How to build your own coronary anastomosis simulator from scratch†

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Abstract

OBJECTIVES: Gaining cardiac surgical competence is a complex, multifactorial process that may take years of experience and on-the-job training. It is critical to provide suitable educational opportunities to gain the necessary knowledge, judgment and skills. In response to the multitude of factors (e.g. European Working Time Directive) currently influencing cardiac surgical training, there have been concerted efforts to reform training practices. Simulation plays an increasingly important role in the educational process and serves to fill the most important gap in the current training model, i.e. operative exposure. Therefore, a contest has been written out for cardiac surgical trainees to construct their own coronary anastomosis simulator using everyday materials.

METHODS: Cardiac surgical trainees were invited to construct their own coronary anastomosis simulator. An international jury of cardiac surgeons assessed the simulator and its presentation according to preset developmental criteria (low fidelity concept, innovative character, general presentation and description, general attractiveness to the scholar, ergonomical issues, perceived haptics, number of applicable components, transportability, ease of construction, repeatability and overall costs of the simulator).

RESULTS: Six prototypes of simulators built by cardiac surgical trainees were generated. A general evaluation of each simulator prototype is provided according to the preset developmental criteria.

CONCLUSIONS: All simulator prototypes have provided a considerable contribution to the field of surgical simulation. By designing simulator prototypes, the trainees have demonstrated their ‘out of the box’ thinking capability, which is of paramount importance for the development of future innovative surgical techniques and procedures. The Valladolid cardiac team coronary anastomosis simulator box was selected for the EACTS Ethicon Simulation Award 2011. This project will be mass produced and distributed to the participants of structured simulation sessions for coronary anastomoses.

Keywords: Cardiac surgery training • Simulation • Coronary anastomosis

INTRODUCTION

One of the fundamental problems faced by cardiac surgical trainees today is decreased operative exposure. This is the result of a combination of reduced working hours due to the European Working Time Directive, and often, shortened surgical training. In addition, there has been much debate over the medico-legal and ethical issues regarding consent, where trainees practise on real patients under the supervision of surgical tutors.

Concerning this, we have much to learn from the aviation industry, particularly regarding the use of simulator training. Simulation has been used for many years to train aviation and military personnel for work in hazardous environments. In regard to cardiac surgical trainees, simulator training allows technical improvement in their own time without endangering the patient and a reduction in the effort required towards the possible attention span.

MATERIALS AND METHODS

The contest invited cardiac surgical trainees to construct their own coronary anastomosis simulator. Any resident/trainee or group of residents/trainees could participate. The submitter (or his/her representative) of the project had to present his project during the 25th Annual EACTS Congress at Lisbon.
The submitted project and its presentation were assessed by an international jury of cardiac surgeons. The assessment was based on several criteria, which were scored from 1 to 5 (1 bad, 5 good). These developmental criteria entailed a low-fidelity concept, an innovative character, general presentation and description, general attractiveness to the scholar, ergonomical issues, perceived haptics, number of applicable components, transportability, ease of construction, repeatability and overall costs of the simulator.

The winning submitter was awarded an unrestricted educational grant, possibility of mass production of the submitted project and finally, global distribution for related educational purposes.

RESULTS

The contest generated six prototypes of simulators build by cardiac surgical trainees. A general evaluation of each simulator prototype is provided according to the preset developmental criteria (Table 1).

(i) The Anman Coronary Anastomosis Simulator (Fig. 1)

This is an example of a box simulator mimicking a moving heart with a water-filled glove. It uses, however, biological materials (intestine) as vessel conduits for anastomotical learning. Additionally, there is the possibility of testing the anastomosis for leakage in this set-up. All utensils are provided within the box. This was an innovative low-fidelity simulator with ease of construction, good transportability and repeatability, and low cost of production. However, the usage of biological tissue did not fit in the developmental concept.

(ii) Valladolid Cardiac Team Coronary Anastomosis Simulator Box (Fig. 2)

This cheap pocket-size box simulator is made from a small metal pencil case. It was modified with small alligator clamps for graft fixation and sucking hooks for box fixation in several planes. It contains reusable latex surgical tubing as a vessel conduit. Due to its small size, the simulator showed excellent transportability so trainees can use it anywhere and anytime. Ease of construction, repeatability, low production costs and the innovative character of the simulator were important assets. A convincing presentation showed the broad capabilities of this low-fidelity preproductional prototype concerning coronary anastomotical techniques.

(iii) Bob Simulator (Fig. 3)

A larger box simulator was made from a cheap plastic square bowl. It contained stiff foam rubber wrapped in a plastic-metal mesh to simulate the cardiac shape. Vessel conduits were created by cutting the strips from latex gloves and rolling these strips into rubber cylinders to simulate a vessel. The cylinders were fixed with a staple to a small piece of a stiffer rubber strip. This rubber strip could then be inserted into several mesh gaps to create a multiple-plane environment for anastomosis. For proximal anastomosis, a bare foam-rubber sheet (10 × 10 cm) was used and clamped on the meshed model with a Satinsky clamp to simulate the partially occluded ascending aorta. This prototype demonstrated an excellent low-fidelity concept that was easy to use and cheap using everyday materials. A potential drawback was the size of the simulator.

(iv) CAB Trainer Simulator (Fig. 4)

This solid box simulator was made out of wood, treated with outdoor waterproof varnish, and iron nuts and bolts. Latex from a sterile glove was glued to form a 3-mm tube as vessel conduit. This tube was connected to an infusion bag with fluid to check for anastomotical leakage afterwards.

Table 1: General assessment of different simulator prototypes

<table>
<thead>
<tr>
<th></th>
<th>Anman Simulator</th>
<th>Valladolid Simulator</th>
<th>Bob Simulator</th>
<th>CAB Simulator</th>
<th>Vienna Simulator</th>
<th>COREsim Simulator</th>
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</thead>
<tbody>
<tr>
<td>Low-fidelity concept</td>
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<td>++</td>
<td>+</td>
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<tr>
<td>Innovative character</td>
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<tr>
<td>General presentation/description</td>
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<td>+</td>
<td>–</td>
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<td>–</td>
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<tr>
<td>General attractiveness</td>
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<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Ergonomical issues</td>
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<td>+++</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
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<tr>
<td>Perceived haptics (no biological tissues)</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Number of applicable components</td>
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<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Transportability</td>
<td>+</td>
<td>+++</td>
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<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Ease of construction</td>
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<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Repeatability</td>
<td>+</td>
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<td>+</td>
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<tr>
<td>Overall costs of the simulator</td>
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<td>–</td>
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</table>
Interesting advantages were the possibility of testing the anastomosis for leakage, durability and repeatability. Possible drawbacks were the monoplane character of anastomotical training, overall construction and transportability.

(v) Vienna Beating Heart Simulator (Fig. 5)

It was made from a cardboard postal box. A hole (20 × 10 cm) was cut out to represent the chest cavity. A foam ball simulated the cardiac shape. The box and foam ball were covered in black felt. The moving off-pump mode uses a motor and battery case from a cable car toy, which is mounted on another piece of cardboard within the box. Rubber bands are used to connect the cardboard with the toy’s gears for smooth movement of the system. A piece of felt is used to cover the cardboard. An adhesive tape is necessary for all steps. Protective sheaths for rectal temperature probes were used as vessel conduits. This simulator was the only prototype that had a moving off-pump mode (however, this was not a prerequisite for the competition). An appealing presentation and great innovative properties for a beating anastomotical environment were the major assets of this prototype. Possible drawbacks were construction time, overall costs and numerous components of this simulator.

(vi) COREsim Simulator (Fig. 6)

It uses a rigid plastic box to represent the chest cavity. A hole was cut in the lid to simulate the sternotomy opening. A foam ball/egg mimics the cardiac shape. A plastic hollow weather stripping as door stop was used as vessel conduit,
which could be fixed to the foam ball in multiple planes. A plastic tube can be anastomosed to this plastic strip. This prototype demonstrated a low-fidelity concept that was easy to use and cheap, using everyday materials. A potential drawback was the size of the simulator.

**DISCUSSION**

Nowadays, cardiac surgical trainees are faced with decreased operative exposure and training opportunities. In this way, the current training model of (cardiac) surgical specialties through saturation may no longer be appropriate to overcome the hurdles in the current era of work-hour restrictions.

In the past, the trainee was viewed as a passive reservoir into which teachers/trainers poured all the knowledge they wanted to impart. Their focus was on subject content, not on the trainee. More recently, teaching and learning surgical skills were put in a larger context: the trainee is an engaged mind, which is both formed by, and acts on, environmental and situational factors [1].

At present, simulation-based training is a prerequisite for all high-reliability organizations (e.g. in the airline, nuclear and oil industries), yet remains a niche player in surgical education [2].

In light of this paradigm shift in (cardiac) surgical training, a simulator-building contest was created, because trainees learn best when they take responsibility for their own learning; are placed in a programme equal with their learning skill; are able to progress at their own pace; are able to get immediate feedback; receive contextual learning; are taught according to learning style and do not have to repeat what they already know [3].

In general, surgical simulators can be broken down into two different groups: high-fidelity and low-fidelity. High-fidelity simulators utilize very realistic materials and equipment to represent the tasks that the trainee must perform. These simulators should provide a better indication of how a trainee will perform on the job. Based on that assumption, one would think that every training centre would want to use high-fidelity simulators. High-fidelity simulators have a high face validity due to their similarity to real life. Trainees will practice in a realistic situation. Another advantage is that they serve as a realistic task/skill preview. This means that the simulator provides the trainee with an idea of what the skill will truly be like.

Since high-fidelity simulators better resemble the task that the trainee has to do compared with low-fidelity simulators, it would make sense that high-fidelity simulators would be better predictors of future performance. The problem is that it is still not clear to what extent the fidelity must be increased in order to ensure that the simulator will be a good predictor. High-fidelity simulators may be better predictors, but they also have several major disadvantages, which is why they are not used as often as one would expect. First, they require more departmental resources, including personnel, infrastructure and equipment. Secondly, these simulators are usually more time intensive and much more expensive.

On the other hand, low-fidelity simulators use materials and equipments that are less similar to what is used on the job. These are preferred because they are less expensive than high-fidelity simulators. They use cheap materials that can be easily replaced and/or used over-and-over again. If there are many trainees, there are usually no funds to pay for more high-fidelity simulators. Moreover, low-fidelity simulators do not require many departmental resources. The main disadvantage of low-fidelity simulators is that they are less realistic.

The often-quoted criticism is that surgical simulators lack fidelity, or are not truly lifelike, though the real problem has more to do with a lack of motivation or understanding on the part of educational leaders than with the eventual outcomes, which for the most part have been remarkably good. The science of adult learning is in favour of using a low-fidelity concept to learn these surgical skills [4–8].

It is clear that all simulator prototypes have provided a considerable contribution to the field of surgical simulation in general. By designing these simulator prototypes, the trainees have
demonstrated their ‘out of the box’ thinking capability, which is of paramount importance for the development of future innovative surgical techniques and procedures.

Of note, developing and actively training on simulators is one (but considerable) step in contemporary adult surgical learning. However, this step can only be successful if constructive feedback is provided by teachers/trainers. Regular feedback is an important part of any learning experience and can guide the trainees’ future learning by identifying strengths and areas that could be improved. Also, trainees need time and encouragement to reflect on the subject and their performance (self-assessment) [9, 10].

After careful deliberation and evaluation of the criteria, the international jury of cardiac surgeons decided to select the Valladolid Cardiac Team Coronary Anastomosis Simulator Box, submitted by Dr Arroyo, for the EACTS Ethicon Simulation Award 2011. This winning simulator prototype is now being translated into an industrial product (Fig. 7) and is currently put into mass production. It will be made available by our industrial sponsor to cardiac surgical residents, at no cost, in Europe and beyond and used as a training tool for the practice of coronary anastomosis.

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REFERENCES


eComment. Coronary anastomosis simulation: assessing surgical dexterity

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This article essentially provides an insight as to how cardiac surgical trainees can benefit from a low-cost coronary anastomosis simulator [1]. In our view, the outcome of the considerable effort spent on the trainees would be further enhanced if they were also given the opportunity to propose their own way of assessing the impact of anastomosis on the simulator constructed. In fact, assessment of surgical dexterity has been a major topic of research across several surgical specialties [2], including cardiac surgery [3], and it is currently an essential element in most simulation systems. More advanced modules such as Virtual Reality simulators, automatically generate several performance parameters ranging from very simple ones (e.g. time to completion), to more complex metrics such as the instrument’s path-length and the type of errors committed [4], though they are useful, these errors are usually analyzed independently, which imposes some difficulties in establishing a relationship with potentially more meaningful competency domains. Hence, it would be very interesting to see if the residents have any proposals as to how to measure such errors and how one could relate key surgical skills [5] with the proposed simulation tools. Moreover, it would be also interesting to see the residents’ thoughts on the role of bimanual dexterity, in terms of the analysis of technical performance, and how this type of skills could be incorporated into the proposed simulation setting.

Hand motion synchronization has recently emerged as an important metric that can be obtained from the hand kinematics based on electromagnetic sensors attached to the surgeon’s hands. This metric has essentially a dual role, as it can serve both for evaluation purposes (e.g. by measuring hand-to-hand...