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Title: Utilizing a 3D Printed Laparoscopic Nissen Fundoplication Model to Shorten a Resident's Learning Curve

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes**

3. Filming location: Will the filming need to take place in multiple locations? **No**

Current Protocol Length
Number of Steps: 23
Number of Shots: 45

Introduction

1.1. **Zhifei Wang:** Our research evaluates whether a realistic 3D-printed model can help surgical residents master complex laparoscopic surgery skills faster and more safely before they enter the operating room.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: 3.2*

What research gap are you addressing with your protocol?

1.2. **Sidney Moses Amadi:** Residents often lack confidence in advanced procedures after standard training. We address the gap between basic simulation and the complexities of real operating room performance and suturing.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What advantage does your protocol offer compared to other techniques?

1.3. **Ketrin Desdery:** Our protocol uses a low-cost, reusable, and anatomically accurate model. It allows for risk-free practice of critical surgical steps, which isn't always feasible with other methods.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B roll: 2.5*

How will your findings advance research in your field?

1.4. **Muhammad Osama Wali Zada:** Our findings provide a validated training pathway that shortens the learning curve. This can directly lead to improved surgical proficiency, reduced complications, and ultimately, better patient outcomes.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Ethics Title Card

This research has been approved by the Zhejiang Provincial People's Hospital Institutional Review Board

Protocol

2. Preparing the 3D Printed LNF Model

Demonstrators: Shijie Yu, Muhammad Osama Wali Zada

2.1. After performing 3D computed tomography **[1],** convert the DICOM *(Die-Com)* profiles into STL *(S-T-L)* format **[2]**. Import the STL files into Magics 24 software by selecting **File** and then **Import [3]**. Run automatic fixing through the **Menu bar**, select **Fix**, and choose **Auto Fix [4]**.

2.1.1. WIDE: Talent at a computer with the CT images displayed on the monitor.

2.1.2. SCREEN: 2.1.2.mp4: 00:06-00:15

2.1.3. SCREEN: 2.1.3.mp4: 00:00-00:18, 01:01-01:03

2.1.4. SCREEN: 2.1.4.mp4: 00:07-00:17, 01:01-01:06, 01:35-01:37

~~2.2. To perform partial manual fixing, select **Menu bar**, **Fix**, and **Manual Fixing [1]**. Then, select **Menu bar** and **Fix** followed by **Remove Noise Shells** to remove noise shells and debris **[2]**.~~ NOTE: This step is not filmed

~~2.2.1. SCREEN: Show the Fix > Manual Fixing option being selected from the Menu bar and the interface for manual model adjustments.~~

~~2.2.2. SCREEN: Show the Fix > Remove Noise Shells option being selected and debris being removed from the model.~~

2.3. Afterward, select **Menu bar**, **Orientation**, and **Create Support** to add support structures **[1]**. Next, to export the repaired and supported model, select the **Menu bar**, **File**, **Export,** and **STL [2]**.

2.3.1. SCREEN: 2.3.1.mp4: 00:05-00:09, 00:22-00:24, 00:30-00:33

2.3.2. SCREEN: 2.3.2.mp4: 00:00-00:17.

2.4. Using an LCD 3D printer, open the Chitubox software and click on **Slice Settings** under the **Resin** tab. Set the layer thickness to 0.1 millimeters, adjust the number of bottom layers to 8, set the bottom layer lift speed to 90 millimeters per minute, and the lift speed to 80 millimeters per minute **[1]**.

2.4.1. SCREEN: 2.4.1.mp4: 00:18-01:07

2.5. Now, clean the printed mold thoroughly in an ultrasonic cleaner using ethanol solvent at a frequency of 40 kilohertz for 3 to 5 minutes **[1]**.

2.5.1. Talent placing the printed mold into an ultrasonic cleaner filled with ethanol solvent.

2.6. Complete the secondary curing of the mold in a UV chamber **[1-TXT]**. After curing, apply a thin layer of petroleum jelly to the inner surfaces of the mold components to act as a release agent **[2].** NOTE: The VO is edited for the moved shot

2.6.1. Talent placing the mold inside a UV curing chamber and starting the curing process. **TXT: Wavelength: 405; Intensity: 30 mW/cm²; Curing time: 30 min**

2.10.1. Talent applying petroleum jelly to the inner surfaces of the mold components NOTE: This shot is moved here as per authors request

2.7. Next, prepare two-component zero-degree silicone **[1].** Place the mixture in an environment maintained at an ambient temperature of 22 to 25 degrees Celsius to prevent high temperatures from affecting the operational time **[2].**

2.7.1. Talent pouring Component A and 750 Component B into a mixing container.

2.7.2. Talent placing the mixed silicone in a temperature-controlled workspace at 22 to 25 degrees Celsius.

2.8. Place the silicone mixture into a vacuum chamber set to a vacuum level of minus 0.09 megapascal for a defoaming time of 8 minutes **[1]**. Pour the prepared silicone from the vacuum chamber into the organ mold **[2]** and observe to ensure that the silicone fills the mold evenly and that no large air bubbles are visible on the surface **[3]**.

2.8.1. Talent positioning the silicone mixture inside a vacuum chamber and starting the defoaming process.

2.8.2. Talent pouring the degassed silicone into the organ mold.

2.8.3. Close-up of the silicone filling the mold evenly with no visible large air bubbles.

2.9. Allow the silicone to fully cure in an airtight environment maintained at approximately 25 degrees Celsius for 1 hour **[1]**.

2.9.1. Talent placing the filled mold inside an airtight curing chamber with a visible temperature display.

2.10. After curing, carefully remove the mold to obtain the final silicone organ model **[1]**. NOTE: The VO is moved from 2.10 to 2.6 for the moved shot

2.10.1. ~~Talent applying petroleum jelly evenly along the mold's inner surfaces.~~ NOTE: This shot is moved after 2.6.1

2.10.2. Talent separating the mold components to reveal the silicone liver model.

2.11. Examine the surface of the silicone model to ensure completeness and clarity of anatomical structures **[1]**.

2.11.1. Close-up shot of the silicone liver model showing intact anatomical details.

3. Assembling the LNF Model

3.1. Place the 3D printed organ models according to the corresponding anatomical layout **[1]**.

3.1.1. WIDE: Talent arranging the 3D printed organ models on the workspace in the correct anatomical order.

3.2. Lay out the oesophagus attached to the stomach so that it enters the mediastinum through the opening between the crura and the gastric fundus **[1]**.

3.2.1. Talent positioning the oesophagus and stomach, aligning them with the opening between the crura and gastric fundus.

3.3. Now, place the omentum, liver, and bile duct adjacent to the stomach, securing them in position with pins **[1]**. Then, place the skin onto the plastic platform and secure it **[2]**. Connect the internal platform light to a power source to enhance visibility **[3]**.

3.3.1. Talent positioning the omentum, liver, and bile duct next to the stomach and fixing them in place with pins.

3.3.2. Talent stretching and attaching the skin to the platform.

3.3.3. Talent plugging in the platform light to a power source and switching it on.

3.4. Next, make 3 incisions on the skin for ergonomic trocar positioning **[1]**. Insert a 5-millimeter trocar for the 30-degree laparoscope at the center to establish the triangle of vision **[2]**. Position two 10-millimeter trocars on either side for laparoscopic needle drivers, atraumatic graspers, and laparoscopic scissors **[3]**.

3.4.1. Talent making 3 measured incisions on the skin.

3.4.2. Talent inserting a 5-millimeter trocar at the central incision.

3.4.3. Talent positioning two 10-millimeter trocars on each side of the central trocar.

3.5. Then, secure the laparoscope using a clamp **[1]** and connect it to the USB port of a high-definition display screen on either a television or laptop **[2]**.

3.5.1. Talent fixing the laparoscope in place with a clamp.

3.5.2. Talent connecting the laparoscope cable to a laptop USB port and displaying the live feed.

3.6. Place a 2-0 silk suture with a CT-1 needle inside the model **[1]**.

3.6.1. Talent positioning the 2-0 silk suture with a CT-1 needle within the surgical model.

4. Training Curriculum

4.1. Gently pass a Penrose drain behind the already mobilized posterior esophagus to serve as a retractor **[1]**. Apply gentle traction to the drain to retract the esophagus, ensuring clear visualization of the right and left crura of the diaphragm **[2]**.

4.1.1. Talent using a grasper to guide the Penrose drain into position behind the esophagus. File name: 4.4.1.mp4 NOTE: Shot 4.1.1 and 4.1.2 has been modified

4.1.2. Talent applies gentle traction on the Penrose drain, retracting the esophagus to clearly expose both crura of the diaphragm. File name: 4.1.2.mp4

4.2. Then, identify the bilateral diaphragmatic crura and place five interrupted sutures to approximate them securely without tension **[1]**. Verify that the crura are firmly closed and adequately aligned to ensure proper approximation of the diaphragmatic pillars **[2]**.

4.2.1. Talent shows the bilateral diaphragmatic crura and placing the first of five interrupted sutures between the crura. File name: 4.2.1.mp4

4.2.2. Close-up of the closed crura showing even approximation without tension. File name: 4.2.2.mp4

4.3. Next, place the mesh symmetrically on the diaphragm **[1]**. Suture the sides of the mesh evenly to the diaphragm **[2]** to ensure it lies flat without wrinkling while maintaining a clear margin between the mesh and the esophageal wall **[3]**.

4.3.1. Talent positioning the mesh evenly over the diaphragm. File name: 4.3.1.mp4

4.3.2. Talent suturing one side of the mesh to the diaphragm. File name: 4.3.2.mp4

4.3.3. Close-up showing the mesh secured flat with an even margin from the esophagus. File name: 4.3.3.mp4

4.4. After passing the bougie through the esophagus into the stomach, perform the 'shoe shine manoeuvre' to mobilize and align the gastric fundus **[1]**. Wrap the fundus over 2 to 3 centimeters of the oesophagus, ensuring a floppy, tension-free, 360-degree fundoplication wrap no longer than 2 centimeters **[2]**.

4.4.1. Talent demonstrating the 'shoe shine manoeuvre' with the gastric fundus. File name: 4.4.1.mp4

4.4.2. Close-up of the gastric fundus wrapping evenly around the oesophagus with no visible tension. File name: 4.4.2.mp4

4.5. Then, close the wrap with three interrupted sutures over a 1.5-centimeter length **[1-TXT]** and inspect thoroughly to ensure that the wrap is firmly secured **[2].** NOTE: The VO is edited for the additional shot

4.5.1. Talent placing the first of three interrupted sutures on the fundoplication wrap. **TXT: Ensure secure, even sutures to maintain wrap integrity** File name: 4.5.1.mp4

4.5.2. ~~Talent passing a bougie through the esophagus to the stomach to confirm appropriate looseness.~~ NOTE: Not filmed

Added Shot: Final inspection to ensure the wrap is firmly done. File name: 4.5.3.mp4

4.6. Conduct a final assessment of live operating room performance under expert surgeon supervision, ensuring all steps meet procedural standards **[1-TXT]**.

4.6.1. Expert surgeon observing and evaluating the trainee performing the final steps of the procedure in a simulated OR setting. **TXT: Assess the 3D printed LNF model training platform**

Results

5. Results

5.1. The experimental group achieved significantly higher OSATS *(O-Sats)* scores compared to the control group **[1]**, while also completing the procedure in a notably shorter duration **[2]**.

5.1.1. LAB MEDIA: Figure 3A. *Video editor: Highlight the taller purple bar labeled "Experimental Group*

5.1.2. LAB MEDIA: Figure 3B. *Video editor: Highlight the shorter purple bar labeled "Experimental Group"*

5.2. Training session performances showed a consistent increase in total scores from session 1 to session 6 **[1]**, reaching values close to the expert benchmark **[2]**.

5.2.1. LAB MEDIA: Figure 4A.

5.2.2. LAB MEDIA: Figure 4A. *Video editor: Highlight the similar height of the blue and orange dots labeled "OR" and "Expert"*

5.3. Median performance scores improved steadily across training sessions **[1]**, starting from 4.5 in session 1 and reaching 9.0 in session 6 **[2]**.

5.3.1. LAB MEDIA: Table 1. *Video editor: Highlight the row "Training Session 1" under "Median IQR" showing 4.5 (3.0–9.75).*

5.3.2. LAB MEDIA: Table 1. *Video editor: Highlight the row "Training Session 6" under "Median IQR" showing 9.0 (6.75–18.75).*

5.4. A strong inverse relationship was observed between procedure completion time and total score, with completion time decreasing as scores increased **[1]**.

5.4.1. LAB MEDIA: Figure 4B.

5.5. Expert evaluations confirmed the model was easy to use **[1]**, highly suitable for surgical training **[2]**, and effective in improving surgical skills **[3]**.

5.5.1. LAB MEDIA: Table 2. *Video editor: Highlight the expert rating value of 4.52 ± 0.50 for "The model is easy to use."*

5.5.2. LAB MEDIA: Table 2. *Video editor: Highlight the expert rating value of 4.80 ± 0.45 for "Using model in surgical training is reasonable."*

5.5.3. LAB MEDIA: Table 2. *Video editor: Highlight the expert rating value of 4.28 ± 0.08 for "The model can help improve surgical skills."*

1. DICOM

- **Pronunciation link:** https://www.howtosay.co.in/pronounce/dicom-in-english/ (Pronouncebee)
- **IPA:** /dɪˈkoʊm/ (HowToSay)
- **Phonetic Spelling:** dih-KOHM

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2. STL

- Acronym pronounced by letters in American English: **"S-T-L"**
- **Pronunciation Link:** *No confirmed link found*
- **IPA:** /ɛs-ti-ˈɛl/
- **Phonetic Spelling:** S-T-L

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3. Magics (as in *Magics 24* software)

- **Pronunciation Link:** *No confirmed link found*
- **IPA:** /ˈmædʒɪks/ (same as plural of "magic")
- **Phonetic Spelling:** MAJ-iks

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4. Ultrasonic

- **Pronunciation link:** Cambridge Dictionary (US): /ˌʌl.trəˈsɑː.nɪk/ (pronouncenames.com, Collins Dictionary, youglish.com, Wikipedia, Cambridge Dictionary)
- **IPA:** /ˌʌl.trəˈsɑː.nɪk/ (Cambridge Dictionary)
- **Phonetic Spelling:** uhl-truh-SAW-nik

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5. Petroleum

- **Pronunciation link:** Cambridge Dictionary (US): /pəˈtroʊ.li.əm/ (Cambridge Dictionary)
- **IPA:** /pəˈtroʊ.li.əm/ (Cambridge Dictionary)
- **Phonetic Spelling:** puh-TROH-lee-əm

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6. Esophagus

- **Pronunciation link:** Cambridge Dictionary (US): /ɪˈsɑː.fə.gəs/ (youglish.com, Cambridge Dictionary)
- **IPA:** /ɪˈsɑː.fə.gəs/ (Cambridge Dictionary)
- **Phonetic Spelling:** ih-SAH-fuh-gus

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7. Silicone

- This is a common technical term; while not sourced, here's the standard American pronunciation:
- **No confirmed link found**
- **IPA:** /ˈsɪl.əˌkoʊn/
- **Phonetic Spelling:** SIL-uh-kohn

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8. Trocar (used in laparoscopic context)

- Pronunciation can vary; here's the standard:
- **No confirmed link found**
- **IPA:** /troʊˈkɑr/
- **Phonetic Spelling:** troh-KAR