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Training the Next Generation of Transplant Surgeons With a 3-Dimensional Trainer: A Pilot Study

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Background. In the United States, no published guidelines promote exposure to technical variants (ie, living donor or split liver) during transplant fellowship. Simulation with hands-on liver models may improve training in transplantation. This pilot study addressed 3 overall goals (material and model creation tools, recruitment rates and assessment of workload, and protocol adherence). **Methods.** A patient-specific hands-on liver model was constructed from clinical imaging, and it needed to be resilient and realistic. Multiple types of materials were tested between January 2020 and August 2022. Participants were recruited stepwise. A left lateral segmentectomy simulation was conducted between August 2022 and December 2022 to assess protocol adherence. **Results.** Digital anatomy 3-dimensional printing was considered the best option for the hands-on liver model. The recruitment rate was 100% and 47% for junior attendings and surgical residents, respectively. Ten participants were included and completed all the required surveys. Seven (70%) and 6 (60%) participants "agreed" that the overall quality of the model and the material were acceptable for surgical simulation. Five participants (50%) "agreed" that the training improved their surgical skills. Nine participants (90%) "strongly agreed" that similar sessions should be included in surgical training programs. **Conclusions.** Three-dimensional hands-on liver models have the advantage of tactile feedback and were rated favorably as a potential training tool. Study enrollment for further studies is possible with the support of leadership. Rigorous multicenter designs should be developed to measure the actual impact of 3-dimensional hands-on liver models on surgical training.

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Technical variant—living donor or split-liver—grafts have been advocated to benefit more patients and improve access to transplantation.[1] However, few transplant centers in the United States can offer adequate experience for surgical fellows to be truly competent. Furthermore, there is no clear guidance on what constitutes adequate training in technical variant grafts to be to be designated as a primary living donor liver transplant surgeon.[2] The lack of these guidelines promotes insufficient exposure to technical variants during fellowship and limited growth of the use of segmental grafts in the country.[3]

To improve training practices, we hypothesize that a 3-dimensional (3D) hands-on liver model will improve surgical training in a regulated environment before performing a living donor hepatectomy or a split-liver transplantation under direct supervision. Three-dimensional models have been shown to impact medical education and simulation in surgical training[4-10] in addition to surgical planning.[6,11-13]

This pilot study was designed to address 3 overall goals: hands-on liver model creation, recruitment rates and assessment of workload, and protocol adherence. Furthermore, we report the lessons from each preparatory component in preparation for a multicenter collaboration.

MATERIALS AND METHODS

Hands-on Liver Model Creation

The principal investigator selected a living liver donor from our research projects (Institutional Review Board No.

1051224 and No. 105326) based on liver volume and vascular anatomy for the hands-on liver model. The imaging was retrieved, and digital segmentation was performed using Mimics Innovation Suite (Materialise NV, Leuven, Belgium). It was then printed using a photopolymer resin-based Polyjet 3D printing technology (Stratasys, uPrint, Eden Prairie, MN). The patient-specific 3D printed solid model was constructed to reflect a 70% life-size model with different colors featuring vascular and biliary anatomy with a clear color for parenchyma. Multiple types of materials were tested across 3 y (January 2020 to August 2022) to determine which material option(s) to use for constructing the hands-on trainer. In addition to mimicking the properties of a liver (ie, realism), the materials needed to be resilient enough to prevent a premature breakdown during the resection process (ie, resilience). For this initial step, we focused on constructing 2 structures: the liver parenchyma and the vasculature. The transection of these materials was performed with a knife, scissors, or Cavitron Ultrasonic Surgical Aspirator Excel (CUSA; Integra LifeSciences, Princeton, NJ). For this aim, the author R.S. provided liver models of different types of materials. Although the authors J.S.-G., A.G.C., J.B., and M.I.R.-D. tested these models and provided a qualitative assessment of each model. The decision of the optimal material to be used was made by consensus among the aforementioned authors.

Recruitment Rates and Assessment of Workload

To document all research activities, the research coordinator and the investigator reported retrospectively their activities related to the participant recruitment, including adapting the protocol to the center and having meetings or correspondence on logistics with third parties or participants.

Between August 2022 and December 2022, we asked junior attendings (<3 y in practice) or senior residents (postgraduate year (PGY)4 or PGY5 who had a transplant rotation during the PGY3) to participate as a surgeon in a hands-on session and were assisted by a junior resident (PGY1 or PGY2 before transplant rotation) to test the hands-on liver model. Residents have a 2-mo transplant rotation during their PGY3 in a transplant center with >100 hepatobiliary surgery cases and adult liver transplants (91 deceased donors and 13 living donors) during 2022. The operative experience in the rotation includes being a primary assistant in complex hepatobiliary surgery, liver and kidney transplantations, and organ procurements.

Protocol Adherence

Each in-person hands-on session was preceded by an anatomy knowledge survey (**Survey 1, SDC,** http://links.lww.com/TXD/A686) and a 10-min online lecture on living donor left lateral hepatectomy (https://pie.med.utoronto.ca/TVASurg/project/transplant-leftlateraldonor/). Afterward, conventional imaging, 3D virtual models, and printed models were delivered for surgical planning (Figure 1). Once the *surgeon* was comfortable, we proceeded with the hands-on session. Each pair was expected to identify all the liver segments in the model with a marker and draw the transection line for a left lateral sectionectomy (ie, from the left suprahepatic vena cava to 1 cm to the right of the Rex recess). The left hepatic artery, the left portal vein, and the left hepatic vein should be identified with vessel loops before parenchyma transection. A small segment 4 portal vein branch should be identified and tied during the parenchyma transection. After completion of parenchymal transection, the left hepatic artery, the left portal vein, and the left hepatic vein should be tied and transected with graft removal as the final step of the session.

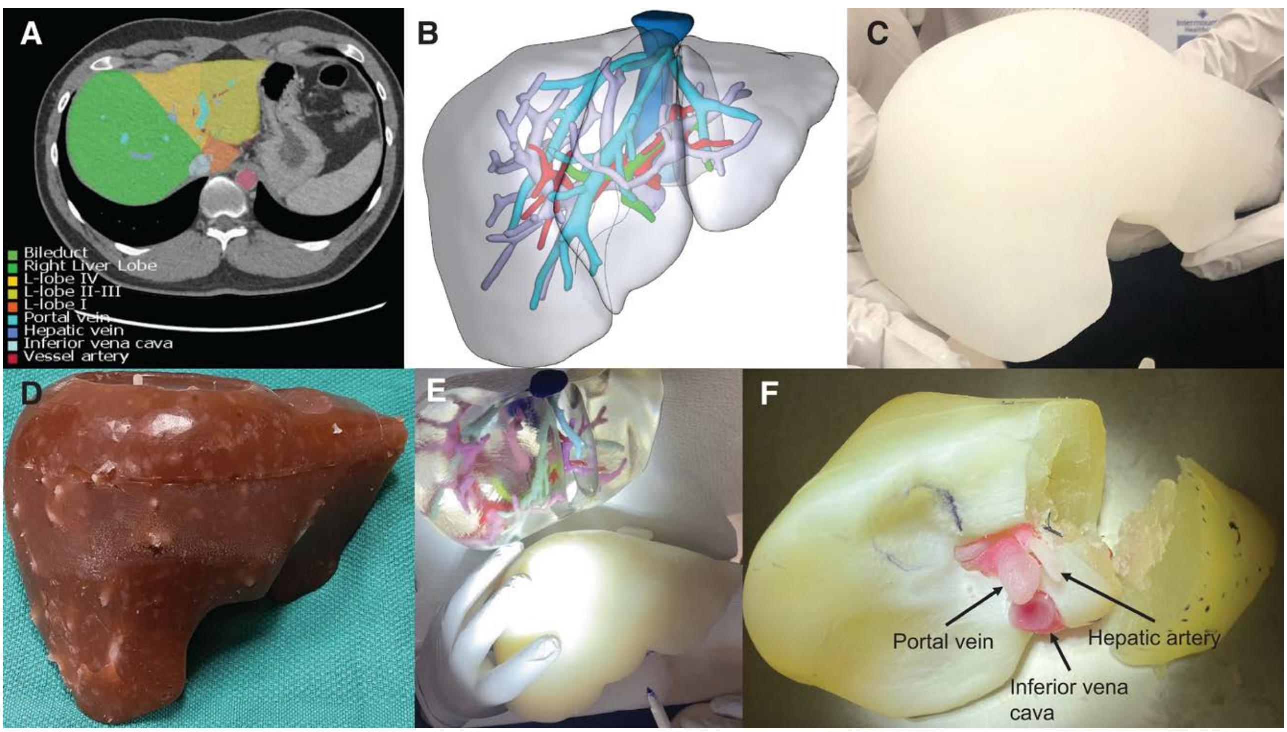

FIGURE 1. CT scan and volumes of the selected liver (A), 3-dimensional digital model (B), silicon hands-on model (C), organic gel hands-on model (D), 3-dimensional printed model for surgical planning along with the digital anatomy 3D printing hands-on liver model before (E), and after performing a left lateral sectionectomy (F). CT, computed tomography.

To assess the time to perform a task, we evaluated the time from starting parenchymal transection to left portal vein transection. As this would be the first time for the participants to use the hands-on liver model, we anticipated that subsequent sessions would take less time for the participants as they increase their learning curve or no change in time if their skills remain similar in subsequent sessions. At the end of each hands-on session, the attendees were asked to answer on a 5-point Likert scale a set of questions used by Yoo et al[5] and modified for liver surgery (**Survey 2, SDC,** http://links.lww.com/TXD/A686) to determine their perceptions of using this hands-on liver model for subsequent training sessions. It should be noted that the participants were not part of the study team.

Statistical Analysis

The sample size was not able to be calculated because of the novelty of this study. Prior pilot studies using hands-on model simulations on other specialties include 10 to 25 participants. Based on those studies, we elected to test this hands-on liver model with 10 participants to determine whether the material and session were appropriate for a multicenter study. Descriptive results are shown as numbers and percentages for categorical data. Continuous variables are reported as medians and interquartile ranges. Inferential analysis was not performed because this is a feasibility study, and the low sample size is a limitation. Statistical analyses were performed with R software, version 4.3.0 (R Core Team, 2021), and RStudio, version 1.3.1093 (RStudio, PBC, 2020).

RESULTS

Hands-on Liver Model Creation

A combination of materials (ie, silicone, organic gel, elastic 3D printing materials, digital anatomy 3D printing materials) was used to discriminate between the 2 structures (vessels and parenchyma), prioritizing parenchymal resilience. A detailed description of these materials is shown in Table 1. It should be noted that organic gel had the advantage that a pigment could be added for a more realistic visualization of the liver. However, the resilience was poor even when using the CUSA (the only CUSA-friendly material), and a cast was needed to ensure anatomical accuracy. Digital anatomy 3D printing material was considered the most acceptable material for resilience and realism with the actual human liver by consensus between the engineering team and the surgeons of the study team. Compared with conventional 3D printing, the models are highly accurate when compared with the actual impression. These models can be delivered within 2 business days when an in-house printer is available and up to 2 wk when printing is outsourced.

Recruitment Rates and Assessment of Workload

Three junior attendings and 15 residents were approached. Recruitment rates via email were 100% and 46.7% (N = 7) for junior attendings and surgical residents, respectively. This represented at least 1 surgical pair enrollment per every month. Three junior attendings and 2 senior residents were primary surgeons. Of the former, 2 were trained as transplant surgeons and 1 was trained as a pediatric surgeon; the latter has a lead role in the hepatobiliary surgery program and has participated in >10 liver transplants (deceased and living donors) at our pediatric center. Finally, 5 junior residents were surgical assistants. Half of the participants were females. Recruitment rate and simulation sessions were limited because of the COVID-19 restrictions at the time of enrollment.

Protocol Adherence

During the initial anatomy survey, 10 participants (100%) completed the anatomy knowledge survey. All 10 participants (100%) correctly identified the falciform ligament, and at least 8 participants (80%) correctly identified segments II, III, and IV. The Rex recess was correctly identified by 3 participants (30%). Eight participants (80%) answered left hepatic

TABLE 1.
Prototypes and materials of hands-on liver trainers

Trainer	Advantages	Disadvantage	Conclusion
Silicone	• Relatively inexpensive • Pigment can be added to mimic the look of the parenchyma • Long shelf life • Resilient during resection	• Material too stiff even when the softest shore value was used • Time consuming to produce (ie, material preparation, molding, curing time)	• Not a realistic "feel" and softness mimicking a liver parenchyma
Organic gel	• Relatively inexpensive • Pigment can be added to mimic the look of the liver parenchyma • Most realistic "feel," softness, and look of the liver parenchyma • CUSA friendly	• Short shelf life (2 wk) • Required refrigeration • Time consuming to produce (ie, material preparation, molding, curing time) • Not resilient; falls apart during resection	• Not a realistic resilience of a liver parenchyma
Elastic 3D	• Long shelf life • Fast turnaround to building a trainer • Low labor involvement in building a trainer • Repeatable and scalable • Some material options allow for adding pigment	• Involves investment in 3D printing • Material too stiff even when the softest shore value was used	• Not a realistic "feel" and softness mimicking a liver parenchyma
DAP	• Long shelf life • Fast turnaround to building a trainer • Low labor involvement in building a trainer • Repeatable and scalable	• Involves investment in DAP 3D printing	• The best option providing a good balance between resilience and realism

CUSA, cavitron ultrasonic surgical aspirator; DAP, digital anatomy 3D printing; 3D, 3-dimensional.

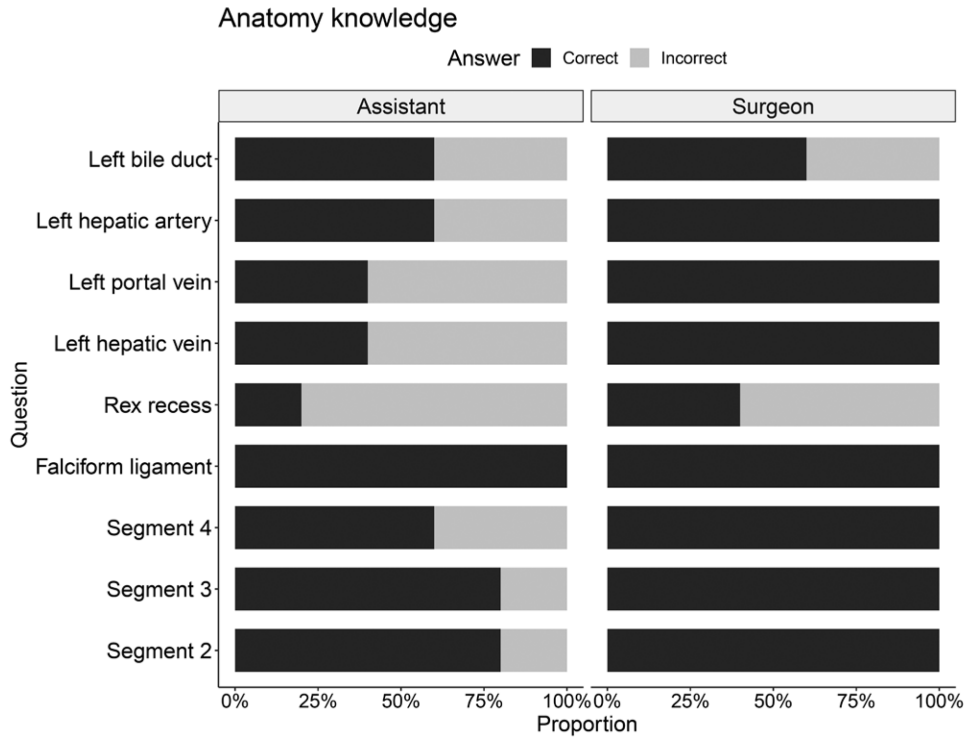

FIGURE 2. Responses provided by the surgeon and assistant regarding anatomy and landmarks of left lateral segmentectomy for living donation.

artery, 7 participants (70%) answered left portal hepatic vein and the left hepatic vein, and 6 participants (60%) answered left bile duct as structures required to identify and transect for a left lateral segment graft (Figure 2). All the primary surgeons correctly marked the liver segments in the model and drew the transection line 1 cm to the right of the Rex recess. Only 1 pair (10%) was not able to identify the segment IV portal vein branch. The median time to portal vein transection was 19.9 and 12.8 min for senior residents and junior attendings, respectively. Median graft weight was 179 g (range, 175–182 g). All participants (100%) completed the survey, providing their perceptions of the material at the end of the session. Five participants (50%) selected "strongly agreed" that the anatomical information provided by the imaging technique (ie, computed tomography scan, 3D digital model, printed model) was necessary for the performed surgery. Seven participants (70%) "agreed" that the overall quality of the model was acceptable. Five participants (50%) "disagreed" that the consistency and elasticity of the material were similar to that of the human liver. However, 6 participants (60%) "agreed" that the material is acceptable for an appropriate surgical simulation. In addition, 5 participants (50%) "agreed" that the training was helpful in improving their surgical skills. Finally, 9 participants (90%) "strongly agreed" that similar sessions of liver training should be included in the residency and fellowship programs (Figure 3). Overall, the training session was <1 h (median: 45 min).

DISCUSSION

This pilot study was designed to provide key information on feasibility aspects for future educational trials in liver surgery. First, we demonstrated that creating a hands-on liver model is feasible and that multiple materials could be used with significant differences in the consistency and accuracy of the model. In this study, 3D hands-on liver models were shown to be extremely promising. It has the advantages of anatomical accuracy—or enhanced surgical landmarks for training purposes—and tactile feedback when compared with virtual modalities.

The Halstedian preceptor-apprenticeship in traditional surgical training is reliant on opportunistic encounters requiring long periods of observation, assistance, and supervised practice,[2,5,14] which in turn is pathology dependent and requires multiple patients before mastering a single basic step.[4] Transplant trainees have limited opportunities to actively participate or practice the crucial steps of a living donor hepatectomy as 2 attending surgeons should perform the surgery by United Network for Organ Sharing Bylaws. Simulation, either virtually or on a physical structure, has been used in other pathologies[4,5,7,15,16] and could be implemented to improve surgical training in technical variant grafts. Furthermore, this anatomical liver model can be applied to other subspecialties, such as hepatobiliary pancreatic or surgical oncology fellowships, to improve training in other types of resections. Fabrication of these 3D models is standardized and reproducible, and their impact on medical education and surgical training or planning has been described elsewhere.[4-13,17-21]

To date, printing materials can be limited because of the different physical properties (ie, consistency, elasticity, tensile strength) and the lack of blood flow compared with those organs of the human tissue.[4,5] A consensus should be agreed upon between the advanced imaging team and the surgeons regarding the appropriate texture of the model to diminish this limitation.[7] As 3D printers and materials are becoming

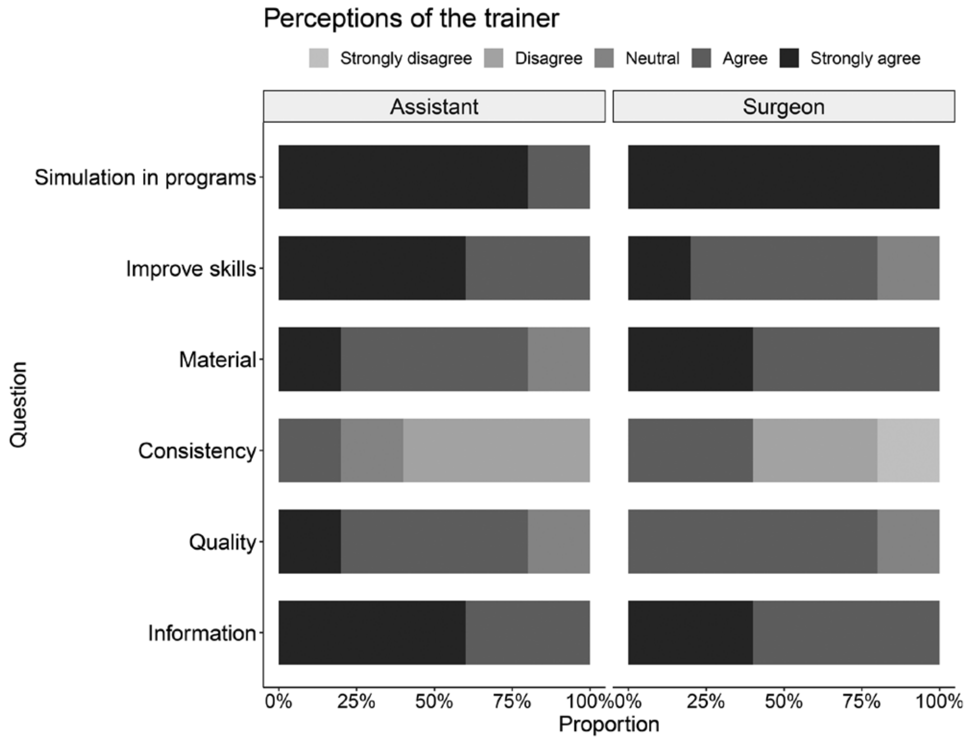

FIGURE 3. Perceptions of the trainer provided by the surgeon and assistant. The questions included if the imaging technique had the anatomical *information* necessary for the simulation. The overall *quality* and appropriateness *material* of the liver model for simulation, and the *consistency* compared with the actual human liver. Finally, if it *improves* their surgical skills and their perceptions of applying these hand-on *simulations* in residency and fellowship programs.

more accessible, these digital anatomy 3D models can easily be dispersed across training programs. Furthermore, the associated material costs can be diminished when multiple specialties introduce 3D technology to their programs. The digital creation of this model is similar to prior reports of resin-based liver models.[22] Finally, the costs of these models were similar to those reported in other specialties, ranging between USD 2000 and 3000.[4] Although this may seem expensive at this moment, the delivery of healthcare value and the impact on the healthcare system are still unknown, and it may have a potential cost-saving if it can reduce surgical complications after implementation of these standardized simulations.

Second, we met our enrollment goal within 1 wk of reaching out to the participants. However, their participation in the study was complicated because of the COVID-19 pandemic policies, which avoided protected time for a 1-d training with all the participants. Despite the fact that we met our enrollment goal quickly, there were some conflicts in the agendas between the participants that delayed this part of the study. Nevertheless, we do not expect that this slow enrollment could occur in the setting of a future multicenter study. We think assertive communication between the Program Director and/or Chair of Surgery can maximize enrollment and recruitment efficiency. Thus, maximizing the chance of achieving a powered study. There are no major consuming activities regarding documentation before or after participant enrollment, which is beneficial to allocate more funding for printing these models. It should be noted that some potential bias from the participants could occur. In this study, only one of the senior residents pursued a transplant fellowship, whereas the remainder preferred other specialties. Junior residents were still open to any subspecialty.

Finally, we demonstrated that residents and junior attendings were willing to participate in these sessions as they completed all the required surveys. Most of the participants of this study thought that similar sessions of liver training with 3D models should be implemented in residency and fellowship and that the 3D hands-on liver model was acceptable for simulation. This is encouraging as the transplant rotation is generally criticized by general surgery residents because of the lack of a defined curriculum[23] and limited didactic teaching tools,[24] which reduces residents' interest in pursuing transplant surgery.[25]

As transplant rotations are highly variable across different general surgery programs, we hypothesize that liver anatomy knowledge could be a surrogate for liver expertise that may allow comparison of residents regardless of the year of training but within the same knowledge of liver surgery. We considered the final graft weight as a marker of a successful session. However, the low variability in the final graft weight makes us reconsider that time will probably be the best marker. Besides that, the time to perform a task (ie, time from transection to cross-clamp of the portal vein) was planned to be the primary endpoint when trying to demonstrate whether these simulation sessions actually improve surgical skills. One question to be answered in a multicenter study design would be how many sessions a resident requires to decrease their median time from 20 to 15 min (25% time reduction).

In conclusion, 3D hands-on liver models are feasible. They have the advantage of tactile feedback and were rated favorably as a potential training tool for liver surgery. This pilot study showed that enrollment can be achieved with the support of leadership. Residents and junior attendings are supportive of similar didactic lessons in the future, but a rigorous multicenter study should be developed to measure the actual impact of these sessions.

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