Objective Assessment of Laparoscopic Surgical Skill Using 3D Motion Capture Metrics

Zachary A. Flahaut[1,2], Daniel L. Benoit[3], Sukhbir S. Singh[4], Caitlin Jago[4], Adam Garber[4], Teresa E. Flaxman[2, *]
[1]Ottawa-Carleton Institute for Biomedical Engineering, University of Ottawa, Ottawa, Canada
[2]Clinical Epidemiology Program, Ottawa Hospital Research Institute, Ottawa, Canada
[3]Department of Health Sciences, Faculty of Medicine, Lund University, Lund, Sweden
[4]Department of Obstetrics and Gynecology, Faculty of Medicine, University of Ottawa, Ottawa, Canada
Email: *tflaxman@ohri.ca

Summary

This study evaluates the use of 3D motion capture metrics to assess laparoscopic surgical skill. Experts and novices performed simulated peg transfer and circle cutting tasks. Metrics such as tool angles, path length, efficiency, smoothness, and speed variability differentiated skill levels. Results highlight motion capture's potential for objective skill assessment and optimized training in surgical education.

Introduction

High-quality patient care depends on the ability of surgeons to refine their skills effectively [1]. Objective, quantitative methods are essential to enhance training outside the operating room and provide actionable feedback to improve movement quality. Existing evaluation models lack these capabilities. This study examines 3D motion analysis as a tool for quantifying skill levels in laparoscopic surgery through metrics of movement efficiency and quality.

Methods

This study involved two groups of participants: novice surgeons (n=13), with no prior surgical experience, and expert surgeons (n=12), including staff surgeons and fellows. All participants watched an instructional video outlining the Fundamentals of Laparoscopic Surgery [2] peg transfer and circle cutting tasks before performing the procedures. These tasks were conducted using a laparoscopic box trainer (Figure 1), with the position and height of the trainer adjusted to suit each participant's comfort and ergonomic preferences. Participant movements during the tasks were captured using a 3D motion capture system (Vicon Nexus, UK) consisting of ten infrared cameras (eight Vero and two Vantage cameras). Retroreflective markers were placed on the participant and surgical tools. Virtual markers for the surgical tooltips, operating within the box trainer, were reconstructed from a static calibration trial.

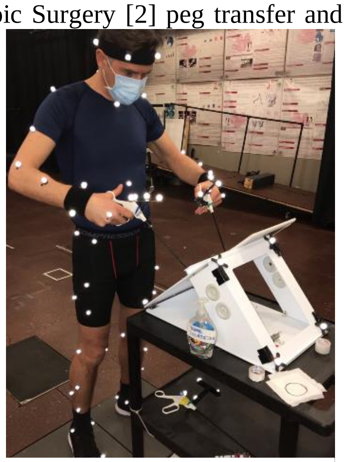

Figure 1. Participant setup with markers standing in front of laparoscopic box trainer.

Primary variables of interest were: 1) path length, (shorter path suggest more controlled and direct movements), 2) non-dominant and dominant hand path length symmetry index, 3) average speed of movement, 4) speed of movement variability, 5) smoothness, (lower values representing more controlled movements), 6) efficiency index, ratio of straight-line distance to actual path length (with values closer to 1 indicating greater efficiency). Workspace utilization was assessed via average/range of tooltip position relative to the box trainer's center and movement volume, measured as the convex hull enclosing tooltip trajectories. Metrics were ensemble-averaged across trials for each participant. Significant group differences were assessed using independent t-tests ($p<0.05$) in JASP (v0.18.1). Significance was defined at $p<0.05$ level, and a trend at $0.05<p<0.10$.

Results and Discussion

For the peg transfer task, experts exhibited a tendency to operate over a larger workspace, as reflected by an increased mean distance from the center of the movement volume, which trended toward significance for both the dominant hand ($\boldsymbol{\mu}_{naive}$ = 2.98 cm & $\boldsymbol{\mu}_{expert}$=4.87 cm, p=0.093, d=0.702) and non-dominant hand ($\boldsymbol{\mu}_{naive}$=2.76 cm & $\boldsymbol{\mu}_{expert}$=3.47 cm, p=0.084, d=0.723). This suggests that experts employ a broader movement strategy, potentially optimizing reach and reducing unnecessary micro-adjustments to enhance control over peg transfers. The efficiency index was trending toward significance for the dominant hand ($\boldsymbol{\mu}_{naive}$=0.28 & $\boldsymbol{\mu}_{expert}$=0.173, p=0.052, d=0.821) and was significant for the non-dominant hand ($\boldsymbol{\mu}_{naive}$=0.32 & $\boldsymbol{\mu}_{expert}$=0.15, p=0.009, d=1.19). These results suggest that novices followed a more linear path compared to experts, reinforcing the idea that experts employ a wider and more fluid movement strategy, likely improving efficiency over multiple trials.

No significant differences were found in dominant-hand path lengths (p>0.1), though non-dominant path length trended toward significance (μ_{naive}=836.34 cm & μ_{expert}=543.21 cm, p=0.109, d=0.668), suggesting a potential disparity in how experts manage movement between their hands. Additionally, the path length symmetry index trended toward significance (μ_{naive}=0.08 & μ_{expert}=0.15, p=0.081, d=0.73), suggesting greater asymmetrical hand use by the novices.

For circle cutting, movement metrics were analyzed separately for the left and right hands, though no kinematic variables investigated showed significant differences (p> 0.1)**.**

Conclusions

This proof-of-concept study demonstrates that quantitative metrics derived from 3D motion capture provide an objective and effective method for assessing surgical skills. Integrating these metrics into surgical training curricula could enhance skill acquisition and proficiency development, ultimately improving patient care outcomes. Future research should focus on real-time feedback systems and validation in larger, more diverse cohorts to further advance surgical education.

References

[1] Reiley C. et al., (2011).*Surg. Endos.*,**25(2)**:356-366 [2] Fundamentals of Laparoscopic Surgery. (2014)., *FLS Manual*