International Journal of Healthcare

ORIGINAL RESEARCH

Feasibility of tracking in open surgical simulation

Vera Hillemans, Bas Verhoeven, Sanne Botden

Department of Pediatric Surgery, Radboudumc – Amalia Children's Hospital, Nijmegen, The Netherlands

Corresponding author: Vera Hillemans, Vera.Hillemans@radboudumc.nl

https://ijohs.com/article/doi/10.54531/JUVJ5939

ABSTRACT

Introduction

The aim of this study was to develop an adequate tracking method for open surgical training, using tracking of the instrument or hand motions.

Methods

An open surgical training model and the SurgTrac application were used to track four separate suturing tasks. These tasks were performed with colour markings of either instruments or fingers, to find the most promising setting for reliable tracking.

Results

Four experiments were used to find the optimal settings for the tracking system. Tracking of instruments was not usable for knot tying by hand. Tracking of fingers seemed to be a more promising method. Tagging the fingers with a coloured balloon-tube, seemed to be a more promising method (1.2–3.0% right hand vs. 9.2–17.9% left hand off-screen) than covering the nails with coloured tape (1.5–3.5% right hand vs. 25.5–55.4% left hand off-screen). However, analysis of the videos showed that redness of the hand was seen as red tagging as well. To prevent misinterpreting of the red tag by redness of the hand, white surgical gloves were worn underneath in the last experiment. The off-screen percentage of the right side decreased from 1.0 to 1.2 without gloves to 0.8 with gloves and the off-screen percentage of the left side decreased from 16.9–17.9 to 6.6–7.2, with an adequate tracking mark on the video images.

Discussion

This study shows that tagging of the index fingers with a red (right) and blue (left) balloon-tube while wearing surgical gloves is a feasible method for tracking movements during basic open suturing tasks.

What this study adds

- Currently, there are limited options for training of open surgical skills.
- Tracking hand movements is a feasible method to assess basic open suturing tasks.
- Tagging of the fingers is an easily accessible method for tracking hand movements.
- Tagging of the index fingers seems the most promising open surgical tracking method.

Introduction

Surgical training is currently focussed mainly on minimally invasive surgery (MIS), because this is a new and challenging technique. However, it is also important to train open surgery, to establish both good basic skills and procedural training. Assessment of these skills is a method to evaluate them before performing surgical procedures in the clinical setting.

There are several methods to assess the skills of trainees during MIS simulator training, ranging from expert observers to Virtual Reality. Tracking of instruments in MIS simulation has been perceived as a valuable method for the training and assessment of laparoscopic skills [1]. The SurgTrac application [2] is one of the applications used for tracking instruments, which can be used in several MIS simulator trainers. The MIS instruments are colour marked, which makes it possible to track them with the software and calculate several indicative parameters. This has been validated previously, showing construct validity in discriminating between expertise levels [3]. Because an assessment can be given during the training, the surgical trainee can improve skills without need of an expert observer assessing the executed training. Consequently, tracking of instruments in MIS simulation is a time- and cost-effective way of training.

Currently, no comparable alternative in open surgical simulation is available and existing MIS simulation settings are not usable for the training of open surgical techniques, because no screen and many different instruments are used during open surgery. And that while it is becoming increasingly difficult to get adequate exposure to open surgical procedures in the clinical setting [4]. This is partly due to the increase in MIS and robotic assisted surgeries, which have replaced a considerable amount of open procedures [5,6]. Also, the relative reduction of clinical procedures during working hours induces a decline of open surgical experience to surgical trainees [7]. It appears that reduction of open surgical experience is associated with a lack of technical skills and a decreasing confidence in executing open surgical procedures [8,9]. Additionally, more complex and rarely performed surgical procedures are difficult to train in the real-life clinical setting. Therefore, it is important to train and assess these skills with a bench model. These elaborations stress the need for a validated open surgical simulation technique.

To develop an open surgical simulation technique using tracking, it was necessary to consider how open surgery can be tracked adequately. Therefore, four research questions were formulated. First of all, it was important to find out whether tracking of instruments or tracking of fingers leads to a more reliable tracking method. This leads to the first two research questions:

1. Is instrument tracking in open surgical simulation an option?
2. Is finger tracking in open surgical simulation an option?

Secondly, it was important to improve the most feasible tracking method through answering the following two research questions:

3. What is the best method to tag fingers/instruments (depending on the answer of the first two research questions) in open surgical simulation?
4. Is there a way to optimize the best method, based on the outcomes of research question 3?

Basic open suturing tasks were used to develop a tracking technique. The overall aim of this study was to evaluate the feasibility and develop an adequate method of tracking the movements during basic open suturing tasks.

Methods

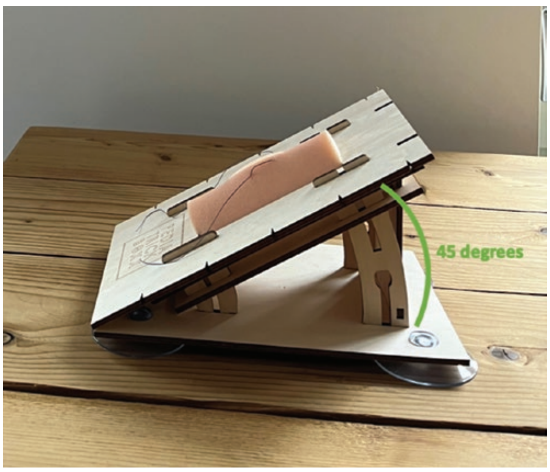
Subjects

All experiments in this study were performed by the same surgeon at the Radboud University Medical Center, Nijmegen, The Netherlands. This expert surgeon performed a minimum of a thousand sutures (per separate suturing task) in the clinical setting. The experiments for this study were executed in June 2020. Blinding the participant and researcher was not possible due to the use of one participant and the visibility of the used methods, such as gloves and the placement of the tags. The choice for just one participant was made to ensure consistency in performance. As a result, a reliable comparison can be made between different methods to track open surgical tasks. No medical ethical approval was required, because of the non-medical intervention setup of this study.

Equipment

The simulation model used in this study was a skin-coloured suturing pad, mounted in a casing of the PediatrickBoxx base [10–12]. PediatrickBoxx is a Dutch company that develops paediatric and adult simulators for the training of surgical tasks. The used simulator was a standard casing for holding suturing pads to train basic surgical skills. This simulator is usable for training paediatric surgery and surgery in adults. In this study, the casing was set at approximately 45 degrees angle, as can be seen in Figure 1. With this 45 degrees angle

Figure 1: Simulation model of PediatrickBoxx for basic open surgical tasks with a 45 degrees angle.



in the simulation model, it was easier to position the camera in a way that the complete operating field is visible.

The camera used, was from an iPhone XR, mounted on a table-smartphone holder, to achieve a steady video and allow for single person use. The optimal position of the camera was tested in several angles: right side next to the shoulder of the trainee, left side next to the shoulder of the trainee, right side lateral view, left side lateral view and behind the simulation model for a straight view. From this evaluation, the position of the right side, next to the shoulder, seemed to be the best position to get a proper vision of the operating field, including both hand and instrument movements (for a right-handed surgeon). Figure 2 shows the setup of the used materials.

The tracking in this study was performed with SurgTrac software [2] used with the application on an iPhone XR. This software is conventionally used for instrument tracking in minimally invasive surgical simulation, in which the right instrument is tagged with a red sticker and the left one with a blue sticker.

Procedure

For this study, four experiments were performed to answer the four research questions and thereby establish the most feasible method to tag instruments or hands, to track the movements in basic open suturing tasks. To discover whether a feasible tracking method could be developed, the first two research questions had to be answered:

1. Is instrument tracking in open surgical simulation an option?
2. Is finger tracking in open surgical simulation an option?

Figure 2: Research setup with a smartphone in a stand next to the right shoulder.

To answer those questions, two experiments were conducted. In each experiment, two suturing tasks were executed with colour marked instruments and fingers respectively. After those two experiments, both tracking methods were evaluated through comparing the measurements of the SurgTrac application with the recorded videos of the executed tasks. All videos were recorded and looked back in the recorded videos the tracking of the colours was visible, by an asterisk appearing on screen, marking the tracked colour. In this way, it was possible to evaluate whether the correct marking was tracked and if the coloured markings were on screen to be tracked.

After evaluation of Experiments 1 and 2, the third research question need to be answered:

3. What is the best method to tag fingers/instruments (depending on the answer of the first two research questions) in open surgical simulation?

Subsequently, Experiment 3 was developed to investigate this research question. In the third experiment, four methods of tagging fingers/instruments were compared. To examine which tagging method seemed to be most reliable for tracking basic open suturing tasks, all four suturing tasks were performed with four different tagging methods. The most promising methods from this experiment were used again in the fourth experiment to answer the last research question:

4. Is there a way to optimize the best method, based on the outcomes of research question 3?

In Experiment 4, two suturing tasks were executed again, but then with white surgical gloves underneath.

After each experiment, the used method was evaluated through comparing the measurements of the tracking system with visual video-evaluation. In this way, the tracking method was developed and constantly adapted through an iterative process until a feasible tracking method was found.

The following four suturing tasks were used in the four experiments:

1) Transcutaneous suturing and knot tying with instruments
2) Knot tying by hand
3) Continuous intracutaneous suturing (4 cm long), without knot tying
4) Vertical mattress suturing (‘Donati’ suture) and knot tying with instruments

To determine whether instrument or finger tracking is feasible for tracking all basic open suturing tasks, at least one task with the use of instruments and one task without the use of instruments is needed. Hence, Tasks 1 and 2 were used for Experiments 1 and 2. Experiment 3 asked for more different suturing tasks to make sure the investigated methods for tracking were feasible in all tasks. For this reason, all abovementioned suturing tasks were used in this experiment. Experiment 4 used one of the methods already investigated in Experiment 3 with a small addition (white surgical gloves) to optimize the best method from Experiment 3. Because of the small difference between methods in Experiments 3 and 4, execution of only Tasks 1 and 2 was necessary to test the added part of the method in Experiment 4.

Outcomes

The SurgTrac software on the iPhone tracked a red and a blue tag during all experiments. The parameters that this tracking software measured for those tags were time (seconds), working space (average distance between tags in centimetres), instrument distance (metres travelled by tags), tags off-screen (percentage), speed (millimetres/second), acceleration (millimetres/second^2), smoothness (millimetres/second^3) and handedness (percentage deviation from equal left and right hand usage). Furthermore, in the videos of the executed tasks a small asterisk was visible on screen as indicator of the measured red and blue tag. For Experiments 1 and 2, this asterisk was used to evaluate whether the red and blue tag are tagged adequately. For Experiment 3, this asterisk was also used, together with all the measured parameters of SurgTrac. In Experiment 4, percentage off-screen and the measured distance and speed were evaluated.

Data analyses

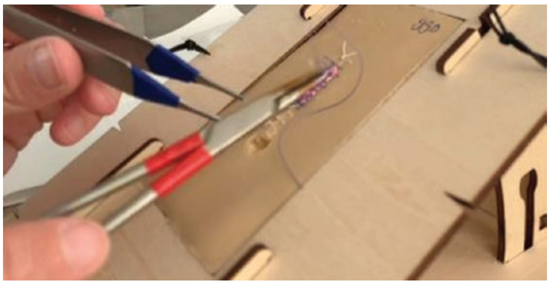
Most data were analysed in the SurgTrac application, which showed the measured parameters and the videos of the executed tasks with an asterisk on the tags. For Experiments 1 and 4, the mean and standard deviation of the parameter off-screen are calculated by IBM Statistical Package for Social Sciences (SPSS), version 25.

Results

Experiment 1: Is instrument tracking in open surgical simulation an option?

The instruments normally used in the right hand (needle-driver and scissors) were tagged with a red tape at the most distal end that did not articulate and was not used for grabbing or cutting. This meant that the tagging was relatively close to the hands of the trainee. For the left instruments (pincer), the same was done with a blue tag, which could be placed more distally, compared to the articulating instruments (Figure 3). A suturing task with knot tying using instruments was performed first (Task 1), followed by knot tying by hands, because a lot of procedures require knot tying by hand (Task 2).

Figure 3: Instruments were tagged at the most distal part possible (red for right and blue for the left instrument).



Outcomes experiment 1

The system gave readings of the task. However, these were not compatible with the visual evaluation on the video. In Task 1, the right instruments were tracked out of view for >25%. For Task 2, the system could not track the instruments because the knot was tied by hand.

This experiment was not successful, and tracking was not valid for the tracking of open surgical tasks.

Experiment 2: Is finger tracking in open surgical simulation an option?

To answer this question, both the index fingers and thumbs were tagged with red (right) and blue (left) tape at the distal phalanx (Figure 4). A suturing task with knot tying using instruments was performed first (Task 1), followed by suturing and knot tying by hands (Task 2).

Outcomes experiment 2

The tracking system was able to track the fingers, with promising outcomes with both tasks. Fingers were tracked <5% out of view. In other words, the fingers were >95% in view and their path were tracked by the system for >95%.

However, when evaluating the videos of the tasks, the tracking system appeared to jump from one finger to the other finger with the same colour marking, which produced inconsistent and unreliable data. It was also not possible to tie knots by hand with the tapes around the fingers.

Finger tracking, using colour markings, seemed to be a feasible option in the tracking of basic open suturing tasks. However, it seemed better to use only one red/blue marking, instead of two on each hand. This way, collecting inconsistent data due to signals jumping from one finger to the other with the same colour marking, should be avoided. Additionally, it was better to not apply circular tape on the finger.

Experiment 3: What is the best method to tag fingers/instruments (depending on the answer of the first two research questions) in open surgical simulation?

Experiments 1 and 2 showed that tracking of fingers was a better method for tracking basic open suturing tasks than tracking instruments. Hence, our third research question

Figure 4: The index fingers and thumbs were tagged with tape (red for right and blue for left).

can get more specified to: 'What is the best method to tag a finger for tracking in open surgical simulation?'.

To establish the best method to tag one finger on each hand, it was of paramount importance to evaluate the outcomes of the previous experiments. This has led to the follow demands for the tagging:

- One finger of each hand should be tagged
- The tags should continuously be visible for the camera during the training (when hands are in the operating field)
- The tags cannot limit the surgical skills (as circular taping did)
- The tags should be universal in use and easily available (such as colored tapes), to make sure it is possible to use for home-based training

This led to four possible options (Figures 5–8), which were explored in this experiment:

1. Red and blue rubber balloon ends (cut from normal balloon) over middle phalanx of index fingers.
2. Red and blue rubber balloon ends (cut from normal balloon, for larger thumb the wider part can be used) over proximal phalanx of thumbs.
3. Red and blue tape only covering the nail of the index fingers
4. Red and blue tape only covering the nail of the thumbs

Outcomes experiment 3

All four tasks were performed by the same surgeon, in all these conditions. The percentage off-screen measured by the SurgTrac application and problems encountered during the training sessions were collected and evaluated in Table 1.

In the first attempt, the left hand was out of view longer, due to the camera requiring adjustment. This explains the higher percentage out of view for the index finger balloon, compared to the thumb balloon. From the results in Table 1, it is evident that balloon tagging of either the index finger or the thumb was more promising than taping of the nails. The system indicated that in all four tasks in which the index fingernail was taped, in two of the thumb nail tapings and one of the balloon tagging on the thumb, tags were out of view of >20% of the task. Which means that the tracking was not proficient.

Both tagging methods did not affect the performance of the tasks, in the opinion of the performing surgeon.

Figure 5: Balloon ends on index fingers.

Figure 6: Balloon ends on the thumbs.

Therefore, the outcomes of the parameters were not affected by these tagging methods. The only difference to be evaluated in this experiment was the effectiveness of the tracking of that tagging method.

Table 2 shows the outcomes parameters of tracking of the fingers with different methods. Methods used were the options to tag the fingers: (1) index fingers covered with balloon, (2) thumbs covered with balloon, (3) nails of index fingers covered with tape and (4) nails of thumbs covered with tape. The tasks used were (1) suturing and knot tying with instruments, (2) knot tying by hand, (3) intracutaneous running suture and (4) 'Donati' suture.

From these results, it seemed that the left hand tracking was a more important feature in this experiment than the right hand tracking. It appeared that the left instrument tracking was correct, when compared with the visualization of the blue tagging on the screen. However, the red tag was often not tracked correctly (which was visible with the small tagging asterisks on the screen). The redness of the inside of the hands was often erroneously tracked as a red tag, instead of the bright red tagging on the finger or nail. Therefore, the tracking of the right tag could not be considered reliable data.

To further explore the most promising method, only the left tag tracking was gathered and the methods were compared based on the task they were used in (Table 3). This showed again that method 3, tagging of the nail of the index finger with tape, was the worst option and tagging of the index fingers or thumbs with a balloon seemed the most promising.

In conclusion, it can be stated from Experiment 3 that balloon tagging of both the index fingers or thumbs were promising tracking methods during basic open suturing

Figure 7: Tape covering nails of index fingers.

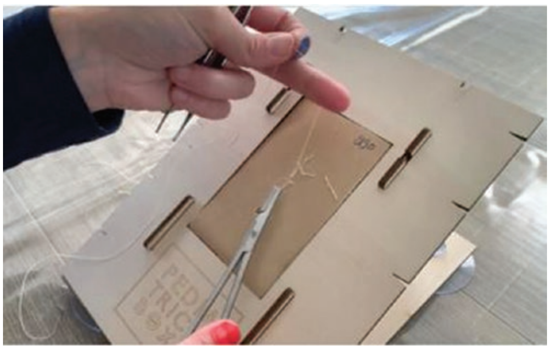
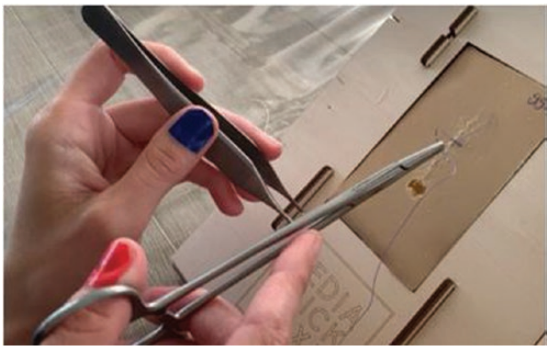


Figure 8: Tape covering nails of thumbs.



tasks. However, in the current form, there is too much redness of the skin, which confounded the tracking of the red tag. Therefore, the following experiment should explore the tracking of balloon tagging of the index fingers and thumbs (separately), while the surgeon is wearing white surgical gloves, to reduce the redness of the skin.

Experiment 4: Is there a way to optimize the best method, based on the outcomes of research question 3?

Based on the previous experiments, it was evident that a white (or non-red/non-blue) underground was needed to place the tags over, to avoid confounding in the tracking of the tags on the fingers. The fourth research question will therefore specifically be: 'Does the tracking of the 'balloon-tube tagged' fingers work properly, if surgical gloves are worn underneath?'.

The most promising tagging was either the balloon-tube over the index fingers or thumbs. Therefore, these two methods (methods 1 and 2) were tested again for the same tasks but placed over white surgical gloves (methods 5 and 6) (Figures 9 and 10).

Because the finger tracking corresponded well with the visualization of the hands on screen, this tracking method was successful. The higher percentage of the left finger off-screen in the fifth method (balloon-tube over index finger) corresponded with the finger out of view during the training of Task 4 (red 1.4% and left 15.6% out of view), as shown in Table 4.

What was also striking during the tracking, was that during method 6 (balloon-tube over thumb), the red tracking

Table 1: Percentages off screen for the right (red) and left (blue) tagging of the finger, using different tagging methods

	% Off screen right (mean, SD)	% Off screen left (mean, SD)
1: Balloon-tube index finger	1.2 (1.3)	17.9 (12.9)
2: Balloon-tube thumb	3.0 (3.5)	9.2 (5.5)
3: Nail tape index finger	1.5 (1.0)	55.4 (25.5)
4: Nail tape thumb (*n* = 4)	3.5 (2.6)	25.5 (19.3)

These are the mean values from all four tasks practiced with the tagging method.

reacted on other parts of the hands, only when the red tag was not in view. This can probably be explained by the right thumb being more out of view in method six than five. Therefore, the tracking of the thumb was less reliable than of the index finger. The longer distance travelled by the right hand when tracking the thumb, could also be caused by the tracking bouncing from one location back to the red tag, when it was in view again (Table 5). The travelled distance of the thumb (method 6) was more than twice as long as the distance of the finger for the red tag (method 5), while it was equal for the blue tag. This was also visible for the parameter speed.

An important feature in the use of the tracking methods is not only whether the tracking is correct, but also if it can be used without discomfort of the trainee or disturbance during the training. The balloon over a glove on the thumb caused some strangulation of the thumb, causing discomfort of the trainee. Together with the previous findings, made balloon-tube tagging over a white glove using the index finger the most promising tracking method.

Discussion

Training of open surgical skills is currently mainly based on direct supervision of an expert [13–16]. Training and assessment of MIS skills, however, has already been widely established, using simulators and assessment systems, ranging from high fidelity virtual reality systems to more low budget simulators with tracking systems [17–22]. The SurgTrac application [23] has been validated for the training and assessment of MIS skills [1,3,19,24] and is a portable application, usable in multiple physical simulators. Therefore, this system was used in our experiments to assess the feasibility of tracking of open surgery.

However, there are currently some methods for training of open surgical skills without need of an expert [25–28]. For example, a simulator with Wii remotes, infrared markers and electromagnetic sensors, was built for the training of an open cholecystectomy. This simulator costs 1500,- Canadian dollars, with the additional costs and availability of a porcine liver [25]. This makes the simulator only usable for courses and not for individual training in the current state. Electromagnets have been used before for tracking hand motions in open surgical simulation, in which an electromagnetic tracker was placed in each hand, covered by gloves. The x, y and z coordinates of these trackers were measured to collect information about dexterity [26,27]. Another method used for tracking open surgical skills, is the use of sensory gloves, which measure the motion of each finger joint, also by electromagnetic sensors [28]. These electromagnetic methods of tracking of open surgical skills measure hand-movements and time of executing of a task. However, they cover the hands and could impede subtle hand movements, needed in open surgery. Additionally, these methods are very expensive and not easy to use in an individual training setting. These could have a place in training centres, but to reach all surgical trainees, in all countries, the method should be easily accessible and usable in all settings.

Table 2: The outcome parameters of tracking of the fingers, using different methods for all four tasks

	Task*	Time (sec)	Distance right (m)	Distance left (m)	Handedness (%right/%left)	Speed right (mm/s)	Speed left (mm/s)
1: Index balloon	1	78	12.72	1.59	89/11	49.66	9.45
	2	31	2.08	0.92	69/31	21.01	9.47
	3	240	18.98	3.93	83/17	25.93	6.13
	4	43	7.54	0.43	95/5	53.15	3.78
2: Thumb balloon	1	43	9.60	1.34	88/12	67.61	9.96
	2	23	2.65	0.59	82/18	35.68	8.35
	3	179	38.93	7.76	83/17	75.21	16.26
	4	69	13.38	4.06	77/23	60.42	20.37
3: Index nail tape	1	32	5.86	2.07	74/26	56.98	39.43
	2	29	2.77	0.41	87/13	29.38	11.00
	3	173	22.42	10.33	68/31	41.18	24.24
	4	76	15.82	0.89	95/5	63.25	27.98
4: Thumb nail tape	1	72	9.69	0.89	92/8	40.74	4.59
	2	45	6.33	0.78	89/11	43.16	5.57
	3	184	17.38	1.26	93/7	31.99	4.49
	4	39	4.32	0.72	86/14	36.52	7.76

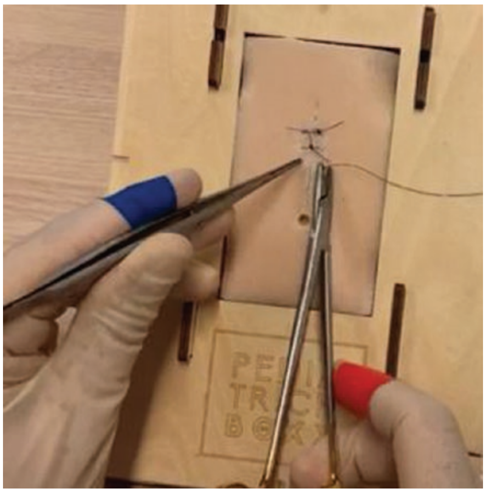
Methods used were the options to tag the fingers: 1: index fingers covered with balloon, 2: thumbs covered with balloon, 3: nails of index fingers covered with tape and 4: nails of thumbs covered with tape.
*Task 1: Suturing & knot tying with instruments; Task 2: Suturing & knot tying by hand; Task 3: Intracutaneous running suture; Task 4: 'Donati' suture.

Table 3: Outcome parameters of tracking of only the left finger, as a reliable comparison

	Method*	Distance left (m)	Speed left (mm/s)	Acceleration left (mm/s2)	Smoothness of motion (mm/s3)	Off screen left (%)
1: Suturing instrument	1	1.59	9.45	3.78	0.24	**34.62****
	2	1.34	9.96	6.51	0.76	5.02
	3	2.07	39.43	6.03	0.95	**49.84**
	4	0.89	4.59	3.32	0.23	18.01
2: Suturing hand	1	0.92	9.47	4.92	0.81	3.31
	2	0.59	8.35	6.21	1.38	4.01
	3	0.41	11.00	3.26	0.57	**60.59**
	4	0.78	5.57	3.62	0.40	5.08
3: Intracutaneous running	1	3.93	6.13	2.41	0.05	15.08
	2	7.76	16.26	2.76	0.08	14.91
	3	10.33	24.24	3.20	0.09	**23.92**
	4	1.26	4.49	1.64	0.04	**50.64**
4: 'Donati' suture	1	0.43	3.78	1.98	0.23	18.77
	2	4.06	20.37	3.47	0.25	13.00
	3	0.89	27.98	0.90	0.05	**87.34**
	4	0.72	7.76	3.77	0.48	**28.31**

In bold are the percentages of blue tags out of view, which indicates that the software could not track the tag properly or that this method is not suited for the tracking in that task.
*Method 1: Index fingers covered with balloon; Method 2: Thumbs covered with balloon; Method 3: Nails of index fingers covered with tape; Method 4: Nails of thumbs covered with tape.
**Because the camera was adjusted with the left hand during this task, the task took longer and the left tag was out of view longer than only based on the performance of the task.

Figure 9: Balloon ends over index fingers over white surgical gloves.



To investigate a reliable, easily accessible method for tracking movements in basic open suturing tasks, four experiments were executed to answer four research questions. In the first experiment instruments were tagged with red and blue tape to be tracked by the SurgTrac application [2] (Figure 3), to answer the first research question: 'Is instrument tracking in open surgical simulation an option?'. Instrument tracking was feasible, however, the tags were often not visible for SurgTrac. It was counted as 'instruments not in view', while they were in view when looking back the videos. Another issue was that this way of tracking was not usable during manual phases of the procedure, such as knot tying by hand. From this first experiment, we can conclude that instrument tracking was not the most reliable method to track movements of basic open suturing tasks, most of all because of the manual tasks that cannot be tracked in this way.

In Experiment 2, red (right) and blue (left) tape was positioned on the distal phalanx of the index fingers and thumbs (Figure 4) to figure out the second research question: 'Is finger tracking in open surgical simulation

Figure 10: Balloon ends over thumbs over white surgical gloves.

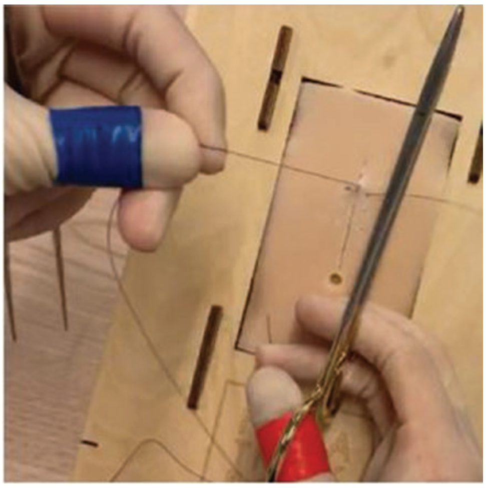


Table 4: Off screen percentages of the different tagging methods: balloon-tube tagging without (methods 1 and 2) and with (methods 5 and 6) gloves underneath

	% Off screen right (mean, SD)	% Off screen left (mean, SD)
1: Balloon-tube index finger	1.2 (1.3) 1.0 (3.0)	17.9 (12.9) 16.9 (31.3)
2: Balloon-tube thumb	3.0 (3.5) 1.9 (7.4)	9.2 (5.5) 9.0 (10.9)
5: Balloon-tube over glove index finger	0.8 (0.7) 0.8 (1.4)	7.2 (6.4) 6.6 (15.6)*
6: Balloon-tube over glove thumb	3.1 (0.9) 3.2 (1.9)	0.6 (0.7) 0.6 (1.3)

The mean values and standard deviations (SD) of the four practiced tasks in this tagging method are shown.
*Method 5 had one task (3) in which the hand was actually out of view when it was assessed as out of view. This was objectified during look back of the video, with a good correspondence of the outcomes of the tracking software.

an option?'. Tracking of the fingers seemed a feasible option to track movements of open surgical tasks, because the SurgTrac application tracked the fingers >95% of the time. However, the tracking jumped from finger to thumb, because of the two red and two blue tapes, which produced inconsistent and unreliable data. Besides, it was not possible to knot by hand properly, because of the hindrance the tape caused at the fingertips. When the tapes were placed on other parts of the fingers, strangulation of the tissue was caused during movements of the fingers. From Experiment 2, we concluded that tracking of fingers seemed to be a feasible option for tracking open surgery with this system, while taping of two fingers on each hand was not a feasible method to track fingers.

In the third experiment, the best method to tag fingers for tracking of basic open suturing tasks was investigated for the third research question: 'What is the best method to tag a finger for tracking in open surgical simulation?'. Placing a red and blue balloon-tube (cut from a normal balloon) over the middle phalanx of the index fingers or thumbs (Figures 5–8), appeared to be the most reliable method. However, the redness of the inside of the hands, was often tracked as a red tag, instead of the bright red tagging on the finger. Therefore, our fourth research question need to be answered: 'Does the tracking of the 'balloon-tube tagged' fingers work properly, if surgical gloves are worn underneath?'. Experiment 4 was executed to explore the tracking of balloon tagging of the index fingers or thumbs while the surgeon was wearing white surgical gloves underneath (Figures 9–10). It appeared that both thumbs were out of view more often than the index fingers, which made tagging of the index fingers the most reliable method. White surgical gloves underneath the red and blue tags on the index fingers resulted in a well correspondence of the SurgTrac tracking results with the visualization of the hands when evaluating the video of the executed tasks, based on the small tagging asterisks on the screen. Therefore, this is a feasible tracking method for open surgical training.

Table 5: Outcome parameters of tracking of the fingers for the methods using the white gloves underneath

	Method*	Distance right (m)	Distance left (m)	Speed right (mm/s)	Speed left (mm/s)
1: Suturing instrument	5	1.15	1.23	9.26	10.63
	6	2.62	0.48	27.61	4.92
2: Suturing hand	5	1.38	0.47	17.13	6.31
	6	2.98	0.58	33.50	6.40
3: Intracutaneous running	5	3.53	0.58	9.39	1.53
	6	15.08	0.69	35.92	1.59
4: 'Donati' suture	5	5.02	0.79	30.39	5.61
	6	11.01	1.06	72.32	6.97

*Method 5: balloon-tube over glove on index fingers, method 6: balloon-tube over glove on thumbs.

A strength of this study is that all experiments were conducted by the same surgeon to avoid bias in the results. The limitation that comes with this fact, is that all experiments were performed by a right-handed surgeon. Future research should show whether these results are consistent for left-handed trainees. Furthermore, it is unknown whether the objective data gathered directly translates into actual proficiency. After the developing of this technique, more research is necessary for further validation of this training technique.

By using the SurgTrac application and white surgical gloves with a red and blue tag on respectively the right and left index finger, a reliable and easily accessible way of tracking open surgical simulation can be developed. The developed tracking method can be used in combination with every desired open surgical simulation model. Therefore, future studies should validate this tracking system for open surgical tasks or procedures, other than basic suturing tasks, as well. After validation of construct, this tracking technique can not only be used by surgical trainees, but for example also by medical interns to improve their suturing skills with limited help of an expert supervisor. This could lead to an objective tracking system to assess trainees on their skills, before entering the operating theatre. Additionally, trainees can train and assess their skills where and whenever they want, because of the compactness and the accessibility of the necessary materials. This method of tracking seems to be a promising, easily usable training tool, which could be accessible for all countries.

Conclusion

The overall aim of this study was to evaluate the feasibility of tracking movements during basic open suturing tasks and to develop an adequate method of tracking these movements. The results of this study show that tracking fingers is a more reliable method to track movements during basic open suturing tasks than tracking instruments. Tagging of the index fingers with a red (right) and blue (left) balloon-tube while wearing surgical gloves is a feasible method for tracking movements during basic open suturing tasks. This is the first method that could be used to train basic open suturing tasks in any setting and without the need of an expert.

Declarations

Authors' contributions

None declared.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials

None declared.

Ethics approval and consent to participate

None declared.

Competing interests

None declared.

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