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Assessment of inertial measurements units for laparoscopic surgery in an ergonomic framework

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1. Introduction

Simulation-based training is carried out on virtual or physical teaching tools, representing part of the human anatomy and/or physiology (Satava, 2019). While mastery of technical gestures and procedures are the main motivations for training, ergonomic issues also need to be taken into account in simulators (Pérez-Duarte, et al., 2012). Several risk factors related to the operator, the environment of the operating room and the patient significantly increase the occurrence of musculoskeletal disorders (MSDs) in surgeons (Schlüssel & Maykel, 2019). To quantify the influence of these variables and integrate them into the simulators, *in-situ* analysis of the surgeon's movements is required using inertial measurement units (IMU). Although assessment of IMUs have been performed (Steinebach, et al., 2020), there is still a lack of knowledge about the ability of IMUs to acquire the prolonged static postures encountered in laparoscopic

surgery, involving the elbows and wrists in particular. The aim of the study was to assess between IMUs and a reference device based on optical motion tracking (MT) within an ergonomic analysis for the elbow and wrist joints during three simulated laparoscopic surgery procedures.

2. Methods

2.1 Subject

The subject of the study was a senior surgeon with over 10 years' experience, male, aged 47, measuring 1.80 metres and weighing 93 kilograms. The participant attended a single test session and no repeated measurements were taken between days. The study was approved by the ETH Human Research Council. Subjects signed an informed consent form before the experiments began.

2.2 Material

The reference measurements were taken using a set of 10 markers installed for the upper limbs and an optoelectronic system consisting of 15 cameras (Vero, Vicon Motion Systems Ltd, United-Kingdom) with an acquisition frequency of 100Hz. 5 inertial measurement units (T-Sens Motion, TEA Ergo, France) were placed on the upper limbs of the hand, wrist and biceps in the middle of the line of the shoulder blades and at pelvic level, all in the frontal plane. Their acquisition frequency was 32Hz.

2.2 Tasks

3 standardised tasks from Fundamentals of Laparoscopic Surgery program were performed successively by the surgeon including peg transfer, pattern cutting and suturing.

2.3 Data management

3 segments (biceps (arm), forearm and hand) on the right side were used to describe the angular values (AV) of four movements at the 2 joints involved: elbow flexion/extension (F/E), elbow pronation/supination (P/S), wrist F/E, and wrist abduction/adduction (A/A). The recommendations in the International Society of Biomechanics standards were applied to the order of the rotation sequences of each joint in MT. Using the manufacturer's software, the IMUs were automatically calibrated to similar parameters landmark. At the end of the acquisitions, the software automatically generates processed data on the selected joints.

2.4 Data processing

The AV of the movements were sorted according to three levels: comfortable (CL), moderate (ML) and uncomfortable (UL). The ranges were established on the basis of ergonomic recommendations derived from RULA (Maurer-Grubinger, et al., 2021) (Table 1).

3. Results and discussion

The proportion of angular values for IMU at CL was lower than for MT in 8 out of 12 cases. This average difference was 21.2% (sd = 21.9%), leading to an

average increase of 15% (sd = 24.4%) and 8.1% (sd = 8.6%) respectively for ML and UL. Conversely, a third of the IMU signals overestimated the CL (4/12) by 27.2% (sd=19.5%) on average. Consequently, the uncomfortable level decreased by 23.2% on average (sd=15.4%), whereas the ML was slightly overestimated by 0.7% (sd=13.8%).

Table 1. Range of AV defining the level of solicitation according to the joint's movements

Joint	Movement	Moderate level of solicitation (°)	Uncomfortable level of solicitation (°)
Elbow	Flex	60	100
	Ext.	-	0
	Pron	20	45
	Sup.	-45	-60
Wrist	Flex.	0	30
	Ext.	-30	-45
	Abd.	10	15
	Add.	-10	-20

On average, the CL was underestimated for the elbow joint in F/E by up to 25.3% (sd=26.3%) and overestimated in P/S by 6% (sd=13.7%). For the wrist, there was an overestimation in F/E by 16.3% (sd=32.1%) and an underestimation in A/A by 15.2%. Focusing on wrist F/E during suturing exercise (Figure 1), the mean absolute error (MAE) averaged 2.2% (sd = 1.84%) throughout the entire range of motion. At comfort/moderate level limits [-30°; 0°], the MAE were 5.1% (sd = 1.16%) for [-34°, -26°] and 3.6% (sd=1.47%) for [-4°, 4°].

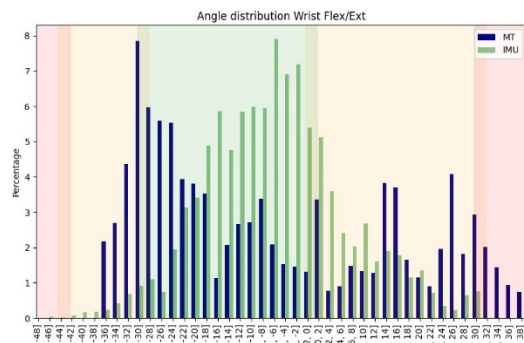


Figure 1. Distribution of the AV of Wrist F/E during suturing task, with green [-30°;0°], yellow([0°;30°],[-45°;-30°]) and red areas (>30°],[<-45°]) respectively labelled as comfort, moderate and uncomfortable level.

The overall distribution of proportions among the ergonomic levels led to an underestimation of the CL. Moreover, the increase in MAE at the thresholds of these levels can introduce additional flaws in data interpretation. The significant scatter in the data would require a Bland-Altman analysis to quantify potential bias in the parameters and to assess the relationship between the dispersion and the measurement span. It

shall be carried out within standardized tasks to assess repeatability and potential drift over time, as well as the causes of these errors

4. Conclusions

Preliminary results from simulating surgical procedures indicate that IMU motion acquisition solutions exhibit a high degree of dispersion. This variation must be quantified before the device can be reliably used to analyze motion in an operating room.

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Conflict of Interest Statement

The authors declare no competing interests

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