Towards A Haptically-Enabled, Low-Cost Training Platform for Laparoscopic Skill Acquisition in Low-Resource Settings

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Aims: The global shortage of trained surgeons threatens access to essential surgical care. In 2024, the AAMC (Association of American Medical Colleges) projected a shortage of 10,100 to 19,900 surgeons in the U.S. by 2036 [1]. In low-resource settings, the situation is even worse with an estimated deficit of 18.9 million surgical procedures in Western Sub-Saharan Africa by 2030 [2]. Expanding access to high quality surgical training is critical to addressing this gap. This work presents a novel, low-cost, haptically-enabled laparscopic training platform designed to enhance skill acquistion through realistic force feedback and automated skill assessment.

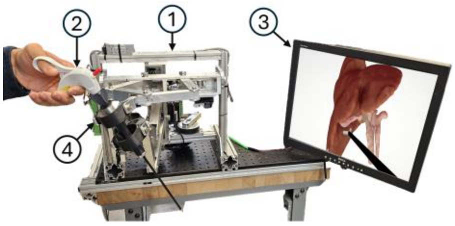

Fig. 1 Training Platform showing single haptic device. ① Haptic device. ② Standard laparoscopic tool. ③ Virtual organ model. ④ Custom low-cost force sensor [3].

Materials and Methods: Our training platform consists of two modular haptic devices (Fig. 1-①) that interface with standard laparoscopic instruments (Fig. 1-②). Users can perform simulated procedures using either virtual organ models (Fig 1-③) or explanted organs. The system estimates tissue-tool interaction forces and renders the corresponding haptic feedback to the user's hand, simulating the sensation of real tissue manipulation. To enhance realism, the deformation of the tissue in response to grasping and blunt dissection is predicted using a machine learning (ML) model (PointNet [4]). Electrocautery effects are also simulated using closed-form heat transfer equations.

The platform operates in two training modes: 1) a passive evaluation mode where the system assesses user performance by analyzing tool motion, applied forces, laparoscopic video feeds, and eye gaze tracking. An ML model then generates an automatic skill score and 2) an active training mode where real-time haptic guidance provides corrective feedback when the user deviates from expert technique. To develop and validate the skill classification ML model, we collected performance data from experienced surgeons and indviduals with limited laparoscopic expertise performing cholecysectomies on explanted porcine livers. The setup for these experiments is shown in Fig. 2.

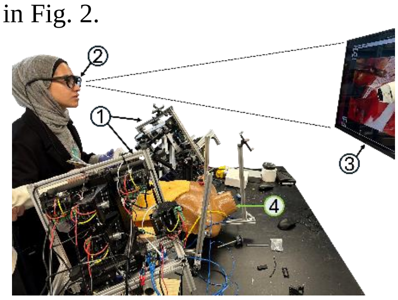

Fig. 2 Novice individual using the trainer in evaluation mode. ① Haptic device. ② Pupil labs Neon eye gaze tracker. ③ Laparoscopic video feed. ④ Torso model containing explanted liver.

Results: Our haptic system achieves stiffness values of 14.5 N/mm (x), 18.2 N/mm (y), and 11.2 N/mm (z). The virtual organ deformation model achieves 94.66% accuracy, with 1.16 ± 0.32 ms inference time. The projected cost per arm is $4970, which is a cost-effective alternative to existing haptic simulators. A comparative study is in preparation to evaluate trainee learning outcomes against conventional training methods.

Conclusions: In this abstract, we presented a low-cost, haptically-enabled training platform for laparoscopic skill acquisition through force feedback and machine learning-driven evaluation. This platform offers a scalable solution for improving surgical education, particularly in low-resource settings. Future studies will validate its effectiveness in accelerating laparoscopic skill development.

Acknowledgements: This project was funded by the Wellcome Trust's Leap SAVE program and by Vanderbilt University internal funds.

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