn with a certain weight. We also measured the length of time it takes to slice the sample at a specific distance and the depth of the incision it makes are both measured. The depth of the sample slices should approximate the depth of the beef slices used as a comparison control with the same force. We need a slice test device that can be used for testing all samples, but there is no suitable testing device, so we created and developed a suitable testing device.

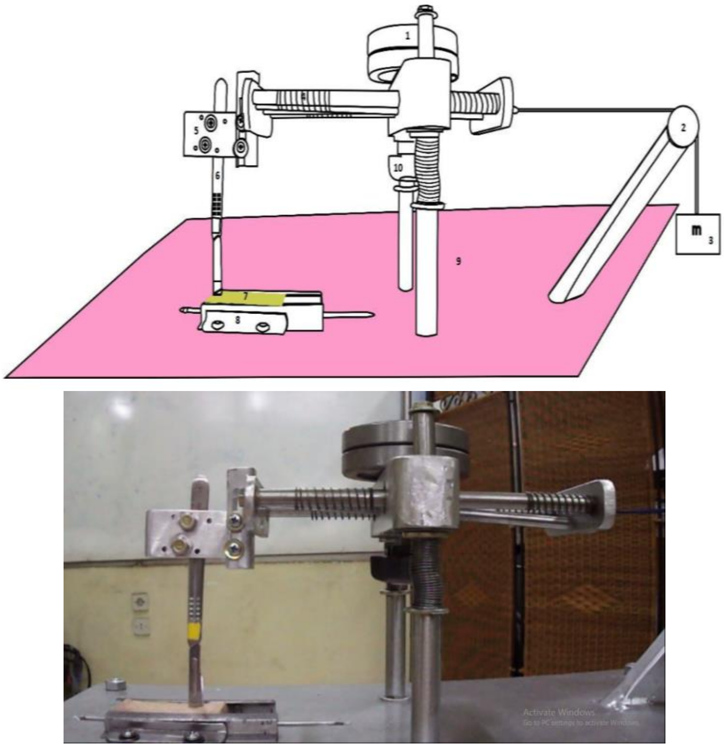

Figure 2 (a) Design of slice test device (b) slice test device

This device is built to have several parts according to their respective functions, including the top load that functions as a compressive force, a pulley, the load that passes through the pulley serves as a tensile force when slicing the sample, a spring, a scalpel clamp, a scalpel used as a slicer, sample clamp, metal base, and stopper. The design of the slice test tool is shown in Figure 2.

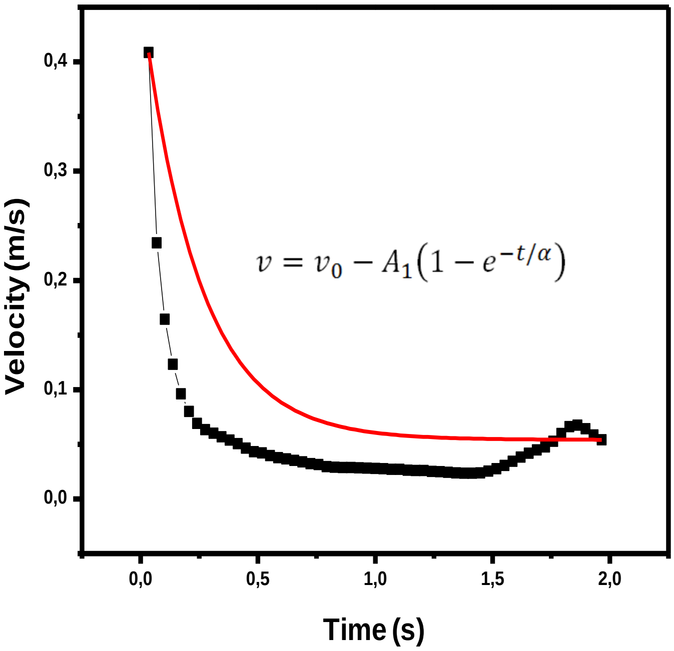

Figure 3 Fitting of the velocity as function of time (red line), the experiment data (black)

This slicing process is recorded and tracked with a video tracker to plot the results, as shown in Figure 3. For simplicity, we estimate the power of this tool as follows:

$$\frac{dv}{dt} = g\left(1 - \frac{\gamma}{mg}v\right) \tag{1}$$

$$\frac{dv}{1-\frac{\gamma}{mg}v} = g\ dt \tag{2}$$

where dv/dt is speed changes every single time, g is gravity, m is mass, and γ is a constant. With this approach, we can write the constant $\beta = \gamma/mg$ and Equation (2) becomes,

$$\int \frac{dv}{1-\beta v} = \int g\ dt \tag{3}$$

$$v = \frac{1}{\beta}\left(1 - e^{-\beta g t}\right) \tag{4}$$

$$x = \frac{t}{\beta} - \frac{1}{\beta^2 g}\left(1 - e^{-\beta g t}\right) \tag{5}$$

We can get the variable β from the speed fitting, as shown in Figure 3. Then the results can be compared to the speed of the scalpel slicing the sample against the time obtained from the experimental results of this slice tester, which satisfies the equation

$$v = v_0 + A_1\left(1 - e^{-t/\alpha}\right) \tag{6}$$

Assuming that the initial velocity (v_0) is zero, and A_1 is 0.2, so the fitting equation can be written as

$$v = 0.2\left(1 - e^{-\frac{t}{0,024}}\right) \tag{7}$$

So we have the variable value of β = 5 from the Equations (4) and (7).

3.2 Slice Test Result

This research is constrained by the limited original human muscles that can be used in research trials. As a result, we used beef as a control sample and Table 1 comparative data on the mechanical properties of specific human muscle components based on other sources (Murniati et al., 2017). Young's modulus tests on beef samples gave a result of 0.21 MPa. The Young's modulus of synthetic muscle test samples with 10 phr of nanosilica filler has 0.209 MPa. These findings suggest that the mechanical properties of the synthetic muscle sample and the control sample were compared. Murniati et.al.(2017) also synthesize nanocomposite that has a mechanical characteristic of the human tissue with the optimization type of filler (nanosilica, caolin and CaCO3), and the optimization of filler nanosilica volume fraction. This research has produced some materials that have a similar mechanical characteristic with internal human tissue characteristic. The mechanical properties were compared to a 16-year-old male's knee with Young's modulus of 0.13 Mpa compared to the comparative data in Table 1. However, this outcome is still far from the biceps or ligaments' Young's modulus value.

Furthermore, beef and synthetic muscle samples were used as controls for the slice test process. In order to capture the actual condition of the object's motion, a video is recorded during the sample slicing. By painting the blade a particular color as a detector of the movement of the blade when slicing the sample, it is possible to track and degrade the location during the slicing process. Following a computer analysis of the video recording findings, tables and graphs are created to show the link between the motion of objects and their physical characteristics, such as position and time. The sample can be cut with a scalpel at various angles for the vertical axis during the test. In this instance, it uses angles of 0, 30, and 40° to represent a wide range of angles. The sample is sliced at a 30° angle. The data of the curved location against time is shown in Figure 4. Then, the sample slice's simultaneous length data was examined for 0.93 seconds. This information is shown in Table 2.

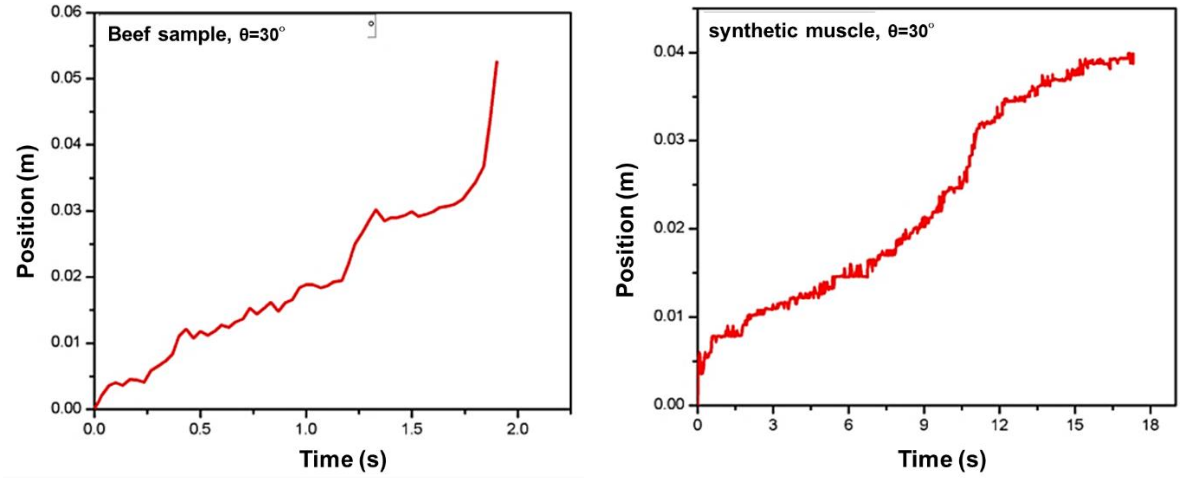

Figure 4 Position versus time curve from the sample slice test results

Table 2 Length of sample slices at the same time

Optimation	Sample	Time (s)	Angle (°)	Length of slice (10^{-2} m)
Meat	Test 1	0.93	30	1.66
Meat	Test 2	0.93	30	1.62
Filler varian	Control	0.93	30	1.07
Filler varian	Kaolin	0.93	30	0.86
Filler varian	$CaCO_3$	0.93	30	0.98
Filler varian	Nanosilica	0.93	30	1.41
Volume fraction of nanosilica	0	0.93	30	1.35
Volume fraction of nanosilica	0.021	0.93	30	1.21
Volume fraction of nanosilica	0.041	0.93	30	1.17
Volume fraction of nanosilica	0.060	0.93	30	1.28
Volume fraction of nanosilica	0.078	0.93	30	1.43
Volume fraction of nanosilica	0.096	0.93	30	1.08

The variation of the sample slice length during 0.93 s showed that the mechanical properties of diverse synthetic muscle samples continue to differ significantly from the beef control samples. Synthetic muscle incision lengths were mostly shorter than synthetic muscle samples of beef. This is because synthetic muscle samples often have a firmer, stiffer texture. However, there are still some synthetic muscle samples, especially those containing nanosilica filler and a volume fraction of 0.078, which is close to the cut length value of beef samples. This shows that the mechanical properties of synthetic muscle samples with nanosilica fillers and control samples are close to the expected results.

4. CONCLUSION

Young's modulus value is significantly different from all optimizations, which show the features of synthetic muscles that mimic human muscles. In contrast, Young's modulus of synthetic muscle comes close to the beef results, particularly in samples containing 10 phr nanosilica filler with 0.209 MPa, which is close to the expected results of Young's modulus of a beef sample of 0.21 MPa. The skin on the human back, which has a modulus of 0.42 MPa, and the cartilage in a male knee, which has a modulus of 0.13 MPa, come close to the young person's modulus when compared to the properties of the human body. The results of the slice test of beef with length 1.64 x 10^{-2} m and synthetic muscle were measured using a slicer characterization; the sample with the results most similar to the beef value was made with nanosilica filler 10 phr with length 1.43 x 10^{-2} m. Slices of synthetic muscle are mostly shorter than beef because of the more rigid texture of synthetic muscle. The expected results to get synthetic muscles similar to the human body's characteristics are close to the expected results in terms of the value of Young's modulus and slice test results.

REFERENCE

Codd, A. M., & Choudhury, B. (2011). Virtual reality anatomy: Is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? *Anatomical Sciences Education*, *4*(3), 119–125.

Da Silva, R. M. G., Matera, J. M., & Ribeiro, A. A. C. M. (2004). Preservation of cadavers for surgical technique training. *Veterinary Surgery*, *33*(6), 606–608.

Davis, C. R., Bates, A. S., Ellis, H., & Roberts, A. M. (2014). Human anatomy: let the students tell us how to teach. *Anatomical Sciences Education*, *7*(4), 262–272.

Fredieu, J. R., Kerbo, J., Herron, M., Klatte, R., & Cooke, M. (2015). Anatomical models: a digital revolution. *Medical Science Educator*, *25*(2), 183–194.

Ghosh, S. K. (2017). Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. *Anatomical Sciences Education*, *10*(3), 286–299.

ISO, I. S. O. (2005). *Rubber, vulcanized or thermoplastic-Determination of tensile stress-strain properties*. Technical report, International Organization for Standardization.

Little, W. B., Artemiou, E., Conan, A., & Sparks, C. (2018). Computer assisted learning: Assessment of the veterinary virtual anatomy education software IVALA™. *Veterinary Sciences*, *5*(2), 58.

Lowe, S. (2015). *Surgical simulation models, materials, and methods*. Google Patents.

McLachlan, J. C., Bligh, J., Bradley, P., & Searle, J. (2004). Teaching anatomy without cadavers. *Medical Education*, *38*(4), 418–424.

Murniati, R. (2018). Nanokomposit Karet Alam/Silikon Sebagai Otot Sintetik Dengan Sifat Mekanik Seperti Otot Manusia. *Jurnal Ilmu Fisika*, *10*(1), 38–45.

Murniati, R., Wibowo, E., Rokhmat, M., Iskandar, F., & Abdullah, M. (2017). Natural rubber nanocomposite as human-tissue-mimicking materials for replacement cadaver in medical surgical practice. *Procedia Engineering*, *170*, 101–107.

Murniati, R., Gunawan, A. F., Saputra, M. N., Imastuti, I., & Abdullah, M. (2022). Nanosilica Particulate Magnetic as Alternative Filler on Natural Rubber Composites with Human-Tissue-Like Mechanical Characteristic. *Jurnal Ilmu Fisika*, *14*(2), 124–131.

Rajeh, N. A., Badroun, L. E., Alqarni, A. K., Alzhrani, B. A., Alallah, B. S., Almghrabi, S. A., & Almalki, L. A. (2017). Cadaver dissection: A positive experience among Saudi female medical students. *Journal of Taibah University Medical Sciences*, *12*(3), 268.

Sheikh, A. H., Barry, D. S., Gutierrez, H., Cryan, J. F., & O'Keeffe, G. W. (2016). Cadaveric anatomy in the future of medical education: What is the surgeons view? *Anatomical Sciences Education*, *9*(2), 203–208.

Souza, A. D., Kotian, S. R., Pandey, A. K., Rao, P., & Kalthur, S. G. (2020). Cadaver as a first teacher: A module to learn the ethics and values of cadaveric dissection. *Journal of Taibah University Medical Sciences*, *15*(2), 94–101.

Varner, C., Dixon, L., & Simons, M. C. (2021). The past, present, and future: a discussion of cadaver use in medical and veterinary education. *Frontiers in Veterinary Science*, *8*.

Ye, Z., Dun, A., Jiang, H., Nie, C., Zhao, S., Wang, T., & Zhai, J. (2020). The role of 3D printed models in the teaching of human anatomy: a systematic review and meta-analysis. *BMC Medical Education*, *20*(1), 1–9.