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Motion analysis in the pediatric laparoscopic surgery (PLS) simulator: validation and potential use in teaching and assessing surgical skills

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ABSTRACT

Background: Construct validity for the pediatric laparoscopic surgery (PLS) simulator has been established through a scoring system based on time and precision. We describe the development and initial validation of motion analysis to teach and assess skills related to pediatric minimal access surgery (MAS).
Methods: Participants were asked to perform a standardized intracorporeal suturing task. They were classified as novices, intermediates, and experts. Motion in the four degrees of freedom available during traditional MAS (PITCH, YAW, ROLL and SURGE) was assessed using range, velocity, and acceleration.
Results: Analysis of motion allowed discrimination between the 75 participants according to level of expertise. The most discriminating motion parameter was the acceleration in performing the ROLL (pronation/supination) with values of 30 ± 27 for novices, 15 ± 5 for intermediates, and 3.7 ± 3 for experts ($p < 0.001$).
Conclusions: Tracking and analyzing the motion of instruments within the PLS simulator allow discrimination between novices, intermediates, and experts, thus establishing construct validity. Further development may establish motion analysis as a useful "real time" modality to teach and assess MAS skills.

There is an increasing demand for structured, objective, *ex vivo* training and assessment of psychomotor skills in minimal access surgery (MAS) prior to having the trainee participate in direct patient care in the operating room. Technical–surgical demands in MAS differ from those in open surgery: reduced depth perception, longer instruments, counterintuitive instrument movement, and loss of joint dexterity [1,2]. The operating room (OR) as a primary teaching environment may not be desirable and it also carries legal and ethical concerns, amplified by increasing pressures with respect to OR efficiency. Simulation-based practice does not put patients at risk and avoids interference with the efficiency of healthcare resources. Currently, evaluation methods for MAS skills are still performed mainly using subjective expert observation [3,4]. The aim of this study was to validate the use of a motion-tracking device for future implementation on a pediatric MAS box trainer.

1. Methods

1.1. Study design

A prospective cohort study.

1.2. Simulator/box design

The PLS simulator purposely maintains its simple, low cost box design. The internal dimensions are 18 (length) × 10 (width) × 9 cm (height) for a volume of 1620 cm^3. It is easily assembled and disassembled for ease of transport and use. It uses a webcam, so any computer can be used as the screen. Costs have purposely been kept as low as possible to allow global access.

This special PLS Simulator box was fitted with custom-built motion tracking hardware and software (Fig. 1). The hardware consisted of an ADNS-7530 mouse sensor (Avago Technologies, San José, CA) and a BMA-180 3-axis accelerometer (Bosch Sensortec GmbH, Reutlingen, Germany) mounted on a custom printed circuit board. These sensors are interfaced with an ATmega168 microprocessor (Atmel, San José, CA) which synchronizes the data from the right and left tool sensors and provides a USB interface to a personal computer (PC). The custom software retrieves position data from the microprocessor and synchronizes it with data acquired from the Lifecam HD-6000 webcam (Microsoft, Redmond, WA) and provides a video display to the trainee.

1.3. Degrees of freedom

With complete freedom of motion, an object has six degrees of freedom. Three of these are termed "translations", and three are termed "rotations". Translations can be forward/backward (SURGE),

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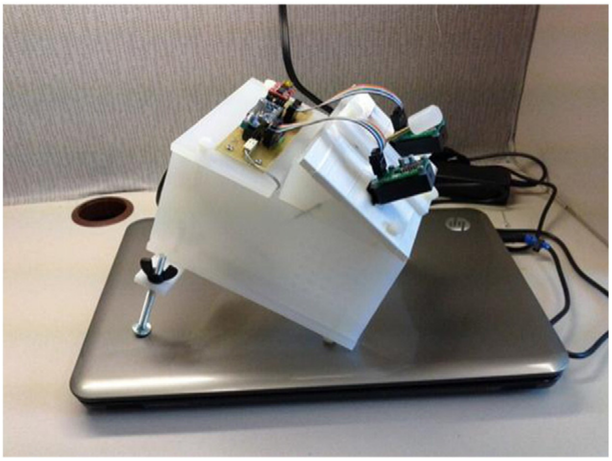

Fig. 1. PLS simulator was fitted with custom built motion tracking hardware.

up/down (HEAVE), or left/right (SWAY). Rotations can be around the vertical axis (YAW), lateral axis (PITCH), or longitudinal axis (ROLL).

In MAS, the ports are fixed, and there exist only four degrees of freedom (one translation and three rotations):

- Surge: the motion/translation ALONG the linear longitudinal axis, i.e. result of pushing hand in or pulling hand out.
- Roll: the motion/rotation ABOUT its longitudinal axis, i.e. result of pronation/supination.
- Pitch: the motion/rotation in the vertical (up/down) axis, i.e. result of moving hand up/down.
- Yaw: the motion/rotation in the lateral (side to side) axis, i.e. result of moving hand side to side.

1.4. Candidates and testing

Candidates were recruited at an education booth at the 2012 International Pediatric Endosurgical Group (IPEG) meeting. Each candidate gave informed consent under a protocol approved by the Hospital for Sick Children (REB# 1000025362). Each participant performed the intracorporeal suturing task on the PLS simulator. Candidates were stratified according to level of expertise: novice (<10 pediatric or adult MAS procedures/year), intermediate (10–50 pediatric MAS procedures/year), and expert (>50 pediatric MAS procedures/year) [3].

1.5. The task: suturing with intracorporeal knot tying

In this exercise, a suture on a needle is placed at a predetermined position within the PLS simulator. The needle is then grasped and correctly positioned for suturing. The suture is passed through target points on either side of a slit in a Penrose drain. The size of the Penrose drain for the PLS is 11 mm × 6 mm × 30 cm cut to a 15 mm length. The surface area of the velcro patch by which the Penrose was secured to the underlying board for the PLS was 1.2 × 0.5 cm. The suture used was 4–0 silk (75–90 cm) on an RB-1 (or equivalent) needle that was cut to a 9–10 cm length. Three millimeter instruments were used. After passing the needle of the suture from one side of the Penrose drain to the other, the participant tied one surgeon's knot (double throw) followed by two simple knots (single throw). Where necessary, the task was explained and/or demonstrated to the participant.

1.6. Statistical analysis

Unless otherwise stated, results were reported as mean ± SD. Statistical analysis was performed using MedCalc for Windows, version 12.5 (MedCalc Software, Ostend, Belgium). Scores for the novice, intermediate, and expert were compared using 1-way analysis of variance. Statistical significance was assessed at $p < .05$.

2. Results

A total of 75 participants were recruited for this study. Participant demographics are listed in Table 1. The four degrees of motions possible in MAS (SURGE, PITCH, YAW and ROLL) were assessed using:

- Velocity: The rate of change of the position of the instrument, equivalent to a specification of its speed and direction of motion.
- Acceleration: The rate at which the velocity of a body changes with time.
- Range: The limits between which 90% of time was spent.

Fig. 2 shows examples of the output of the motion analysis tracking. Furthermore, a single numerical output for each movement was summarized by the number of times each movement deviated more than twice the standard deviation (indicating a deviation from normal distribution).

Table 2 summarizes the result of comparison between novice, intermediate and expert for the dominant hand. Results of the motion analyses for velocity, acceleration and range in all four degrees of motion allowed discrimination between levels of expertise, with the exception of the range of the SURGE. We were also able to differentiate between level of expertise in a post-hoc test with the exception of acceleration of the YAW and velocities of ROLL and SURGE between intermediate and experts. The most discriminating motion parameter was the acceleration in performing the ROLL (pronation/supination), followed by acceleration of the SURGE and velocity of the PITCH.

3. Discussion

To our knowledge, this is the first study to describe the use of motion analysis in pediatric MAS. Our results demonstrate that the analysis of motion within the PLS simulator allowed us to distinguish between novice, intermediate, and expert groups in a statistically significant manner. While the results of motion analysis always allowed discrimination between novice and intermediate as well as between novice and expert groups (thus establishing construct validity), it did not always allow discrimination between intermediates and experts. This speaks to the very definition of expertise based solely on number of cases performed. Most would agree that someone who performs <10 pediatric or adult MAS procedures/year is likely a novice. We know, however, from our years of testing that some of the intermediates (10–50 pediatric MAS procedures/year) perform at an expert level, while some experts (>50 pediatric MAS procedures/year) perform closer to an intermediate level (when informally observed performing MAS tasks). This is, in fact, the subject of a current study being carried out by our group.

For the purpose of this study, the task consisted of suturing with intracorporeal knot tying within the PLS simulator. This task is an essential skill in pediatric MAS: it not only teaches and measures depth perception, visual-spatial perception, and the ability to use both hands in a complimentary manner, but it also fosters the development

Table 1
Demographic data of participants.

	N = 75
Age (years)	42 ± 10
Sex (male:female)	(46:29)
Experience level	
– Novice	26
– Intermediate	12
– Expert	37

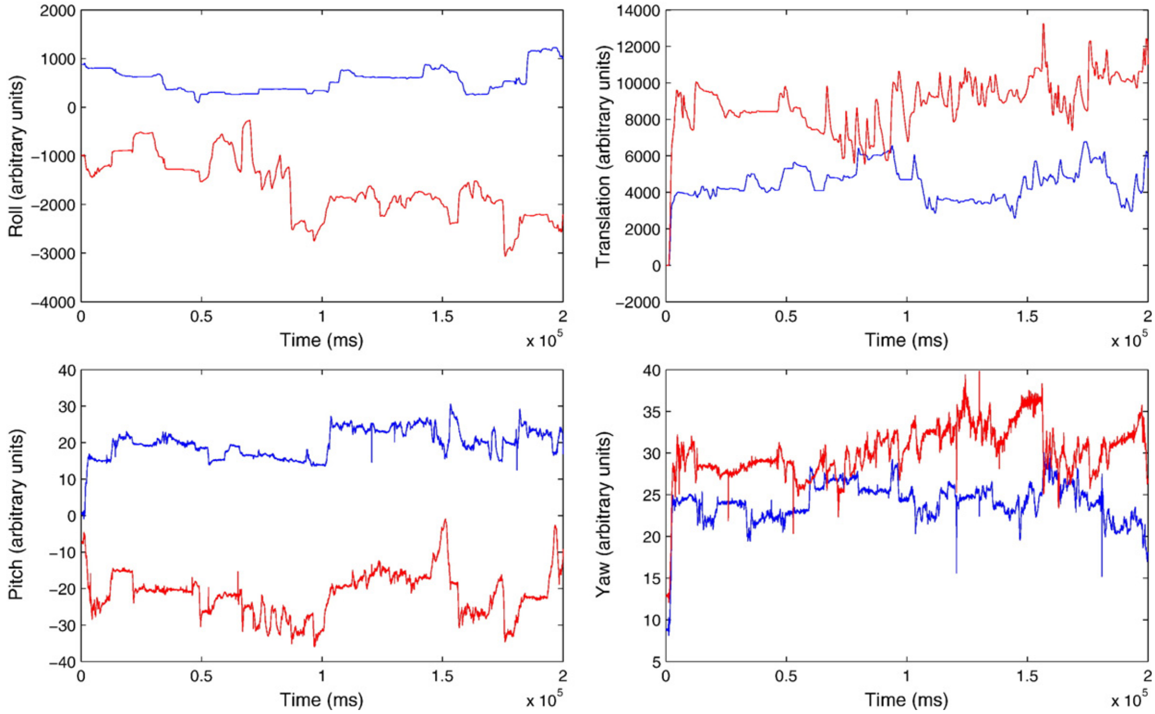

Fig. 2. Examples of the output of the motion analysis tracking.

of visual and tactile cues as to the amount of force and traction required for actual laparoscopic suturing and knot tying. Moreover, it is viewed by all surgeons as an important, practical skill to learn: this relevance makes candidates more likely to try to master this task [3,5]. We also believe that this relevance has been important in attracting participants, and will likely be important in terms of having them practice on a regular basis.

In assessing the range of movement, the velocity, and the acceleration in the four degrees of motion available in MAS, all but the range of the SURGE, permitted statistically significant differentiation between novices, intermediates and experts, thus establishing their construct validity in this specifically defined task.

Interestingly, we found that the most discriminating motion parameter was the acceleration in performance of the roll: rotation about the longitudinal axis. The important educational correlate in this specific suturing task is that we have a specific performance parameter to target: pronation/supination. In an era when many educators of psychomotor skills feel that deconstruction of a task is crucial for its teaching, this type of technology may allow us to more thoughtfully "reconstruct" performance of a specific task or skill. As educators, we can then measure the impact of our intervention. In general terms, based on these results, special attention should perhaps be paid to this movement when teaching pediatric MAS skills to trainees, specifically suturing tasks. Having said this, one of the advantages of being able to analyze a candidate's motion in real time is that it may allow us to determine with more certainty where to focus our educational efforts, and to track the impact of said educational interventions.

By the same token, the range of SURGE (the motion/translation ALONG the linear longitudinal axis, i.e. result of pushing hand in or pulling hand out) was not discriminative between levels of expertise. There may be less need to address a candidate's psychomotor behavior (pushing in or pulling out) in this specific task. We do however, recognize that this result would be expected in a "pre-placed single suture model" such as ours, where you are not inserting and removing sutures and where the suturing task is in an ideal location relative to the needle driver (the axis of the needle driver is parallel to the slit opening in the Penrose drain which is located flat on the floor of the simulator box). In a model or task requiring insertion and removal of sutures, the range of SURGE may be more relevant. Certainly, in real surgery, the range of the SURGE (in and out movement) is clinically relevant as manifested by the potential for past pointing and the injuries that may ensue. While the range of SURGE was not discriminative in this particular context, it may be relevant in cases where multiple sutures are required. In our previous publication [3], we were able to discriminate between levels of expertise using precision and time taken to complete said task. We believe that motion analysis represents yet another parameter which may be useful in the teaching and assessment of pediatric MAS.

Motion metrics are a potentially important source of information when addressing the assessment of surgical expertise [4,6–8]. They allow for the assessment of surgical dexterity using parameters that are extracted from movement of the hands or laparoscopic

Table 2
Comparison between novice, intermediate and expert.

	Novice (N = 26)	Intermediate (N = 12)	Expert (N = 37)	P value
PITCH				
– Velocity >2 SD	52 ± 44	29.4 ± 19	13.6 ± 6	0.001
– Acceleration >2 SD	85.8 ± 60	45 ± 32	29.6 ± 13	0.002
– Range	150.3 ± 50	90.2 ± 68	26.3 ± 12	0.02
YAW				
– Velocity >2 SD	46.3 ± 38	29.8 ± 16	8.6 ± 4	0.002
– Acceleration >2 SD	80 ± 70	30 ± 28*	20 ± 7*	0.001
– Range	178.2 ± 20	122.8 ± 42	26.3 ± 16	0.02
ROLL				
– Velocity >2 SD	16 ± 18	6.2 ± 6.2*	3.8 ± 0.9*	0.001
– Acceleration >2 SD	30 ± 27	15 ± 5	3.7 ± 1.1	<0.001
– Range	10445 ± 2404	8697 ± 1973	3923 ± 988	0.007
SURGE				
– Velocity >2 SD	26.6 ± 21	15.7 ± 7.5*	7.8 ± 0.6*	0.002
– Acceleration >2 SD	38 ± 33	19 ± 11.5	7 ± 2	<0.001
– Range	1004 ± 450	931.8 ± 562	753.6 ± 111	0.6

SD: Standard deviation.
* Nonsignificant results in post hoc test.

instruments. Several different motion analysis systems have been developed in adult surgery. They can be in-built (like the PLS), within a simulator (e.g. ProMISTM) [9,10], or as a separate device, enabling flexible use (e.g. Imperial College Surgical Assessment Device, ICSAD) [7,11]. Objective assessment of laparoscopic skill could be carried out using motion analysis if endpoints for each parameter are quantified according to predefined levels of experience.

The conversion of motion analysis data into competency-based scores or indexes could provide a valuable source of trainee feedback. This could eventually be measured and displayed so that the candidate performing the task would receive "real-time", instant feedback. While the testing of precision and time for a given a task can also be measured immediately, they currently require completion of the task and a scoring process before results can be used for feedback and assessment. Motion analysis could be set up to provide feedback and assessment during task completion, thus proving to be a powerful educational tool. Analysis of a candidate's motion could not only simultaneously track and provide feedback, but also demonstrate motion parameters that more experienced candidates (experts) would have. This could potentially serve as a testing tool at the time of clinical assessment of surgical trainees. The progress could be charted and tracked more easily than the precision of task completion. As for time of task completion, most surgical educators would agree that "first you get good, and then you get fast" [11].

We have established the construct validity of motion analysis within the PLS simulator. Because of the possibility for real-time feedback, motion analysis has the potential to be a useful tool for the teaching and assessment of candidates interested in improving their psychomotor skills. Our results are based on the performance of one specific task: further investigation will be required before we can make more sweeping statements regarding the educational role of motion analysis.

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