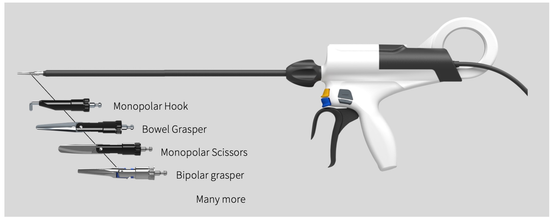
Automated Intracorporeal Tool Exchange with the Symphera Multi-Tool Prototype: Evaluation of Efficiency and Surgeon Workload in a Porcine Laparoscopic Model

Fabian Haak[1], Conrad Heid[2], Brett Colton Parker[3], Antonello Forgione[4], Jacques Marescaux[4]

INTRODUCTION



Frequent instrument exchanges during laparoscopic surgery interrupt workflow, prolong operative time, and increase surgeon workload. The Symphera prototype consolidates multiple laparoscopic tool tips into a single handheld instrument. Its automated exchange mechanism enables seamless intracorporeal switching, aiming to improve procedural efficiency and ergonomics. This preclinical study compared the Symphera prototype with standard laparoscopic instruments regarding tool-change performance, procedural efficiency, and usability in a porcine model.

METHODS

A prospective randomized within-subject crossover study in a porcine model (n = 8) was conducted at IRCAD Strasbourg. Two experienced laparoscopic surgeons each operated on four models, performing three standardized procedures per animal (incl. one cholecystectomy). Each surgeon completed two models using the Symphera prototype and two using standard instruments, with alternating use across days to counterbalance order effects.

	Day 1	Day 2
Surgeon A	Pig 1 (Symphera)	Pig 5 (Control)
	Pig 2 (Control)	Pig 6 (Symphera)
Surgeon B	Pig 3 (Control)	Pig 7 (Symphera)
	Pig 4 (Symphera)	Pig 8 (Control)

Each Pig: 3 stadardized procedures, incl. Cholecystectomy

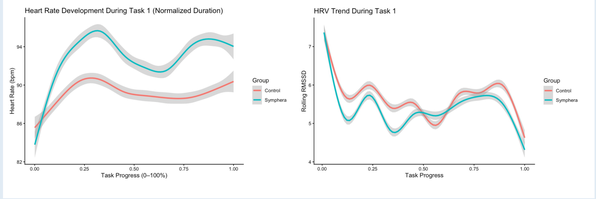
Primary endpoints were task time, number of tool changes, individual plus cumulative tool-change time, and type of tool change (intracorporeal tool tip change versus extracorporeal instrument exchange). Secondary outcomes included adjusted NASA-TLX workload scores and post-procedural usability ratings, transformed so that higher values indicated more favorable responses. Differences between conditions were analyzed using linear mixed-effects models with participant, pig, and task as random factors.

RESULTS

Impact of the Symphera prototype on operative efficiency and instrument exchange.

Metric	Control	Symphera
Eyes on (%)	89.3 ± 0.2	91.1 ± 7.4
Eyes down (%)	7.6 ± 0.8	6.9 ± 6.5
Eyes off (%)	3.2 ± 1.1	2.7 ± 0.1
Eyes-off events (n)	44	9
Mean eyes-off duration (s)	4.91 ± 5.58	11.00 ± 13.64
Total eyes-off time (s)	238	99

Values are reported as mean + SD where applicable. Percentages represent averages across participants; eyes-off duration statistics refer to episodes following eyes-on → eyes-off transitions.



Heart rate (left) and RMSSD (right) across normalized task duration (0–100%) for Symphera and control. Heart rate increased during the task and was consistently higher with Symphera, while RMSSD decreased early and then stabilized in both groups. Shaded areas indicate 95% confidence intervals.

Impact of the Symphera prototype on task duration and instrument exchange

Across all tasks, the mean total task duration was 27.25 ± 10.88 min in the Symphera condition and 33.9 ± 13.18 min in the control condition (–19.64%).

The mean number of instrument exchanges was 27.08 ± 16.78 with Symphera and 24.00 ± 14.14 in the control condition (+12.85%). The mean cumulative time spent on instrument exchanges was 3.54 ± 2.26 min with Symphera and 9.45 ± 6.82 min in the control condition (–61.47%), while the mean duration of a single exchange was 8.62 ± 4.03 s and 22.42 ± 9.95 s, respectively (–60.22%).

In the cholecystectomy subgroup, mean task duration was 20.88 ± 3.07 min with Symphera and 28.09 ± 10.90 min in the control condition (–25.68%). The mean number of instrument exchanges was 8.25 ± 3.96 and 8.50 ± 5.45 (–2.94%), the cumulative exchange time was 1.31 ± 1.10 min and 2.98 ± 2.19 min (–56.08%), and the mean time per exchange was 8.28 ± 4.99 s and 20.25 ± 4.21 s, respectively (–54.32%).

Visual attention and gaze behavior

Across all tasks, surgeons spent the majority of operative time looking at the laparoscopic monitor. Eyes-on time accounted for 89.1–89.4% of task duration in the control condition and 85.8–96.3% with Symphera. Eyes-down time ranged from 7.0–8.2% in the control condition and 2.3–11.5% with Symphera, while eyes-off episodes were infrequent (2.4–3.9% vs. 2.6–2.8%).

Eyes-down episodes were primarily related to extracorporeal work (n = 77), followed by instrument exchange (n = 31) and equipment troubleshooting (n = 20), and occurred more often in the control condition (46 vs. 31; 23 vs. 8; 17 vs. 3).

A total of 44 eyes-off events occurred in the control condition compared with 9 events with Symphera. Individual episodes were longer with Symphera (11.0 s vs. 4.9 s), while cumulative eyes-off time was lower (99 s vs. 238 s). In both groups, gaze transitions predominantly returned to the laparoscopic monitor.

Surgical workload (SURG-TLX)

Subjective workload measured by the SURG-TLX was lower when using the Symphera prototype. Mean scores decreased from 72.9 in the control condition to 40.2 with Symphera (–44.9%), with median values declining from 80.0 to 40.7. However, this difference did not reach statistical significance (p = 0.114).

Heart rate and heart rate variability

Heart rate increased during task execution in both groups and remained consistently higher in the Symphera condition across most of the normalized task duration.

Heart rate variability (RMSSD) decreased early during the task and then stabilized in both groups. Linear mixed-effects analysis showed no significant effect of group, task phase, or their interaction on RMSSD (group: estimate −0.31, SE 0.48, t = −0.65).

CONCLUSION

The Symphera prototype demonstrated the potential to streamline laparoscopic workflow by substantially reducing the time required for instrument exchanges while maintaining procedural safety and visual focus on the operative field. Despite a slightly higher frequency of exchanges, the automated intracorporeal switching mechanism shortened both the total time spent on instrument changes and the duration of individual exchanges, resulting in a meaningful reduction in overall task duration. These effects were particularly evident in the cholecystectomy subgroup, suggesting that procedures characterized by frequent instrument switching may benefit most from the system.

The use of Symphera did not negatively affect surgeons' visual attention to the operative field. Gaze behavior remained focused on the laparoscopic monitor, and the number of attention-diverting events—especially those related to instrument exchange and troubleshooting—was reduced compared with conventional laparoscopy. Although individual eyes-off episodes were longer, their overall cumulative duration was markedly lower with Symphera due to the amount of events.

Subjective workload showed a notable reduction when using the prototype, even though statistical significance was not reached, likely due to the limited sample size of this preclinical study. Physiological stress markers, including heart rate variability, remained comparable between conditions, indicating that the modified workflow did not increase measurable physiological strain.

Taken together, these findings suggest that integrating multiple laparoscopic tool functions into a single instrument may enhance operative efficiency and reduce workflow interruptions. Further studies in larger cohorts and clinical settings are warranted to evaluate the impact of this technology on operative performance, surgeon workload, and patient outcomes.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support and collaboration of all participating institutions. This work was conducted through a multidisciplinary collaboration between the Division of Hepatobiliary Surgery and Visceral Surgery, Department of Visceral, Transplant, Thoracic and Vascular Surgery, University Hospital Leipzig[1]; Symphera GmbH, Munich, Germany[2]; the Division of Minimally Invasive Surgery, Department of Surgery, The Johns Hopkins University School of Medicine, Baltimore, Maryland[3]; and IRCAD (Institut de Recherche contre les Cancers de l'Appareil Digestif), Louis Pasteur University, Strasbourg, France[4].

The authors would like to express their sincere gratitude to IRCAD France for providing access to their facilities and infrastructure, which enabled the performance of the preclinical surgical testing conducted in this study. The technical support and outstanding training environment at IRCAD were instrumental in facilitating the experimental procedures.

Conflict of interest: Fabian Haak reports a financial interest in Symphera. Conrad Heid is the co-founder of Symphera. Brett Colton Parker serves as a scientific advisor to Symphera. Antonello Forgione and Jacques Marescaux are affiliated with IRCAD, which has a financial interest in Symphera.