Validation of a Simulation Model For Laparoscopic Myomectomy Developed with 3D-Printed Molds

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We have no actual or potential conflicts of interest in relation to this program or presentation.
BUT FIRST...A THANK YOU!

- Department of Obstetrics and Gynecology, Section of General Obstetrics and Gynecology
- Medical Illustration Graduate Program
- Medical Summer Scholars Program
- Educational Innovation Institute
OBJECTIVES

1. Describe the role of 3D printing in the medical field.
2. List the various materials and the steps used in the process of creating a realistic uterine model.
3. Discuss the aspects of the model that required troubleshooting and any modifications that were made.
4. Explain the importance of interprofessional collaboration in the development of the model.
5. Discuss any future plans or areas of research involving the uterine model as well as other anatomic models.
3D PRINTING: THE RISE TO FAME

- Invented by physicist Charles Hull in 1986
  - Originally used by the manufacturing industry to create product prototypes
  - “...a method and apparatus for making solid objects by successively ‘printing’ thin layers of the ultraviolet curable material one on top of the other.” – Charles Hull
- The technology entered into the medical field in the early 2000s
  - Used to create dental implants and custom prosthetics
3D PRINTING: THE RISE TO FAME

“A very powerful tool that can create anything.”
Charles Hull

LulzBot Mini
$1,250 (Amazon)

MakerBot Replicator
$2,499 (Amazon)
How is 3D printing revolutionizing the medical field?

Customization and Personalization
3D PRINTER IN ACTION
TYPES OF 3D PRINTERS

- Filament, Fused Deposition Modeling (FDM)
  - Plastic filament heated and deposited in layers
- Light cured resin, Stereolithography (SLA)
  - Laser cures liquid resin
  - High resolution
- Polyjet (PJ)
  - Deposited photopolymer in layers like an inkjet printer
  - High-resolution
- Selective Laser Sintering (SLS)
  - Laser cures a powder
  - Nylon, ceramics, glass, metals

FDM Printing Schematic
<table>
<thead>
<tr>
<th>Material based type</th>
<th>Liquid</th>
<th>Filament</th>
<th>Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Liquid solidification</td>
<td>Material melted and solidified by cooling</td>
<td>Material sintered by laser</td>
</tr>
<tr>
<td></td>
<td>Liquid solidification</td>
<td>Material solidified with liquid binder</td>
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<tr>
<td>Process</td>
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<td>FDM</td>
<td>SLS</td>
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<td></td>
<td>PJ</td>
<td></td>
<td>BJ</td>
</tr>
<tr>
<td>General building speed (slow/intermediate/fast)</td>
<td>Intermediate</td>
<td>Slow$^{39}$</td>
<td>Fast$^{39}$</td>
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<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Printing quality</td>
<td>Accuracy (low/intermediate/high)</td>
<td>High$^{39}$</td>
<td>High$^{37}$</td>
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<tr>
<td></td>
<td>Resolution of a typical machine (µm)</td>
<td>5–25</td>
<td>15–30</td>
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<td></td>
<td>100</td>
<td>125</td>
<td>100</td>
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<td>Costs</td>
<td>Machine ($/$/$/$)</td>
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Garcia, J. et al, 2017
CURRENT APPLICATIONS IN THE MEDICAL FIELD

Tracheal Splints
(University of Michigan)

Prosthetics
(University of Toronto)
CURRENT APPLICATIONS IN THE MEDICAL FIELD

Microporous Scaffolds Seeded with Ovarian Follicles
(Northwestern University)

Cranium Replacement
(University Medical Center in Utrecht)
CURRENT APPLICATIONS IN MEDICAL EDUCATION

Forbes: The State of 3D Printing, 2017
ANATOMICAL MODELS FOR SURGICAL TRAINING

- Pre-Surgical Planning of Complex Cases
  - Patient-specific model generated using CT/MRI data
  - Printed with resin that resembles the organ(s) of choice
ANATOMICAL MODELS FOR SURGICAL TRAINING

- Liver parenchyma (transparent)
- Inferior vena cava and hepatic veins (purple)
- Portal vein (blue)
- Tumor and hepatic arterial supply (pink)
Resident Simulation Training

- Cost-effective method of producing simulation models that demonstrate the anatomical and pathological characteristics of a disease process
- When combined with the use of silicone and other modeling agents, 3D printing can create specific devices resembling the haptic properties of the organ(s) of choice
Uterine fibroids are the most common benign uterine tumors in women. For symptomatic patients who want to preserve fertility, laparoscopic myomectomy (LM) may be indicated. LM requires advanced surgical skill in order to successfully complete fibroid excision and laparoscopic suturing. Procedural difficulty and lack of provider comfort has led to decreased exposure of LM in residency programs.
In procedure-based residency programs, surgical simulation is an essential component to residents’ training.

For training in LM, limited commercial simulation products for LM exist and are cost-prohibitive for consistent use.

Thus, our research questions was as follows:

Can we use 3D printing in combination with other modeling agents (silicone, etc.) to create a cost-effective simulation model for LM?
A fibroid uterus computer model was generated using Pixelogic® Z-brush design software.

The model consisted of the following:

- Uterine body
- 4 fundal subserosal fibroids (2 anteriorly and 2 posteriorly)
- Fallopian tubes
- Round ligament
UTERINE MODEL FOR LAPAROSCOPIC MYOMECTOMY

- Fallopian tube
- Fibroid
- Round ligament
- Velcro to fasten it in the trainer box
MATERIALS AND METHODS: DIGITAL DESIGN

Preliminary model generated in Z-brush
MATERIALS AND METHODS: TEST PRINT
MATERIALS AND METHODS: TEST PRINT
The positive shape of the uterus was subtracted from a four-part mold design. The four parts of the mold include:

- Two main pieces that close to form the body
- Two pieces to avoid entrapment of the fallopian tubes
- The fibroids required an additional two-part mold
Uterine Fibroid Mold
MATERIALS AND METHODS: 3D PRINTING

- The molds were exported as a StereoLithography (STL) file
- STL file was uploaded to Ultimaker® Cura software
- The molds were printed from a LulzBot TAZ 6 3D printer using polylactic acid 3mm filament
MATERIALS AND METHODS: CASTING THE MODEL

- Smooth-On Dragon Skin 10® with a durameter of 10 was used for the uterus.
- Smooth-On Dragon Skin 30® with a durameter of 30 was used to create the fibroids.
  - Utilizing silicone of different durameters contributed to the distinct haptic properties of the model.
- Factor II Functional Intrinsic II- Silicone Coloring System was used to add realistic color to the uterus and the fibroids.
MATERIALS AND METHODS: CASTING THE MODEL
## MATERIALS AND METHODS: CASTING THE MODEL

<table>
<thead>
<tr>
<th></th>
<th>Uterine Molds</th>
<th>Uterine Fibroid Molds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Durameter of Silicone</strong></td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><strong>Quantity of Silicone</strong></td>
<td>~400 grams</td>
<td>~100 grams</td>
</tr>
<tr>
<td><strong>Cure Time</strong></td>
<td>~15 minutes</td>
<td>~15 minutes</td>
</tr>
<tr>
<td><strong>Set Time</strong></td>
<td>2.5 - 3 hours</td>
<td>1 hour</td>
</tr>
<tr>
<td><strong>Workflow</strong></td>
<td>Silicone painted in molds → cure → placement of fibroids → fill with remaining silicone → set</td>
<td>Silicone poured into molds → cure → set</td>
</tr>
</tbody>
</table>
Bottom Uterine Mold

Top Uterine Mold
### MATERIALS AND METHODS: TOTAL COST

<table>
<thead>
<tr>
<th>Total Cost for Study</th>
<th>Cost per Model Recast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molds</strong></td>
<td><strong>Molds</strong></td>
</tr>
<tr>
<td>$170.00</td>
<td>$0.00</td>
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<tr>
<td><strong>Silicone</strong></td>
<td><strong>Silicone</strong></td>
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<tr>
<td>$130.00</td>
<td>$26.00</td>
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<tr>
<td><strong>Pigment</strong></td>
<td><strong>Pigment</strong></td>
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<tr>
<td>$18.00</td>
<td>$3.60</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
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<tr>
<td>$318.00</td>
<td>$29.60</td>
</tr>
</tbody>
</table>

5 uterine models with 4 fibroids each
Materials and Methods: Validating the Model

- Velcro was sutured into the base of each model in order to fasten it in the simulation trainer box.
- Residents evaluated the model and its effectiveness in simulating LM upon simulation completion.
MATERIALS AND METHODS: VALIDATING THE MODEL
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MATERIALS AND METHODS: VALIDATING THE MODEL

- Thirteen residents evaluated the model upon completing the simulation.
- The evaluation was presented as a 5-point Likert scale with 1 meaning “strongly disagree” and 5 meaning “strongly agree”.

13. This model correlates with the essential skills needed for laparoscopic myomectomy.
   - 1  2  3  4  5

14. This model is able to mimic the anatomy of a fibroid uterus.
   - 1  2  3  4  5

15. This model helps to develop skills needed for laparoscopic dissection.
   - 1  2  3  4  5

16. This model helps to develop skills needed for laparoscopic myomectomy.
   - 1  2  3  4  5

17. This model helps to develop skills for laparoscopic suturing.
   - 1  2  3  4  5

18. The myomectomy task is a valuable training experience.
   - 1  2  3  4  5

19. Use of this model will increase resident competency in laparoscopy.
   - 1  2  3  4  5

20. Please provide any suggestions that you may have for improvement of the model.
MATERIALS AND METHODS: VALIDATING THE MODEL

Resident Responses (N=13)

- Realism: 4
- Dissection: 4.5
- Suture: 4.5
- Training: 4.5
- Skills: 4.5
- Competency: 4.8
Compatibility with surgical instruments

- A cautery is the typical surgical device used in the procedure
- However, a cautery requires organic material to initiate the appropriate reaction
  - Uterine model lacked organic material
  - Tofuterus? Perhaps in the future
Solution: Use a harmonic scalpel during the simulation

- Utilizes ultrasonic vibration, rather than an electric current, to cut and cauterize tissues
TROUBLESHOOTING AND MODIFICATIONS

- Fibroid adherence to the “myometrium”
  - During the simulation test, residents found that the base of the fibroid adhered to the ”myometrium,” making it difficult to excise
- Fibroids were initially coated in a separator (dish soap)
  - Too little separator?
  - Inadequate mixing of the separator? (typically 1:1)
TROUBLESHOOTING AND MODIFICATIONS

- Solution: Careful mixing of the dish soap/water mixture
- Solution: Place a small piece of Saran Wrap® behind the fibroid to facilitate excision
TROUBLESHOOTING AND MODIFICATIONS

- 3D printer malfunction
  - Still unsure of the exact cause of malfunction
  - Misalignment?
  - Overuse?
TROUBLESHOOTING AND MODIFICATIONS

- Solution: Outsource the design!
  - [www.3dhubs.com](http://www.3dhubs.com)
  - [www.makexyz.com](http://www.makexyz.com)
To make the model more economical, we devised a method to repair the model with silicone and Saran Wrap®

- Reuse the fibroids
- Re-cast with silicone
INTERPROFESSIONAL COLLABORATION

- Members of the Team
  - Ob-Gyn Clinicians
  - Medical Illustrators
  - Ob-Gyn Residents
  - Medical Students
We recommend a **multidisciplinary** team approach for production of simulation models.

- Provides an ideal combination of medical sculpture knowledge and clinical skills.
FUTURE AREAS OF RESEARCH
"What is the NIH 3D Print Exchange?"

“Few scientific 3D-printable models are available online, and the expertise required to generate and validate such models remains a barrier. The NIH 3D Print Exchange eliminates this gap with an open, comprehensive, and interactive website for searching, browsing, downloading, and sharing biomedical 3D print files, modeling tutorials, and educational material.”

https://3dprint.nih.gov/
CREATE A PATIENT-SPECIFIC MODEL FROM IMAGING DATA

Capture the area of interest from the medical imaging

Creation of 3D geometry from dataset specific to the area of interest

Transformation of the 3D object to a file ready for printing

Selection of the appropriate 3D printer

Selection of the appropriate use of material

Garcia, J. et al, 2017
3D ULTRASOUND FOR PATIENT-SPECIFIC MODELS

Figure 2  Examples of post-processing functions include surface render and volume contrast imaging. A: Three-dimensional (3D) ultrasound with surface rendering of a normal uterus in the coronal plane; B: 3D ultrasound with volume contrast imaging of the same uterus.

Wong L et al., 2015
REFERENCES

THANK YOU!