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Use of a Pulsatile Beating Heart Model for Training Surgeons in Beating Heart Surgery

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ABSTRACT

Background: Coronary artery bypass on the beating heart has undergone a resurgence with the introduction of minimally invasive techniques and new stabilizing devices. It is important to develop a method for training surgeons to perform accurate anastomoses despite cardiac motion and to develop the skills needed for consistent results in this demanding field.

Methods: A prosthetic model of the beating heart was created by Limbs and Things, Ltd. (Bristol, U.K.) and used in our center to simulate clinical situations of beating heart surgery. Anastomotic quality was evaluated using a pre-established set of criteria on patency and suturing with each anastomosis graded on a 12-point scale.

Results: The average scores for trainees using the Pulsatile Beating Heart Model were 8.5 while that of the expert surgeon with MIDCAB experience was 11. Defects seen included cross-wall suturing and significant narrowing of the toe of the anastomosis. Scores improved with increasing practice during each session. Operators with more clinical experience scored higher. All surgeons felt the model duplicated the exposure and feel of the tissue characteristic of clinical cases.

Conclusions: The beating heart simulator provides excellent training for new as well as experienced surgeons, provides visual feedback of anastomotic errors, and instills increasing confidence in the participants in their ability to construct accurate anastomoses on the beating heart.

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INTRODUCTION

The results of beating heart techniques for coronary artery bypass grafting (CABG) are becoming more widely accepted. There is a growing need for a simple training method with an ex vivo simulator which will allow both the veteran surgeon and the surgeon-in-training the opportunity to develop the skills needed for consistent results when performing coronary bypass on the non-arrested heart. The objective of this investigation was to assess a newly designed pulsatile beating heart model created for training surgeons in the specific requirements of minimally invasive direct coronary artery bypass (MIDCAB) and sternotomy beating heart surgery.

MATERIALS AND METHODS

An ex vivo beating heart model (Limbs and Things, Ltd., Bristol, UK) (see Figures 1 and 2 ◎) was evaluated initially by three senior surgeons, then by three more junior surgeons-in-training and compared to one surgeon experienced with beating heart surgery. The simulated operation was carried out in the clinical operating theater using standard coronary artery micro-instruments. A total of 17 anastomoses of the left internal mammary artery (LIMA) to the left anterior descending (LAD) and one anastomosis of the LIMA to the circumflex were carried out on the beating heart model using a sternotomy approach with the Octopus 1 stabilizer. The LIMA anastomosis was often performed as a free pedicle rather than the in situ method (although the model does allow for the in situ method) (see Figure 3 ◎). One surgeon blinded to the trainee operator made assessment of the anastomoses. For this, a scoring system was developed (see Table 1 ◎) to evaluate the quality of patency and neatness of the suture line with particular reference to defects of suturing, both internally and externally. To facilitate this, the special anastomotic pads were removed from the pulsatile heart model and opened from underneath exposing the anastomosis from below. The scorer was blinded to the operator or sequence of anastomoses. Independent timings were carried out of

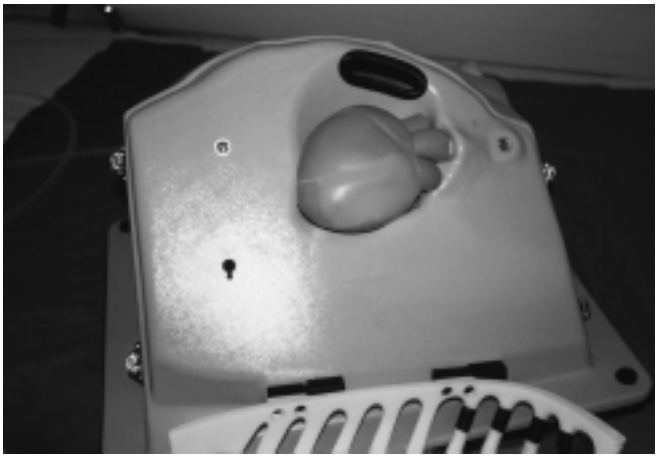

Figure 1. Heart of Beating Heart Model

both set-up time and anastomotic time. These were added to the scoring system (see Table 1 ◎).

RESULTS

Assessment of Model

The evaluation of the training model was very favorable with regard to the feel of the tissues, handling, realism, and the ability to use stabilizers. In general, the following features were found to be lifelike in handling and dissection. The pericardium was quite strong and able to be sutured to the skin without ripping and assisted in exposure of the heart. The fat pads around the coronary held a consistency very similar to that of the human, particularly similar to a cardiopleged human heart. The vessels, both LAD and LIMA, were of appropriate size (over 2mm) and provided a good feel, although they tended to be a little stiff after completion of the anastomosis such that smooth beveling was helpful in producing a better anastomosis in scoring.

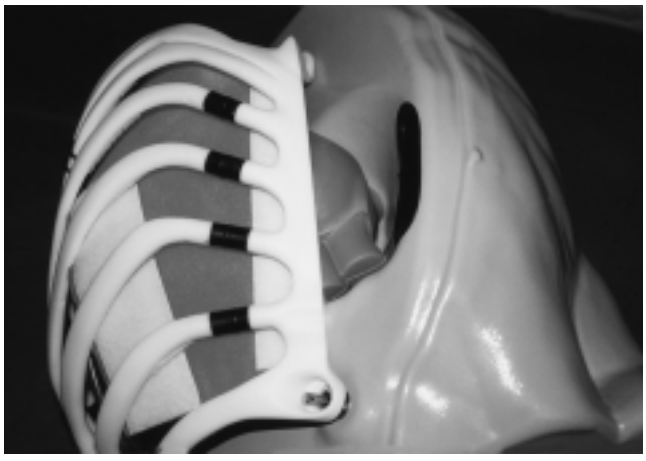

Figure 2. Heart within Thoracic Cage

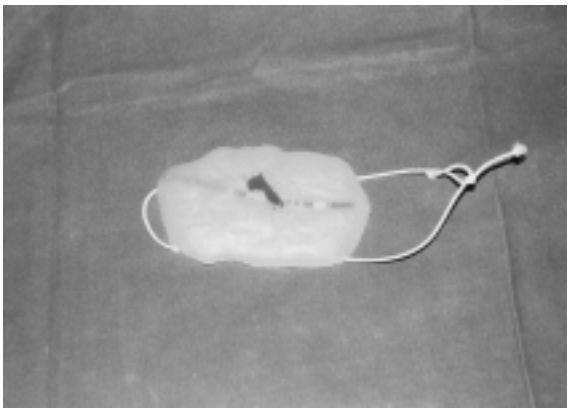

Figure 3. LAD removable pad, with anastomosis

In MIDCAB surgery, the ready-made incision was submammary and appropriately placed. The ribs had an expansile sensation when spread by specific IMA retractors. The pad underneath the chest wall was composed of sponge lined on the inner side by a thicker membrane (see Figure 4 ◎). This gave an excellent feel to the subcostal tissues surrounding the LIMA and of the pleural fascia lining it. Retraction on this was helpful in dissection as occurs in the human. The IMA contained fluid but there

Table 1. Scoring Assessment for Beating Heart Model*

Patency
- 3—fully patent; wide open; no resistance to 2.0 mm probe
- 2.5—patent; mild resistance to 2.0 probe
- 2—patent mild resistance to 1.5 mm probe
- 1—patent mild resistance to 1.0 mm probe
- 0—closed or marked resistance to 1.0 mm probe

Neatness

External
- 4—neat, good anastomosis
- 3—puckering, narrowing or kinking in one area
- 2—puckering, narrowing, kinking or loss of lumen in two areas
- 1—marked distortion

Internal
- 5—excellent, neat anastomosis
- 4—puckering, narrowing, kinking or loss of lumen in one area
- 3—puckering, narrowing, kinking or loss of lumen in two areas or severe changes in one
- 1—severe distortion or narrowing at heel/toe
- 0—closure of heel/toe or cross suture

Time

Scoring for anastomosis
- 4—7 min or less
- 3—7 < 10 mins
- 2—10 < 13 mins
- 1—13 < 16 mins
- 0—More than 16 mins

* Does not include setup time

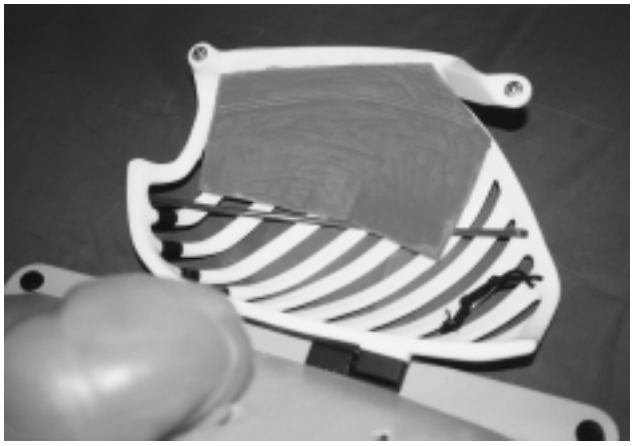

Figure 4. Inside of IMA pad and thoracic cage

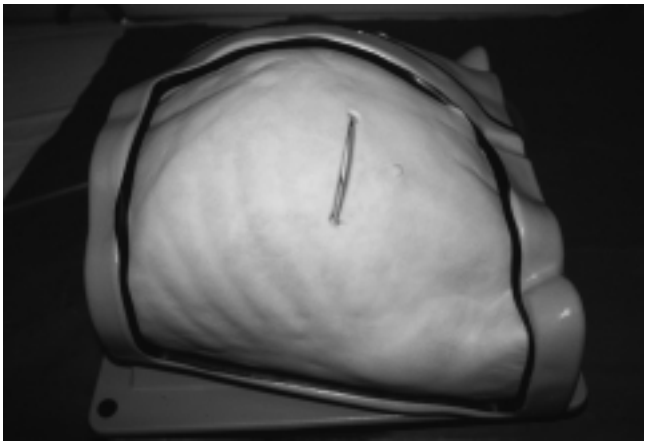

Figure 5. External appearance of model with MIDCAB minithoracotomy

was no continuous infusion and there were no branches, which was a deficit. Exposure of the IMA was quite realistic and did require special retractors to take down the full length equivalent to dissection to the first intercostal space as well as special light sources (e.g., videoscopic camera) (see Figure 5 ◎).

Cardiac movement was realistic, such that attempting anastomosis without a stabilizer would induce the same problems noted in early MIDCAB off-pump surgery. The rate of beating could be adjusted. For the assessment sessions, the rate was kept at 60 beats per minute. Two stabilizers were evaluated on the pulsatile model: the Genzyme footplate (Genzyme Surgical, Boston, Massachussetts) in the MIDCAB position and the Medtronic Octopus 1 (Medtronic, Minneapolis, Minnesota), including a special St Mary's adapter for the Octopus 1–2. Both stabilizers performed well and similar to that found in human practice. In particular the octopus suction did not distort or pull off the IMA fat pads and both provided good immobilization.

Assessment of Training

The first session consisted of three surgeons performing three anastomoses each on the LAD through a sternotomy. All had performed coronary bypass grafting in the cardiopleged and fibrillating heart and two were quite experienced. The various degrees of experience between these investigators are listed in Table 2 (◎). The results showed that most of the anastomoses carried out by these investigators were good (see Figures 3 and 6 ◎), with a mean score of 8.5 out of a possible 12, compared to the expert score of 11 of 12. There was one cross-wall suturing and several others showed significant narrowing near the toe of the anastomosis.

The second session involved three different surgeons-in-training; one registrar and two junior trainees at the level of senior house officer without any prior experience of performing coronary artery bypass surgery. The results (see Table 3 ◎) showed better anastomoses with the more experienced operators. Two operators were present at both sessions and could have their results compared to the first session (see Table 4 ◎). Both showed improved scores from the

Table 2. First Session: Scores of LIMA on LAD

Test #	Neatness external (1-4)	Neatness internal (1-5)	Patency (0-3)	Subtotal	Mean Score	Prepare Time (mins)	Anastamosis Time (mins)	Time Score	Total Score	Mean Score Total
Registrar 1										
1	3	2	2.5	7.5		2	14	1	8.5	
2	3	3	2	8	7.7	5	9	3	11	10
3	3.5	2	2	7.5		3	8	3	10.5	
Registrar 2										
1	1	4	1	6		4	10	2	8	
2	1	3	2.5	6.5	5.3	2	7	4	10.5	8.3
3	2.5	0	1	3.5		3	9	3	6.5	
Registrar 3										
1	3	2	2.5	7.5		6	14	1	8.5	
2	4	4	2.5	10.5	8.0	3	9	3	13.5	10
3	2	3	1	6		5	10	2	8	

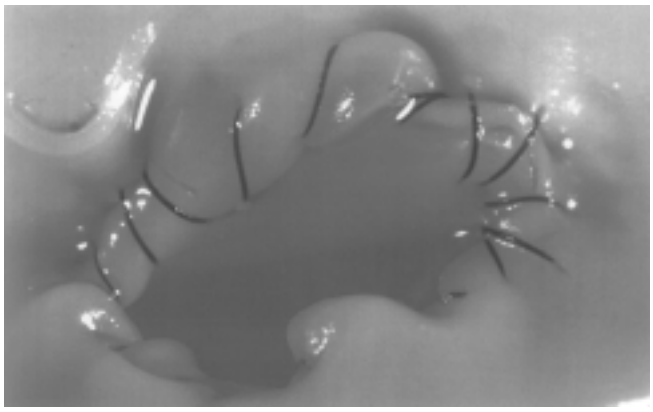

Figure 6. Inside of LIMA / LAD anastomosis

first session. Registrars reported that anastomosis and preparation time as well as comfort all improved with practice. However, it was found unexpectedly that all the results were best on the second attempt rather than the third within each session (see Table 5 ◉). This may suggest casualness or complacency or undue speed towards the end of the training period. On the strength of these studies a range of excellent to poor scores were obtained and these may be used to quantify a necessary score required for trainees before embarking on beating heart surgery in human patients.

DISCUSSION

In the past, training in the microsurgical technique of coronary anastomosis has been done through graduated steps in living patients. These steps include prior training in general and vascular surgery, followed by assisting and then supervised operating with senior staff. These methods have withstood the test of time and tradition, but may not be appropriate for the increased level of difficulty presented by beating heart surgery. In the past, the heart was arrested for every case, and the field was dry and motionless. The popularity of minimally invasive and off-pump grafting is increasing. However, there is no safe and relatively easy situation in which to offer trainees the chance to perfect skills on the beating heart. For this reason, the advent of an ex vivo simulator offers many unique advantages.

We tested the Pulsatile Beating Heart Model (Limbs and Things, Ltd., Bristol, UK) and found the results were very useful. Trainees initially had only modest results in constructing LIMA to LAD anastomoses, but their skills improved with practice during the same session and from one session to the next. The more experienced surgeons performed better than those with less experience and the range of results can be used to give an assessment of when a trainee is ready to proceed to beating heart surgery in the clinics.

The model itself proved effective and life-like with regard to feel of all tissues as well as surgical access and exposure. The circumflex was particularly well commented upon. The advantages of the model include realistic appearance and feel, the ability to expose deficiencies of surgical skill, and in providing experience in the use of exposure tricks and the use of stabilizers. The disadvantages include 1) no continu-

Table 4. Comparative Data: First to Second Sessions

Registrar	Session	Anastomosis Time		Total Scores
		Time Total	Score	
1	First	7.7	2.3	10
	Second	8	4	12
2	First	5	3	8
	Second	9.25	3	12.25

Table 3. Second Session: Scores of LIMA on LAD

Test #	Neatness external (1-4)	Neatness internal (1-5)	Patency (0-3)	Subtotal	Mean Score	Prepare Time (mins)	Anastamosis Time (mins)	Time Score	Total Score	Mean Score Total
Registrar 1										
1	4	2	2	8		.3	6.35	4	12	12
Registrar 2										
1	4	2	2	9		1.4	7.2	3	12	
2	5	3	2	11	9.3	1.3	9	3	14	12.3
3	3	2	2	7		2	7.4	3	10	
4 (Cx)	5	2	3	10		1.3	7.1	3	13	
Registrar 4										
1	2.5	1.5	2	6	6	1.2	7.4	3	9	9
Registrar 5										
1	3	2	1	6	6	1.25	15	1	7	7
Registrar 6										
1	2	1	3	6	6	3	15.1	1	7	7

Key: Register 1=Exp, 2=Spr, 3=Mod, 4=New, 5 & 6=Junior (SHO)

Table 5. Within Sessions Comparison

Registrar	Session	Test #	Anastomosis Time		Total
			Time Total	Score	Scores
		1	7.5	1	8.5
1	1	2	8	3	11
		1	6	2	8
2	1	2	6.5	4	10.5
		3	6	3	6.5
		1	7.5	1	8.5
3	1	2	10.5	3	13.5
		3	6	2	10.5
2	2	1	9	3	12
	2	2	11	3	14
	2	3	7	3	10
Summary	Test #				
	First	30	7	37	
	Second	36	13	49	
	Third	26.5	11	37.5	

ous perfusion through either the LIMA or coronary vessels thereby giving the trainee a false impression of hemostasis, 2) the absence of branches on the LIMA and, 3) no hemodynamic effects consistent with manipulation of the heart.

CONCLUSION

The Pulsatile Beating Heart Model (Limbs and Things, Ltd., Bristol, UK) provides an excellent simulator for trainees in beating heart coronary anastomoses. Extension of this concept can also be made to the arrested (cardioplegic) mode of CABG by stopping the mechanical pulsator and thereby providing a solid basis for training young surgeons to perform coronary artery bypass grafting under cardioplegic arrest as well. Further, this model may be useful to determine whether an applicant has sufficient manual dexterity to be accepted into a cardiovascular training program. Indeed such a model may in the future be used as an important adjunct in selection of cardiac surgical trainees. At the very least, the model tends to self teach and helps instill confidence in the trainee and in the consultant alike.