DE GRUYTER Current Directions in Biomedical Engineering 2025;11(1): 529-531

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Integrating biological tissue suturing into minimally-invasive surgical training with the Lübecker Toolbox simulator

https://doi.org/10.1515/cdbme-2025-0234

Abstract: This study introduces an innovative approach to enhance surgical training using the Lübecker Toolbox simulator. Addressing the limitations of current simulators that rely on unrealistic artificial tissues, we developed custom 3D-printed fixtures to integrate biological tissue (pig feet) into the training environment. The fixture securely holds the biological specimen, while a specially designed stencil enables trainees to create uniform incisions for consistent practice and evaluation. User feedback indicated a significantly improved training experience due to the enhanced realism and haptic feedback provided by the biological tissue. This research highlights the potential of additive manufacturing to create tailored solutions that address specific needs in medical education, ultimately leading to more effective surgical training.

Keywords: Surgical Simulation, 3D printing, Medical Education, Additive Manufacturing, Lübecker Toolbox, Surgical Training

1 Introduction

Surgical training simulators have become essential in medical education, providing trainees with opportunities to develop technical skills in a controlled environment. The Lübecker Toolbox is a widely used simulator for basic surgical skills training. However, a significant limitation of many current surgical simulators, including the default configuration of the Lübecker Toolbox, is their reliance on artificial materials that inadequately simulate the haptic and mechanical properties of living tissue.

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Recent studies have highlighted the importance of realistic simulation in laparoscopic surgery training. Varras et al. (2020) emphasized that minimally invasive surgery has a longer learning curve compared to open surgery, making effective simulation crucial [1]. Likewise, Lohre et al. (2020) demonstrated that virtual reality simulation can significantly improve surgical performance [2].

The Lübecker Toolbox offers various applications for surgical training, including basic laparoscopic skills, suturing, and instrument handling. While it provides a standardized platform for skill development, its primary limitation lies in the use of artificial tissues, which lack the realistic haptic feedback and tissue behavior crucial for developing advanced surgical skills [3].

To address these limitations, we integrated the application of biological tissue for surgical training on the Lübecker Toolbox. For that, we developed a 3D printed specialized fixture that securely holds pig feet, as a biological tissue, to create a more authentic surgical training experience. Moreover, we designed a 3D printed stencil to allow uniform incision creation across training sessions to move toward standardized task performing. This approach can bridge the gap between simulation and clinical reality, potentially reducing the adjustment period during early clinical experiences and better-preparing trainees for the psychological aspects of handling biological tissues.

2 Materials and Methods

The Lübecker Toolbox is a comprehensive laparoscopic surgery simulator that provides a platform for various training modules. It consists of a box mimicking the abdominal cavity, with ports for instrument insertion and a camera system for visualization. The standard configuration uses artificial materials for training exercises [4].

While artificial materials offer consistency and reusability, they fail to replicate living tissues' complex mechanical properties and haptic feedback. Pig tissue was chosen for this study due to its similarity to human tissue in terms of mechanical properties and handling characteristics, making it an ideal ex-vivo model for surgical training [5].

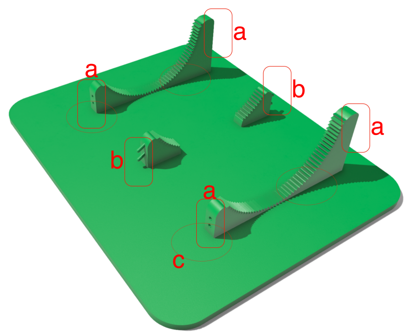

Fig. 1: CAD view of the fixture, highlighting (a) four mounting points for M2 screws to secure the wraps, (b) two alignment pins to ensure consistent stencil placement, and (c) four designated slots for 20mm magnets to affix the fixture within the toolbox.

Fig. 2: CAD view of the stencil, illustrating various incision lines and two alignment holes for precise positioning on the fixture.

2.1 Fixture Design and Prototyping

We defined the following design goals for the 3D printed fixture:

1. Secure fixation of biological specimens.
2. Maintenance of proper positioning relative to the toolbox camera.
3. Compatibility with standardized assessment protocols.
4. Reproducibility through additive manufacturing techniques.

The design process focused on fulfilling the requirements of securely holding biological tissues while ensuring compatibility with the Lübecker Toolbox's camera system. The holder itself was designed with magnets for stability, adjustable straps, and gears to firmly secure the tissue in place. It also allowed optimal positioning relative to the camera's point of view (POV). Figure 1 shows the CAD view of the designed fixture. The design files for this fixture are freely available for download at: https://gitlab.gwdg.de/cds/LTB_designs/.

2.2 Stencil Design and Prototyping

The 3D printed stencil was designed to provide a standardized template to create uniform incisions across training sessions, enabling consistent evaluation of trainee performance. The stencil allow the creation of three horizontal incisions (two measuring 2.5 cm and one measuring 3 cm) and one vertical incision (2.5 cm), strategically positioned to create varying challenges. Bendable materials were incorporated to enable flexibility in creating diverse incision patterns, including curved or angled lines. This versatility ensures adaptability for various surgical tasks and enhances training realism. Figure 2 shows the CAD view of the designed stencil. Moreover, the design files for the stencil is available for public access at: https://gitlab.gwdg.de/cds/LTB_designs/.

2.3 User Test

In order to evaluate the performance of the modified Lübecker Toolbox with biological tissue, we planned a user test with three surgical residents. All three were aged between 30 and 40 years, with intermediate (1-3 years, two participants) or advanced (more than 3 years, one participant) surgical experience. In the test, each trainee used the designed stencil to perform three standardized incisions on the pig feet and then performed tissue suturing as a standard surgical training task. After that, we used a questionnaire to collect the trainees feedback on the training session with the biological tissue. The questionnaire included five questions that focused on the following points:

1. Ease of understanding and using the setup
2. Intuitiveness of the stencil for making defined cuts
3. Stability of the holder during procedures
4. Effectiveness of animal tissue for practicing cutting and suturing skills
5. Overall satisfaction with the training session

Additionally, open text questions allowed for general feedback as well as ideas to further improve the model.

3 Results

The final fixture design was successfully integrated with the Lübecker Toolbox while providing secure positioning for pig foot specimens. The standardized template created uniform incisions across all training sessions, allowing for consistent evaluation of suturing technique and efficiency.

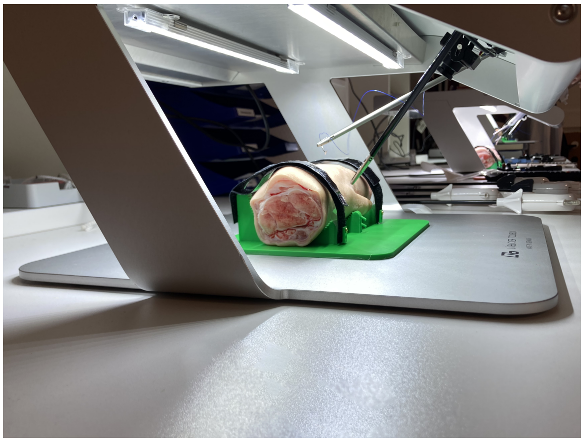

Fig. 3: Final assembled fixture with magnets and wraps shown inside the Lübecker Toolbox holding a pig foot. Surgical instruments and camera positioning are visible in this setup.

All participants agreed that the setup was easy to use regarding handling and task description. Furthermore, they highlighted the intuitiveness of using the stencil. The stability of the holder was rated as realistic, with the hint that a certain flexibility of the pig foot is desired to mimic suturing in abdominal surgeries. All three participants were highly satisfied with the training session and found the practice effective for increasing their skills. However, they suggested to also include more biological tissue types, i.e. liver, to further diversify the training experience.

4 Discussion

This study highlights how integrating biological tissues into simulation can bridge gaps between artificial simulation and clinical practice. This study is one of the first to offer an open-access, easily adaptable solution for biological tissue integration into surgical training simulations. The fixture's open-source nature allows educators worldwide to adapt designs according to their specific needs, while the biological tissue, i.e. pig feet, is widely available and cheap.

One core advantage is the standardization of cuts, and thus the exercises, even though pig feet might look differently. This stencil approach allows for mostly comparable ratings across sessions, making it possible to introduce goal times to reach.

While pig's foot offers considerable benefits, other tissues such as the liver could provide more complex training scenarios, encouraging further exploration of tissue-specific modifications. However, our proposed design provides a flexible basis for a tissue holder in the Lübecker Toolbox. Thus, the open-access design files are easily adaptable to adapt for other organs. Similarly, the approach of using a stencil for cuts provides a general template for standardized training exercises. Therefore, our work could present the basis for a wide range of training intra-corporal suturing in simulator on biological tissue with comparable and objective results.

5 Conclusion

In conclusion, this project demonstrates how targeted modifications to existing simulation systems can address specific educational needs in surgical training. The positive feedback from users confirms the value of this approach and suggests a potential for expanded applications in surgical education. As the next step and in order to apply the feedback form the trainees, we will focus on adopting the current setup to include other types of biological tissues in the surgical training.

Author Statement

Research funding: This work was supported by the Ministry of Science and Culture (Ministerium für Wissenschaft und Kultur - MWK) of Lower Saxony (grant number ZN4094) as well as by AKB Stiftung. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research complies with national regulations and institutional policies following Helsinki Declaration principles, and has been approved by the author's institutional review board or equivalent committee..

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