Global Versus Local Kinematic Skills Assessment on Robotic Assisted Hysterectomies

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Global versus local kinematic skills assessment on robotic assisted hysterectomies

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INTRODUCTION

Surgical skills assessment is a crucial step to help understanding surgical expertise and to provide technical knowledge to beginners. Scores, such as GOALS [1], have been designed to assess surgical skills. However, these scores are subjective and need experts to compute them.

With the advent of robotic surgery, it is possible to compute Automated Performance Metrics (APMs) based on the motion of robotic arms to assess surgical skills. Several studies have demonstrated statistically significant differences between APMs from different levels of expertise [2], [3]. The majority of these studies performed a global analysis, i.e., studying the surgical procedure or training task as a whole.

By using the Surgical Process Model (SPM) methodology [4], it is possible to describe the surgery at different levels of granularity and break it down into a sequence of elements. Riffaud et al. [5], decomposed Lumbar Disc herniation surgery by phases and demonstrated that the main expertise differences in terms of duration are due to specific phases or actions.

In this paper, we will combine SPM and APMs to study global and local kinematic skills during robotic-assisted hysterectomies.

MATERIALS AND METHODS

Data – Fifty-two robotic-assisted laparoscopic hysterectomies (RALH) performed on the Da Vinci SI (Intuitive®) robotic system have been acquired between June 2020 and September 2021 thanks to the DVLogger. Thirty-six surgeries have been performed by 5 expert surgeons (more than 35 RALH at inclusion) and 16 surgeries by 3 intermediate surgeons (less than 20 RALH). For each case, we recorded the surgical video (25Hz) and the kinematic data (50Hz). The kinematic data contains the position (x, y, z) and the Euler angles for each of the left and right robotic arms.

Data annotation – Each surgical sequence has been annotated following the SPM methodology at phase granularity by one gynecologic resident thanks to the surgical video. Height phases have been defined: “surgical approaches”, “exhibition”, “adnexal dissection left”, “adnexal dissection right”, “anterior dissection”, “dissection of the uterine pedicles”, “resection” and “restoration of the operating site”. According to our clinical partner, the most difficult phases are the “adnexal dissection left” and the “dissection of the uterine pedicles”. The complexity of the first one is due to the uterus preventing direct access of arm 2 (right-hand) to the left adnexa for right-handed people. The second is due to the high risk of adverse events such as blood loss or ureteral injury.

Data synchronization – We used the timestamp information provided by the DVLogger and the SPM description to synchronize the kinematic data with the video.

Extraction of global and local kinematics – In the surgical environment, the endoscope is connected during the instrument preparation made by the scrub nurse. This generally happens few minutes before the beginning of surgery. Even if kinematics and video are synchronized, to only study the robotic movement during the surgery, we have to take into account the real duration of surgery. For that, we extracted the kinematic data thanks to the SPMs which are synchronized with videos. The global kinematic sequences are the kinematic data for the complete duration of the surgeries, and the local kinematic sequences are the ones for each phase.

APMs extractions – For each global and local kinematic sequence, we extracted 16 APMs. These APMs are the average velocity ($m.s^{-1}$), the average acceleration ($m.s^{-2}$), the average jerk ($m.s^{-3}$), the smoothness ($m.s^{-3}$) [6], the trajectory length (m), the working volume (m^3) and the economy (m^2) for each robotic arm independently (14 APMs). We also computed the duration (s) and the bimanual dexterity (2 APMs).

Statistical analysis – The Shapiro-Wilk test was used to test the normality of the data for each feature for each local kinematic sequence. In all cases, the feature distribution was non-normal. A Wilcoxon-Mann-Whitney test was performed to ensure that the differences were significant between the sequences of the experts and those of the intermediates ($p < 0.05$).

RESULTS

The Table 1 summarizes the statistically significant APMs for each phase and robotic arms. On the global kinematic analysis, only 4 APMs were statistically different between experts and intermediate (p-value <0.05): average velocity, average jerk for each arm.

For the local kinematic analysis, all phases, except “surgical approaches” and “exposition”, have at least one statistically significant feature. Of the 16 APMs, 15 of them are significant for at least one phase with a p-value <0.05, and 4 of them with a p-value <0.001.

Phases	Arm 1 (Left)		Arm 2 (Right)		Both arms	
All surgery (global)	2	Velocity Jerk	2	Velocity Jerk		
Adnexal dissection left			1	Smoothness		
Adnexal dissection right	1	Path length	4	Velocity Path length Volume Economy		
Anterior dissection	4	Velocity* Path length Volume Economy	3	Velocity* Acceleration Volume		
Dissection of the uterine pedicles			2	Jerk Volume		
Resection	2	Acceleration* Jerk	2	Acceleration Jerk		
Restoration of the operating site	1	Smoothness	4	Velocity Acceleration Jerk Smoothness	1	Duration*

Table 1 Statistically significant APMs by phases and robotic arms. All APMs have a p-value <0.005, the APMs with a star (*) have a p-value <0.001.

For the "adnexal dissection left", the smoothness is statistically different for robotic arm 2 (p=0.039, Fig 1.a). Experts have a lower value than intermediate, i.e., more smooth motion (48.81±22.50 $m.s^{-3}$ vs. 74.22±32.25 $m.s^{-3}$).

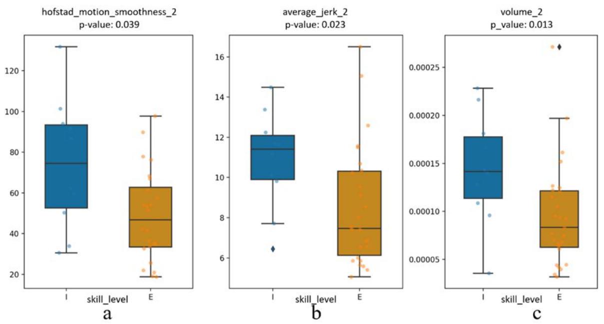

Figure 1: Boxplot for the right robotic arm of "adnexal dissection left" for the motion smoothness (a), of the "dissection of the uterine pedicles" for the jerk (b), and the working volume (c) of experts (E) vs. intermediates (I) surgeons.

For the second complex phase, "dissection of the uterine pedicles", the jerk and the working volume were statistically different for robotic arm 2 (p=0.023, Fig 1.b & p=0.013, Fig 1.c). Experts had a jerk of 8.54±3.03 $m.s^{-3}$ and a working volume of 95.46±54.32 cm^3, whereas intermediates had respectively 10.86±2.44 $m.s^{-3}$ and 144.35±57.29 cm^3.

DISCUSSION

This study analyzed kinematic data coming from surgical routine to analyze expertise whereas most similar previous studies relied on simulated procedures. Additionally, our local analysis based on SPM methodology gives more information than a global one. While the significant differences were only in acceleration and jerks at the global levels, the local analysis allows us to better understand the specificity of each surgical phase. In the case of "adnexal dissection left", the uterus blocks the movement of the right tool (arm 2), leading to less smooth motion for intermediates. One tip to counter this would be to improve mobilization of the uterus with the uterine manipulator.

The main limitation of this paper is the focus on phases to perform the local analysis. Make a focus on a finer granularity would allow better understanding. For example, the "dissection of the uterine pedicles" phase is split into two different steps relative to the laterality of the pedicles. It is possible that the uterus has also an impact on the robotic arm motion. Future works will focus on this point.

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