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TEACHING ANATOMY

SIM Life: a new surgical simulation device using a human perfused cadaver

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Abstract

Purpose In primary and continuing medical education, simulation is becoming a mandatory technique. In surgery, simulation spreading is slowed down by the distance which exists between the devices currently available on the market and the reality, in particular anatomical, of an operating room. We propose a new model for surgical simulation with the use of cadavers in a circulation model mimicking pulse and artificial respiration available for both open and laparoscopic surgery.

Methods The model was a task trainer designed by four experts in our simulation laboratory combining plastic, electronic, and biologic material. The cost of supplies needed for the construction was evaluated. The model was used and tested over 24 months on 35 participants, of whom 20 were surveyed regarding the realism of the model.

Results The model involved a cadaver, connected to a specific device that permits beating circulation and artificial respiration. The demonstration contributed to teaching small groups of up to four participants and was reproducible over 24 months of courses. Anatomic correlation, realism, and learning experience were highly rated by users

Conclusion This model for surgical simulation in both open and laparoscopic surgery was found to be realistic, available to assessed objectively performance in a pedagogic program.

Keywords Training · Surgical simulation · Cadaver · Academic teaching · Simulators

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Introduction

Worldwide, embalmed or fresh cadavers provide an exceptional modality for surgical skills training. But the major problem with cadavers remains, the lack of realistic environment during dissection because of the absence of circulation.

In the field of surgical education, basic surgical mechanics simulators and computed simulators dedicated for laparoscopic surgery or porcine model may be used as models. Many pitfalls have been found: some existing training devices are expensive (computed simulators, animals), not easy to use by several trainees in a row (requiring replacement of part of the internal organs, i.e., laparoscopic cholecystectomy in mechanical simulator), the lack of possibility to simulate dissection of circulating vessels.

In the literature all perfused cadaver models to date have involved partial vascular reperfusion: Garret proposed an arterial reperfusion specifically for endovascular practice [5, 8, 11]. Varga proposed the opposite with a vein reperfusion available for central line placement [15]. When both arteries and veins are perfused, those models were available only for flap raising, microsurgery on limbs or neurosurgical training [1, 9, 13].

More recently some more realistic cadaveric models have been developed for trauma surgery [2] and also general surgery [3, 7].

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The greatest limitation to these models was the access to fresh cadaver. Another limitation was the fact that high-fidelity simulation would, ideally, have the look and feel like human tissue but cannot replace true living tissue. Moreover the perfusion solution used for perfusion was colored tap water, making consistency much less thicker than real blood. In addition, cadavers were not embalmed and therefore fully pathogenic.

Thus, the rationale for the present study was an educational need in primary training and in continuing medical education. Our goal was to create a human cadaveric circulation model with a perfused trunk to provide a lifelike environment for more realistic thoracic-abdominal surgery.

Setting and participants

This study took place in the Anatomy, Biomechanics and Simulation Laboratory of the University of Poitiers (France) and was approved by the institutional research board of the faculty Of Medicine. All participants signed an informed consent form. Results were kept confidential.

Objectives

The primary objective was to evaluate the trainee-reported realism of the training model.

Secondary objectives were as follows:

1. To calculate the cost of the model.
2. To evaluate the possibilities of such model in both open and laparoscopic surgery.
3. To evaluate the reproducibility of the model.
4. To secure the human cadaveric model against viral contamination.

Model construction

Previous models

In the literature, the use of an elaborate system aiming to perfuse the whole body was developed for flap raising courses, endovascular practice, and trauma surgery [1, 5, 9, 11, 13, 15].

The first models were very realistic but focused on specialized part of the surgery: endovascular surgery, limb surgery. The trauma model was able to mimic traumatic injuries seen in clinical practice involving the heart, lungs, liver and major vessels maintaining emergent airway control [2]. This model, designed for surgical hemorrhage control, needed an intra-aortic balloon pump placement

which was not compatible with intricate surgical procedures like simulated organ procurement. Moreover this model was not designed for laparoscopic surgery. Some study tried to get round this major obstacle [7] but surgery was limited by the use of simple fresh cadavers.

Goals

The following goals guided the design of the model. (a) To create a realistic environment during pelvic-abdominal and thoracic surgery. (b) The model should allow for assessment of both laparoscopic and open surgery.

Authors

Five experts were involved: three adult visceral surgeons and anatomists (JPR, JPF, JD), an adult urologist surgeon (POD), a pediatric intensivist and simulation expert (DO) and an academic faculty specialist in biomechanics (CB). The latter selected the materials needed to construct the model and built the perfusion devices.

All the experts included in this study had considerable previous experience in dissection of human corpses for the purpose of creation of a surgical high definition surgical simulation device.

Model component

According to the French legislation, cadavers are donated by the individual and can not at all be purchased by the research facility. Nevertheless, the research facility agrees to pay all transportation and cremation expenses when work with the cadaver is completed. The ashes were buried in a specific grave of a local cemetery. The total cost averages 1000 Euros per cadaver.

An infectious status is checked for enrollment as donators. Moreover each cadaver (HIV, hepatitis status) arriving at the Body Donation Center of the Faculty of Medicine are enrolled in this procedure. Selection of anatomic and surgical good donors is done during the preparation procedure described below. The goal of this selection is to keep a lifelike environment, so only bodies that don't exhibit an adequate response to circulation are rejected for research purpose and therefore embalmed for other academic courses.

Construction

The description of the model and its assembly includes two phases: preparation of the cadaver and the controlled perfusion devices called SIM life control (Fig. 1). Concerning the SIM life control device a patent application is pending (no. 1 560488, no. submission 1 000318748).

An oral-gastric tube is placed and opened to gravity. Oro tracheal tube or tracheotomy is also performed.

Through appropriate bilateral incisions we exposed both vein and artery in the femoral and brachial areas. A bilateral cervical incision allowed dissection of common carotid arteries and internal jugular veins (Fig. 2).

In all these sites (except for the brachial one where we only performed a vessels ligation), we performed a ligation of the distal part of vessels. The proximal parts were used as sites for subsequent catheter cannulation (size of cannulae were adapted to the diameter of the vessels). Thus the result was an isolated vascular tree of a trunk body.

This vascular tree was cleared from thrombi by flushing 4 L of a diluted solution of heparin (50,000 UI in the first 2 L) and warm water (37 °C) at a pressure of 0.4 Bar.

This solution was flushed anterograde by carotid and femoral arteries. The liquid was retrieved through the femoral and jugular veins. Occasionally a retrograde flush was performed to remove adherent thrombi. No added benefit has been demonstrated by use of irrigation with other preservatives or antibiotics [3], but light chest compressions and abdominal thrusts may help to mobilize clots.

After this preparation, cadavers were maintained in a frozen state below −20 °C. No embalming was performed.

Three days prior to a surgical simulation course, cadavers were slowly warmed up to reach 20 °C for preparation: day one at a constant temperature of 4 °C in a refrigerated room, day 2 and 3 in the dissection room at constant temperature of 18 °C. Regarding to the body mass index of the body (>25) the step one at 4 °C starts one day before. During this warm up time, we check skin body temperature every day to approach 15 °C.

Procedural equipment

The module "SIM Life control" served to inject blood simulated liquid: 37 °C water with red food coloring (dilution approximately realized to obtain "red like blood") into the inserted arterials cannulas (Fig. 3).

Pressure and injection rate could be adjusted to modify pulsatility and arterial pressure of the cadaver. Injection rate was carried out using a solenoid valve coupled to an USB low frequency generator (computer controlled). Injection pressure was roughly adjusted by a pressure limiter (with gauge) and finely by varying the percentage of cycle of the solenoid valve. The connection between the two modules was performed via 10 mm inner diameter pipes, which provided the perfusate under pressure to the injections cannulas.
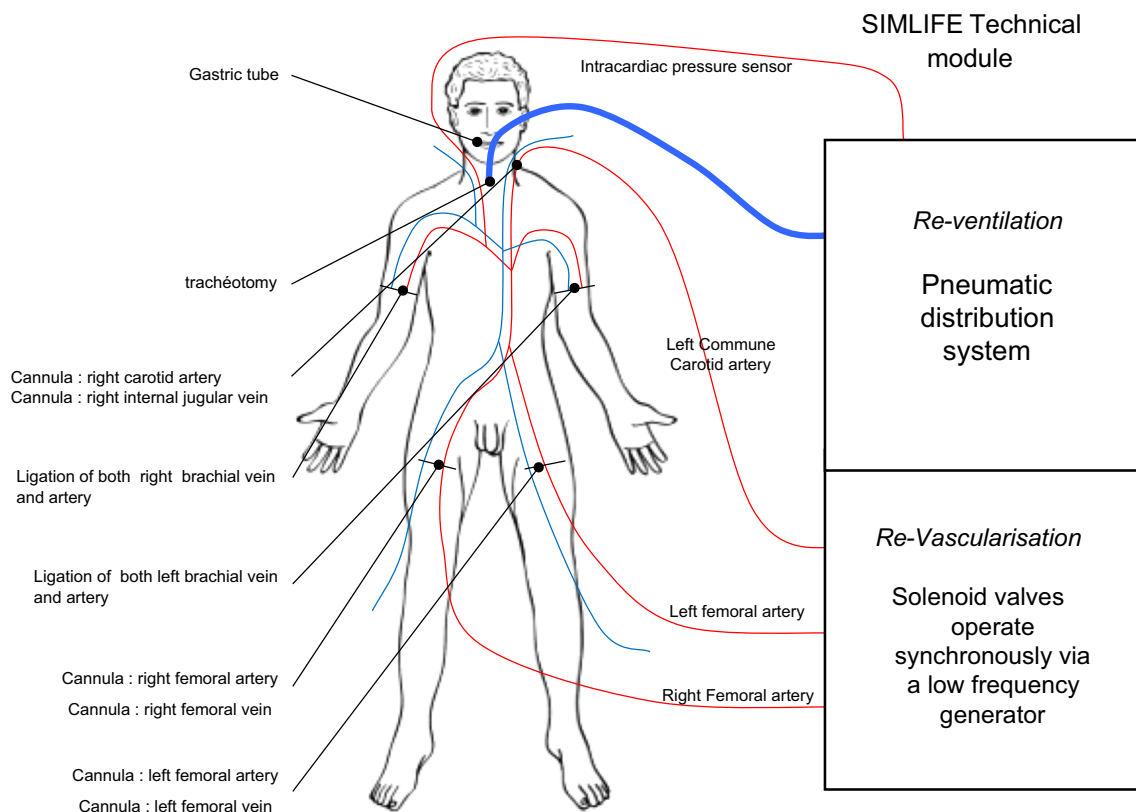

Fig. 1 Principle of SIM Life model: *dashed lines* arterial system; *solid lines* venous system

Fig. 2 Vascular access:
a femoral vessels; **b** cervical vessels
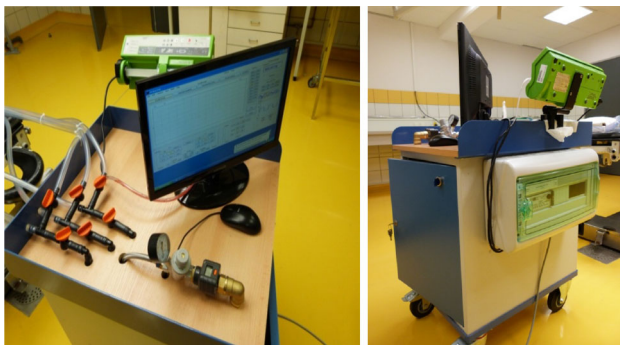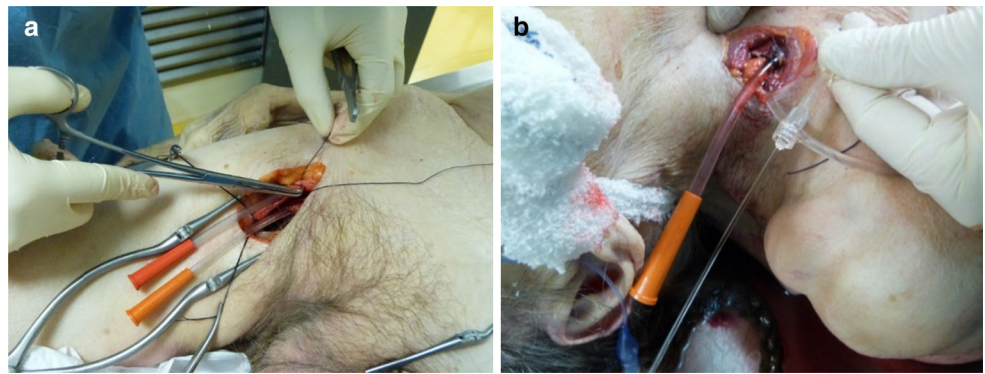

Fig. 3 SIM Life control device (patent application no. 1 560488, no. submission 1 000318748)

The blood simulated liquid is retrieved by the venous cannulas.

The day of the use of the SIM Life model for surgical simulation, the temperature in the dissection room is at 25 °C before the beginning of the simulation session, and we decrease it at 22 °C when the surgical team starts simulation session.

Temperatures regulation in the room and the cadaver body, increased the compliance of the pulmonary parenchyma. This fact made possible a mobilization of the lungs by controlled pressure ventilation instead of volume controlled ventilation. The choice of this model allowed regulating the insufflations pressure, avoiding a pulmonary tear that may be induced by high volume ventilation. The aim of this lung mobilization was to induce movement of the diaphragm to mimic real ventilation. The respiratory system is connected to a pneumatic distribution system (a valve) which corresponds to a solenoid valve controlled by a low frequency square wave generator which allows obtaining ribcage movements. In simulated inspiration, air is injected at a maximum pressure of two bars in a closed respiratory system; in simulated expiration, the system is at rest and opens toward the outside to force the air out of the lungs via a biological filter.

Modifications

Ten surgeons and surgery residents performed simulated organs procurement (lung, heart, liver, pancreas and kidney) on the pilot model, which was then modified as needed.

Five modifications brought about significant improvements that rendered the anatomic model highly pertinent for training purpose.

- The cadaver vasculature was pressurized using a pump; the pulse was induced by frequency of the pump so pulse could be modified during procedure. To increase the fidelity of this model and to give surgeons real hemodynamic measures we inserted into the right carotid artery a catheter running to the left atrium. This cardiac catheter gave the arterial central pressure.
- To improve realism perfusate was warmed up to 37 °C mimicking blood temperature. Thus, after 1 h of perfusion, tissues had the look and feel like true human living tissue.
- As described by Garret [4] the perfusion solution induced oedema formation after 4 h, and therefore we first had to stop the perfusion until the fluid had drained from the bodies. To avoid this disagreement perfusate was created to simulate blood using water, food coloring and corn syrup at a dilution of 10 ml/l of water associated with 9 % saline solution at a dilution of 30 ml/l of water. This modification induced two improvements: when bleeding occurred from capillary vessels, it could be stopped using electrosurgical coagulation [3] and from vessels to a diameter up to 5 mm, it could be stopped using a vessel sealer device. The presence of saline solution decreased the osmotic pressure avoiding the oedema induced by perfusion.
- To increase mimicking of a real surgery procedure, after warming the body to a temperature of 30 °C, elasticity of the lungs was sufficient to allow mechanical ventilation. So orotracheal intubation was

performed for all specimens. A specific ventilation device was added to SIM-live control system.

Testing of the model

Population

The model was used by 30 trainees. In open surgery 20 trainees consented to the research project for a procedure of organs procurement: heart, lung, liver, pancreas, and kidneys (5 transplant surgeons and 15 surgery residents).

Ten of them had never performed organ procurement, five had done more than five times and five ten times during the previous year. In laparoscopic surgery, 10 trainees consented to the research project for colorectal (left colon resection) and bariatric (sleeve) procedures: all 10 were senior surgeons with an experience of more than 50 of each procedure.

Intervention

Open surgery: During a national university course of organs procurement, all participants received a didactic lesson: 4 h (anatomy, surgical technique of organs procurement, pitfalls to avoid) and then performed on the cadaveric model.

Laparoscopic surgery: during a course for laparoscopic general surgery course, residents of Gastro. Intestinal. Surgery performed laparoscopic procedures on the model.

All courses were followed by an individual good-judgment debriefing [12].

Outcomes

Feedback from the trainees included considerations on their learning experience and realism of the model. Initially, we did not use an evaluation form, and the first ten trainees gave their feedback orally. To be more systematic, a feedback form was distributed to the 20 subsequent trainees to evaluate the model on a 0–10 Likert scale (0 = not at all to 10 = perfectly) [6, 12]. Questions involved (1) facilitation of learning a technical procedure with this model; (2) fidelity of the corresponding anatomic landmarks in comparison with clinical reality; (3) degree of realism of the model; and (4) overall satisfaction with the training model.

Statistical analysis

Analysis was performed on SAS 9.3 software. Means and SDs of the scores were reported.

Construction of the model

Cost

The total cost supplies are 2000 Euros and are summarized in Table 1.

Time

For the total cost, one should add two additional times. In one hand, the time required by the academic faculty specialist in biomechanics to design the SIM Life control device and in the second hand the time required by the technician to prepare the model: 2 h when the cadaver was arriving at the laboratory and 2 h again before the surgical simulation procedure. Also, it should be borne in mind the necessary time of warming up the SIM Life body 3 or 4 days before surgical simulation.

Once built, the SIM Life control device could be used more than 100 times.

Usability

This model was found to be feasible and adequate for training. Of course this model was a time-consuming and heavy system to set up because of the necessity to design the SIM Life control device, but once built the only time of preparation consist in adding the cannulas when the cadaver arrived at the laboratory and verifying that circulation was efficient before the training session.

Another important part of the session preparation was to organize the "operating room" environment to be more realistic.

Reproducibility

Reproducibility of the model was tested by repeated constructions at different times (over 2 years): we currently have 4 SIM Life controls available at the laboratory.

Table 1 Cost of the SIM Life simulation procedure

Donation Center : 1100 €	Transport, cremation, burial and the biological tests of viral infection
SIMLife Institute : 250 €	Cannulas, hoses, drains,… and suturing devices
SIMLife Institute : 150 €	Technical preparation of the SIMlife 3 or 4 days before surgery simulation
SIMLife Institute : 500 €	Per simulation SIMlife management
	Research and development of the model

Discussion

Our results

We created a realistic model for both laparoscopic and open surgery made of a perfused trunk cadaver with a pulsating perfusion device mimicking real operating room conditions.

To our knowledge, no publication on such a complete and realistic model for training in surgery presently exists.

Evaluation by the trainees

The 30 trainees received an evaluation form on training with this model, and all responded. They expressed praise for the high realism and educational value of the model, with which they were fully satisfied (Table 2).

Limitations

Although our model seemed to prove to be a valuable tool in training laparoscopic and open surgeons, it had some limitations.

Availability of cadavers: 25 % of cadavers arriving at the Donation Center were not available for SIM life procedure. Reasons of failure are described in descending order: 60 % of impossibility to clear the vascular tree to allow perfusion, 30 % due to the previous medical history (vascular or cardiac surgery), and 9 % due to the inability of the technical team to perform SIM Life preparation few hours after the body arrived and 1 % because of the viral profile was positive.

Thus, in a surgeon's education carrier this high reality simulator is not the first step of open or laparoscopic surgery training. Mechanicals (Ex: pelvic trainer) or numeric devices (Ex: Symbionix Lap Mentor™) will help the learner to gain the basic techniques in performing the skills. So addition of perfused cadaver allows the learner to apply basic skills in a more realistic environment with anatomy variability and in a model that more closely represents the learner's patient before they performed in the operating room. Such formation session in this model is like a "dress rehearsal" before the operating room.

Table 2 Trainees responses to Questionnaire (on a 0–10 Likert Scale) about the quality of the Model

Questions	N = 30
Learning a procedure with this model	8.03 (0.83)
Anatomic correspondence	8.75 (0.98)
Realism	8.36 (0.96)
Overall satisfaction	8.33 (0.87)

Infectious risk: The risk of disease transmission was limited using for all procedures the personal protective equipment and safeguards for all sharps. Before participation, all students were informed about the safety policies and risk prevention and their consent to participate according to laboratory policies was documented.

Cost and usability: Total cost of a SIM Life surgical day, either laparoscopic or open procedure, is 2000 Euros per learner.

This cost may be important, but SIM Life simulation isn't a basic model, its use should be correlated with a more integrated academic pedagogic program which involved financial possibilities.

Comparison to other simulation possibilities

The use of animal models can be beneficial in that the tissue closely resembles human tissue; however, more often than not, the anatomic comparison to humans falls short. Commercially available simulators provide a means to practice basic surgical skills and are reproducible [4, 10, 14] but tend to be costly and inaccurate with respect to anatomic variation or replication of tissue consistency.

For these reasons, there has been a resurgence of interest in using fresh cadavers for surgical education.

Conclusion

The SIM Life model covers teaching procedures requiring a realistic surgical model such as in teaching, open and laparoscopic surgery, communication and crisis resource management.

This model appears to be another arm in the armada available for surgical education. This preliminary study need to be completed by a comparative study with both animal and non-perfused cadaver model as educational support.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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