Experience with porcine beating heart simulator for coronary artery bypass surgery residency training

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ABSTRACT

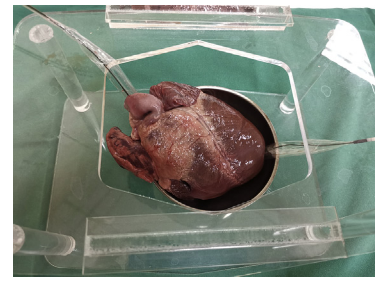
Objective: To evaluate the effect of our uniquely designed beating heart simulator for coronary artery bypass surgery residency training.

Methods: The balloon of intra-aortic balloon pump (IABP) was inserted into the left ventricle of an isolated porcine heart to form a beating heart simulator. This model simulated off-pump coronary artery bypass grafting (OPCABG), and the nonbeating heart model simulated the on-pump coronary artery bypass grafting (ONCABG) for training of surgeons. From 2017 to 2019, 60 trainees were randomly divided into nonbeating and beating heart simulator training groups. The training period was 3 months. The performance of anastomosis was evaluated at the beginning (after 1 month), midpoint (after 2 months), and at the end of the assessment (after 3 months).

Results: Trainees improved their performance of coronary artery anastomosis respectively after 3 months of training, whether they were trained on beating heart simulator or nonbeating heart simulator ($P < .05$). On both nonbeating and beating heart simulator test, trainees in the beating group performed better than those in the nonbeating group in the use of microsurgical instruments, anastomotic quality, and anastomotic speed after 3 months of training ($P < .05$).

Conclusions: The effect of our uniquely developed beating heart simulator training was better than those of nonbeating heart simulator for OPCABG and ONCABG training of surgeons during residency. (J Thorac Cardiovasc Surg 2021;161:1878-85)

ADULT



Beating porcine heart and nonbeating heart.

CENTRAL MESSAGE

Our beating heart simulator could mimic the scene of OP-CABG and the simulation results were satisfactory. It was very convenient for clinicians to be trained in their spare time and might shorten learning curves.

PERSPECTIVE

The effect of our beating heart simulator training was better than that of nonbeating heart simulator training for coronary artery bypass surgery residency training. It is convenient for coronary artery bypass surgery resident clinicians to train in their spare time, and the simulation results were satisfactory.

See Commentaries on pages 1886 and 1887.

Off-pump coronary artery bypass grafting (OPCABG) is a major method for surgical coronary revascularization, especially in high-risk and elderly patients.[1] Beating-heart surgeries are technically challenging procedures that require the operators to perform an accurate and expeditious anastomosis on constantly moving target vessels. Young surgeons need to be well trained before attempting this procedure on patients. The use of live-animal models to gain proficiency in surgical skills is not cost-efficient and not generally accepted due to legal and ethical concerns. Thus, simulation-based learning can provide the necessary training and practice outside the operating room.[2-4] A widely acceptable simulator should provide a realistic and graduated training experience with the valid educational objective; be cost-effective requiring relatively low maintenance, and allow the trainee to practice in his or her spare time without being constrained by work hour limitations and availability of animal laboratory facilities. The

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Abbreviations and Acronyms

- IABP = intra-aortic balloon pump
- LAD = left anterior descending artery
- ONCABG = on-pump coronary artery bypass grafting
- OPCABG = off-pump coronary artery bypass grafting

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simulation and animal laboratory experience have been used extensively in cardiothoracic surgery research and training in Western countries, with synthetic and mechanical cardiac simulators developed in the 1990s. However, these simulation training devices are extremely expensive to promote or are too complicated and inconvenient for clinicians to use in training.[5,6] In China, due to the difference in the social system, simulation-based learning has not yet been established. The training of Chinese cardiac surgeons and other specialists remains in the traditional apprenticeship form, and the training process is not standardized and objective, so it cannot adapt to the rapid development of modern medicine. Based on our previously designed coronary anastomosis training container, we developed an on-pump coronary artery bypass grafting (ONCABG) and OPCABG training simulator. By February 2019, we had conducted a total 22 training courses and had trained more than 350 residents and postgraduates in cardiac surgery. In this study, we tried to evaluate the effect of our designed ONCABG and OPCABG simulator for residency training, and also wanted to test the hypothesis that the effect of OPCABG simulator training was better than that of ONCABG simulator training for residency training.

METHODS

This study was a single-center, blinded, prospective trial approved by our university. From September 2017 to February 2019, a total of 60 cardiac surgery residents and postgraduates from 6 affiliated hospitals of our university, who had not received any training in coronary artery anastomosis technology in the past, were randomly divided into a nonbeating heart simulator training group and a beating heart simulator training group.

Study Protocol

After grouping, all trainees received the coronary artery bypass anastomosis test on the nonbeating heart simulator and the beating heart simulator to serve as a baseline value. To reduce the bias of experimental results, we stipulated that each trainee's training time and intensity was consistent. The training period was 3 months. The performance of anastomosis was evaluated at the beginning (after 1 month), the midpoint (after 2 months), and the end of the assessment (after 3 months). At each test time, all trainees received a test on the nonbeating and beating heart simulator separately (Figure 1).

Nonbeating Heart Simulator

The porcine hearts were obtained from abattoirs from animals slaughtered for consumption and prepared for use. The remnants of human saphenous veins were used as grafts for anastomoses. The porcine heart was prepared and supported in our designed anastomosis training container (Chinese National Utility Model Patent 2014206891414). In the experiment, we used left anterior descending artery (LAD) as the target vessel for training and assessment. We mainly considered that the location of LAD was relatively constant and the diameter of the vessel was large, which was beneficial for beginners to learn and master. It was convenient to unify the assessment criteria, eliminate the interference factors such as variation of porcine heart coronary artery, muscle bridge, and too thin caliber. This nonbeating heart model was used to simulate the ONCABG technique under extracorporeal circulation and cardiac arrest. The trainees were educated about the technique for exposing the LAD, performing arteriotomy, and completing distal end-to-side anastomosis. The distal end of the saphenous vein segment was beveled, and a continuous running suture technique was used to perform the coronary anastomosis. Subsequently, the role was reversed between the operator and the assistant.

Beating Heart Simulator

To simulate the coronary artery bypass under the condition of a beating heart, the clinical waste catheter of intra-aortic balloon pump (IABP) was used after disinfection. The balloon of the IABP catheter was inserted into the left ventricle of the porcine heart from the aorta and passed through the apex (Figure 2).The other end of the IABP catheter was connected to the IABP machine. The balloon was connected to a console that regulated the inflation or deflation of the balloon with the passage of helium. The volume of the balloon was controlled by regulating the volume of inflation, and the amplitude of the porcine heart beating according to the left ventricle cavity size and the operational requirements was adjusted. The built-in frequency of the IABP machine (80 beats/min) was used. The methods of exposure to LAD and coronary artery anastomosis training were similar to the procedure of the nonbeating heart simulator. The beating heart model was used to simulate the OPCABG technique (Video 1).

Performance Assessment

The performance of anastomosis was evaluated according to a 5-point global rating scale (1 = excellent, 2 = good, 3 = average, 4 = below average, and 5 = poor) (Table 1). The attending surgeons were instructed about the use of the 5-point rating scale, which was modified from the objective structured assessment of technical skills. The components of this assessment included graft orientation, bites, spacing, use of needle holder, use of forceps, needle angles, needle transfer, suture management, and tension.[7,8] Red ink was injected into the great saphenous vein to check the unobstructed anastomosis or the occurrence of anastomotic bleeding. Finally, in the proximity of anastomosis, the great saphenous vein was cut off. The anastomosis was detected by the coronary artery probe from the cavity (Figure 3). The performance of trainees were recorded with a digital video camera and stored for subsequent review. The complete video data were rated according to the 5-point global rating scale by 6 experienced surgeons in a blinded manner.

Data Analysis

First of all, we checked whether the values of data were normal distribution. For continuous variables, Student t test and paired t test were

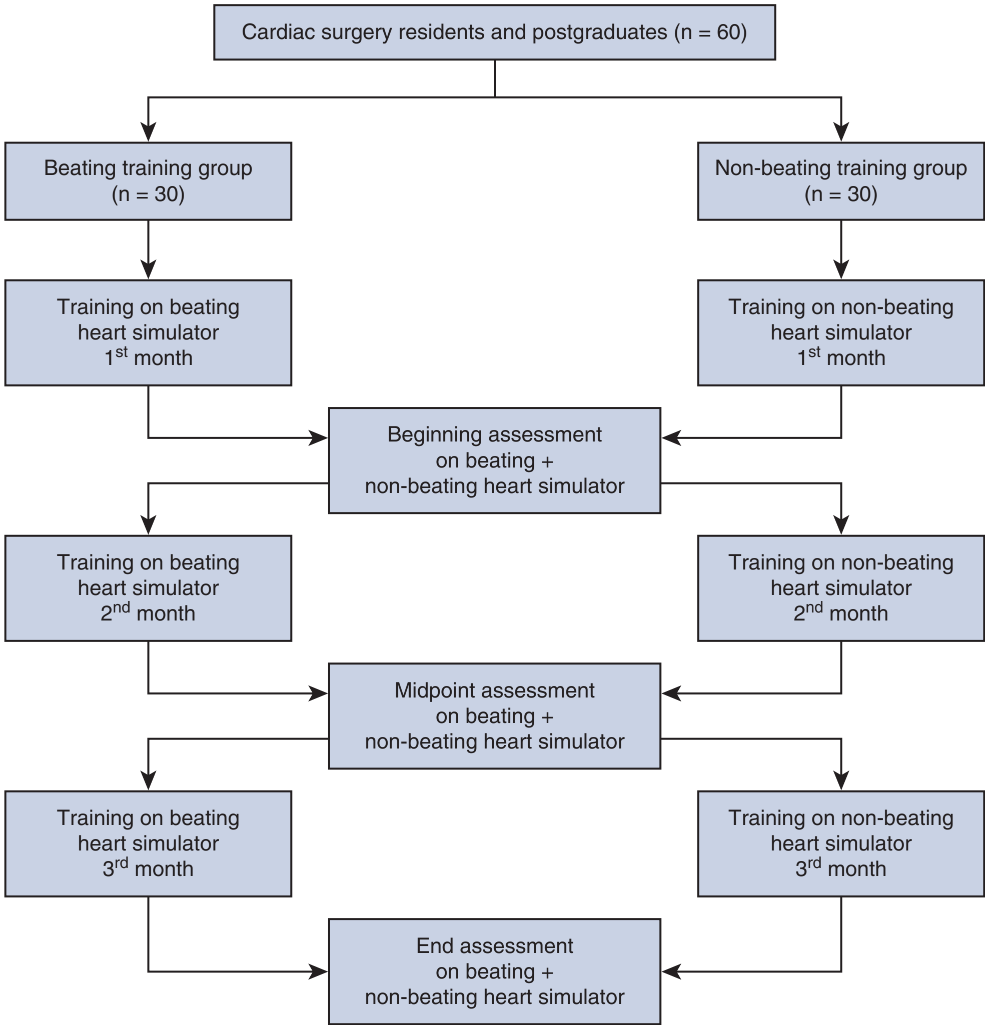


FIGURE 1. The training period was 3 months. The performance of anastomosis was evaluated at the beginning (after 1 month), the midpoint (after 2 months), and the end of assessment (after 3 months). At each test time, all trainees of the 2 groups underwent testing on the nonbeating and beating heart simulator separately.

used to estimate the differences in a normal distribution. The data were presented as mean ± standard deviation, and paired *t* test was performed for baseline versus end value, with Bonferroni correction. The interobserver reliability of reviewers was evaluated using Cohen' kappa statistics on beating and non-beating heart simulator. The results were analyzed with SPSS version 20 software (IBM-SPSS Inc, Armonk, NY) by reliability analysis tests and kappa measurement. Weighted kappa statistics were defined as follows[9,10]: ≤0, poor reliability; 0.01 to 0.2, slight; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.8, substantial; and 0.81 to 1, almost perfect.

RESULTS

On nonbeating heart simulator, kappa values ranged from 0.67 to 0.86 between reviewers, which revealed good interobserver reliability. And kappa values ranged from 0.65 to 0.80 between reviewers, which revealed good interobserver reliability on the beating heart simulator. The interrater reliability of the reviewers for the performance rating scores was >0.65, demonstrating moderate reliability. There were no differences between groups at the baseline assessment on the nonbeating heart simulator. And there were no differences between the groups at baseline on the beating heart simulator (Tables 2 and 3).

On the nonbeating heart simulator test, trainees in the beating group surpassed those in the nonbeating group in evaluation index item E (use of Castroviejo needle holder), F (use of forceps), G (needle angles), and L (the completion time of anastomosis) after 3 months of training ($P < .05$). No difference was observed between the groups with respect to evaluation index item A (graft orientation), I (suture management), B (bite appropriate), C (spacing appropriate), D (coronary incision size), K (the shape of anastomosis), and J (leakage of anastomosis) ($P > .05$) (Table 2).

On the beating heart simulator test, trainees in the beating group were better than those in the nonbeating group in

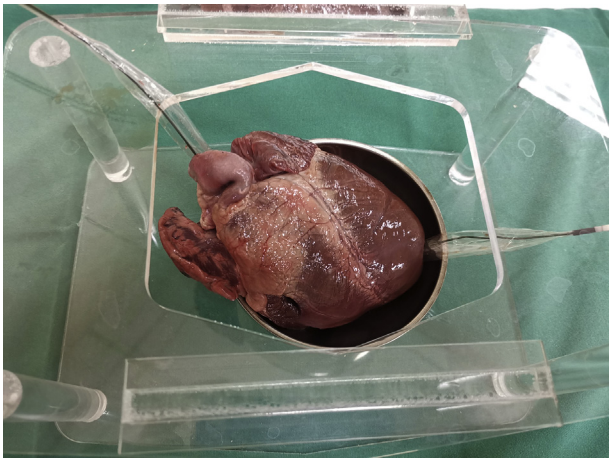
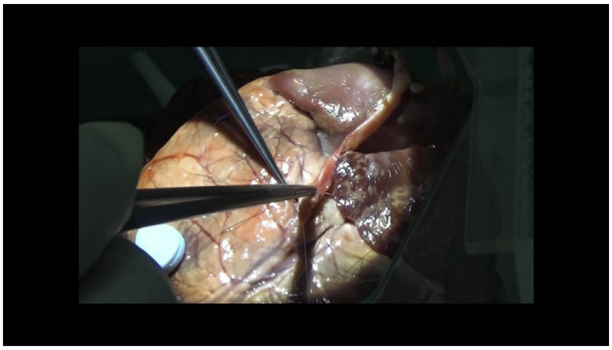


FIGURE 2. The porcine heart was prepared and supported in our designed anastomosis training container. The balloon of the intra-aortic balloon pump catheter was inserted into the left ventricle of the isolated porcine heart from the aorta to form a beating heart simulator.

the use of microsurgical instruments, anastomotic quality, and the anastomotic speed after 3 months of training ($P < .05$). Significant differences were noted in posttraining evaluation index items B (bite appropriate), C (spacing appropriate), D (coronary incision size), G (needle angles), K (shape of anastomosis), J (leakage), and L (completion time of anastomosis) ($P < .05$). No difference was noted between the beating group and nonbeating group concerning posttraining evaluation index items A (graft orientation) and I (suture management) ($P > .05$) (Table 3).



VIDEO 1. The porcine heart was supported in anastomosis training container. The balloon of the IABP catheter was inserted into the left ventricular cavity of the isolated porcine heart from the aorta and passed through the apex, and triggered with the built-in frequency to form a beating heart simulator. The built-in frequency of the IABP machine (80 beats/min) was used. The heart was positioned to expose the left anterior descending artery. The trainees were educated about the technique for exposing the LAD, performing arteriotomy, and distal end-to-side anastomosis. The distal end of the saphenous vein segment was beveled, and a continuous running suture technique was used to perform the coronary anastomosis. Completed anastomosis, red ink was injected into the great saphenous vein to check the unobstructed anastomosis or the occurrence of anastomotic bleed. Video available at: https://www.jtcvs.org/article/S0022-5223(20)30568-7/fulltext.

Under the nonbeating and beating heart conditions, the two groups of trainees improved their own performance of coronary artery anastomosis after 3 months of training ($P < .05$) (Table 3). For the trainees trained with the beating heart simulator, significant differences were noted in the assessment of baseline value and posttraining value. On the nonbeating heart simulator test, the slope of evaluation index items showed the largest slope from baseline to beginning point (index items A, B, E, F, G, H, and I), whereas the slope decreased significantly from beginning point to end point in the resulting spaghetti graph (Figure 4). The slope of evaluation index items, including C, D, J, K and L, was approximately straight line from baseline to end point. On the beating heart simulator test, the slope showed the largest slope from baseline to beginning point (index items A, B, C, D, E, F, G, H, and I), whereas the slope decreases significantly from beginning to end point in the spaghetti graph. The slope of evaluation index items J, K and L, was an approximately straight line from baseline to end point (Tables 2 and 3 and Figure 4).

DISCUSSION

OPCABG is a minimally invasive procedure that can reduce the damage of heart and systemic organs by avoiding cardiopulmonary bypass and ischemia reperfusion.[1,11] However, beating heart surgeries are technically challenging procedures that require the operators to perform an accurate and expeditious anastomosis on constantly moving target vessels. Young surgeons need to be well trained and there is a relatively long learning curve before attempting this technique on patients.[2,12,13] Thus, the operating room might not be an ideal location for early surgical training due to ethical concerns, time constraints, and complex procedures performed on high-risk patients.[14] In addition, cognitive and technical learning in an operating room provides little opportunity for practice and reflection. Wu Jie-ping, chairman of the former Chinese Medical Association Department of Surgery, stated that "a surgeon who can operate satisfactorily is not a good doctor, but a surgeon who does not perform good operation cannot be a good doctor."[15]

Thus, simulation-based learning could provide necessary training and practice outside the operating room. Beginners could learn how to expose the heart, incise the coronary artery, and place the intracoronary artery shunt. Also, the operator could practice how to use Castroviejo microscissors, Castroviejo microneedle holder, and microforceps to perform coronary artery vascular anastomosis employing specific methods. We designed a coronary artery surgery training simulator (a nonbeating heart simulator) 20 years ago, and hundreds of cardiac surgeons have been trained and good results have been achieved. But some cardiac

TABLE 1. Performance rating items and scores

Evaluation index item	Rating score*				
(A) Graft orientation (proper orientation for toe-heel, appropriate start and end points)	1	2	3	4	5
(B) Bite appropriate (entry and exit points, number of punctures, even and consistent distance from edge)	1	2	3	4	5
(C) Spacing appropriate (even spacing, consistent distance from previous bite, too close vs too far)	1	2	3	4	5
(D) Coronary incision size (compared to graft) and orientation	1	2	3	4	5
(E) Use of Castroviejo needle holder (finger placement, instrument rotation facility, needle placement pronation and supination, proper finger and hand motion, lack of wrist motion)	1	2	3	4	5
(F) Use of forceps (facility, hand motion, assist needle placement, appropriate traction on tissue)	1	2	3	4	5
(G) Needle angles (proper angle relative to tissue and needle holder, consider the depth of field, anticipating subsequent angles)	1	2	3	4	5
(H) Needle transfer (needle placement and preparation from stitch to stitch, use of instrument and hand to mount needle)	1	2	3	4	5
(I) Suture management/tension (too loose vs too tight, use tension to assist exposure, avoid entanglement)	1	2	3	4	5
(J) Leakage of anastomosis (1, none; 2, oozing; 3, 1-point leak; 4, 2-point leak; 5, dehiscence)	1	2	3	4	5
(K) Shape of anastomosis (1, cobra head; 2, flat; 3, deformation; 4, stenosis; 5, obstruction)	1	2	3	4	5
(L) Completion time of anastomosis (1, <5 min; 2, 6-10 min; 3, 11-15 min; 4, 16-19 min; 5, >20 min)	1	2	3	4	5

*Unless otherwise indicated, scores were: 1, excellent, able to accomplish goal without hesitation, showing excellent progress and flow; 2, good, able to accomplish goal deliberately with minimal hesitation, showing good progress and flow; 3, average, able to accomplish goal with hesitation, discontinuous progress and flow; 4, below average, able to partially accomplish goal with hesitation; 5, poor, unable to accomplish goal, marked hesitation.

surgeons pointed out that the training effect and fidelity of the nonbeating heart simulator were unsatisfactory for OP-CABG. To simulate the condition of a beating heart, we developed our beating heart simulator through inserting the IABP balloon catheter into the left ventricle of an isolated porcine heart. In this study, we wanted to test the hypothesis whether the effect of beating heart simulator training was better than that of nonbeating heart simulator for residency training.

Our trainees were resident physicians who had not received any training in coronary artery anastomosis technology in the past. This study observed significant differences in the coronary artery anastomosis accuracy, anastomosis quality, and anastomosis speed in the 2 groups of trainees receiving different training methods. Based on the assessment results, trainees in the beating group were superior to those in the nonbeating group in the application of microsurgical instruments, anastomotic speed, and anastomotic quality after 3 months of training on a beating heart simulator test. Also, trainees in the beating group were superior to those in the nonbeating group in the application of microsurgical instruments and anastomotic speed after 3 months of training on nonbeating heart simulator test. The trainees in the beating group had obvious advantages in the use of microsurgical instruments and the control of needles. We speculated that the training under beating heart conditions might be more helpful for trainees to improve the coordination of needle holder and forceps, as well as the coordination of eyes and hands, especially in the selection of needle insertion site, the angle of needle insertion, as well as forceps assisting in needle extraction on the moving target vessel. Fluid needle insertion and extractions improve the integrity of anastomotic stoma, leave no leakage, create good shape, and shorten the anastomotic time. Distal anastomotic morphology, leakage, and completion time of anastomosis were critical indicators for evaluating the technical level of coronary artery bypass grafting proficiency.[16,17] Proficiency in the use of microsurgical instruments was the basis for improving the quality and speed of anastomosis. So, anastomotic quality and anastomotic speed were always the focus of our training and assessment. And anastomotic quality and anastomotic speed were a relatively slow process to be improved, which could explain the trend of slope change in the spaghetti graph. Whether training on beating heart condition could help trainees overcome their hand involuntarily shaking and relieve emotional tension was not supported by direct measurement results.

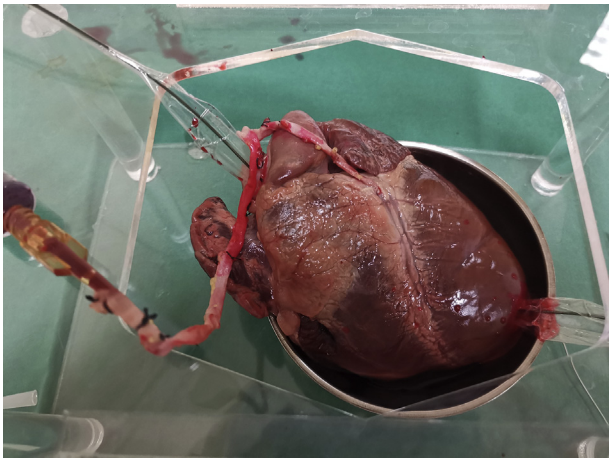


FIGURE 3. Red ink was injected into the great saphenous vein to check the unobstructed anastomosis or the occurrence of anastomotic bleeding.

TABLE 2. Mean performance rating scores of the 2 groups baseline and 3 months posttraining on nonbeating heart simulator test

Evaluation index item	Kappa value	B group (n = 30) Baseline	B group (n = 30) Posttraining	N-B group (n = 30) Baseline	N-B group (n = 30) Posttraining	P value: B group baseline vs B group posttraining	P value: N-B group baseline vs N-B posttraining	P value: B group posttraining vs N-B group posttraining
(A) Graft orientation	0.79	4.10 ± 0.82	1.52 ± 0.52	3.90 ± 0.70	1.54 ± 0.82	<.0001	<.0001	.4210
(B) Bite appropriate	0.80	4.20 ± 1.00	1.55 ± 0.76	4.10 ± 0.79	1.59 ± 0.88	<.0001	<.0001	.3123
(C) Spacing appropriate	0.85	3.80 ± 1.10	1.57 ± 0.89	3.7 ± 0.65	1.60 ± 0.78	<.0001	<.0001	.0822
(D) Coronary incision size	0.75	3.58 ± 0.70	1.64 ± 0.84	3.76 ± 0.80	1.72 ± 0.87	<.0001	<.0001	.5034
(E) Use of Castroviejo needle holder	0.86	4.20 ± 0.90	1.63 ± 0.85	4.25 ± 0.67	1.78 ± 0.97	<.0001	<.0001	.0359
(F) Use of forceps	0.83	4.15 ± 0.90	1.56 ± 0.94	4.10 ± 0.51	1.72 ± 0.82	<.0001	<.0001	.0438
(G) Needle angles	0.75	4.10 ± 1.20	1.51 ± 0.89	4.12 ± 0.34	1.65 ± 0.78	<.0001	<.0001	.0401
(H) Needle transfer	0.67	4.20 ± 1.00	1.46 ± 0.96	4.10 ± 0.73	1.83 ± 0.75	<.0001	<.0001	.0234
(I) Suture management/tension	0.81	3.31 ± 0.91	1.58 ± 0.69	3.30 ± 0.68	1.63 ± 0.78	<.0001	<.0001	.7091
(J) Leakage of anastomosis	0.78	3.50 ± 0.90	2.00 ± 0.85	3.55 ± 0.59	2.15 ± 0.76	<.0001	<.0001	.6382
(K) Shape of anastomosis	0.74	3.91 ± 0.85	2.21 ± 1.2	3.90 ± 0.76	2.30 ± 0.96	<.0001	<.0001	.2875
(L) Completion time of anastomosis	0.85	3.78 ± 1.20	1.78 ± 1.20	3.72 ± 0.52	2.20 ± 1.00	<.0001	<.0001	.0412

Values are presented as mean ± standard deviation. Paired *t* test was performed for baseline data versus posttraining data. Parameters were compared between the groups in the posttraining data versus posttraining data. *B group*, Beating heart group; *N-B group*, nonbeating heart group.

The 2 groups of trainees improved their own performance of coronary artery anastomosis after 3 months of training, whether they were trained on beating heart simulator or nonbeating heart simulator. For the trainees using the beating heart simulator, significant differences were noted in the assessment of baseline value and posttraining value. On the nonbeating heart simulator test, the slope of evaluation index items showed the largest slope from baseline to beginning point (index items A, B, E, F, G, H, and I), whereas the slope decreased significantly from beginning point to end point on our spaghetti graph. The slope of evaluation index, including items C, D, J, K, and L, was

TABLE 3. Mean performance rating scores of the 2 groups baseline and 3 months posttraining on beating heart simulator test

Evaluation index item	Kappa value	B group (n = 30) Baseline	B group (n = 30) Posttraining	N-B group (n = 30) Baseline	N-B group (n = 30) Posttraining	P value: B group baseline vs B group posttraining	P value: N-B group baseline vs N-B posttraining	P value: B group posttraining vs N-B group posttraining
(A) Graft orientation	0.76	4.15 ± 0.90	1.58 ± 0.41	4.00 ± 0.58	1.60 ± 0.60	<.0001	<.0001	.7845
(B) Bite appropriate	0.78	4.10 ± 0.91	1.55 ± 0.74	4.20 ± 0.52	2.40 ± 0.85	<.0001	<.0001	<.0001
(C) Spacing appropriate	0.75	4.08 ± 1.10	1.63 ± 0.98	3.99 ± 0.91	2.60 ± 0.76	<.0001	<.0001	<.0001
(D) Coronary incision size	0.77	3.85 ± 0.90	1.65 ± 0.82	3.82 ± 0.42	2.63 ± 0.93	<.0001	<.0001	.0012
(E) Use of Castroviejo needle holder	0.68	4.12 ± 0.85	1.48 ± 0.44	4.10 ± 0.94	1.86 ± 0.54	.0001	<.0001	.0447
(F) Use of forceps	0.69	4.10 ± 1.20	1.51 ± 0.78	4.20 ± 0.97	1.89 ± 0.89	<.0001	<.0001	.0371
(G) Needle angles	0.75	4.12 ± 1.10	1.51 ± 0.75	4.15 ± 0.68	2.34 ± 0.88	<.0001	<.0001	<.0001
(H) Needle transfer	0.70	4.15 ± 0.93	1.45 ± 0.80	4.10 ± 0.81	2.16 ± 0.98	<.0001	<.0001	<.0001
(I) Suture management/tension	0.80	3.78 ± 1.00	1.45 ± 0.90	3.74 ± 0.83	1.52 ± 0.72	<.0001	<.0001	.6516
(J) Leakage of anastomosis	0.76	4.19 ± 0.80	2.24 ± 1.20	4.20 ± 0.77	3.65 ± 1.20	<.0001	.0014	.0012
(K) Shape of anastomosis	0.69	4.10 ± 1.00	2.20 ± 1.90	4.15 ± 0.74	3.57 ± 0.96	.0370	.0410	.0101
(L) Completion time of anastomosis	0.80	4.25 ± 1.11	2.13 ± 1.2	4.22 ± 0.52	3.96 ± 1.21	.0385	.0460	<.0001

Values are presented as mean ± standard deviation. Paired *t* test was performed for baseline data versus posttraining data. Parameters were compared between the groups in the posttraining data versus posttraining data. *B group*, Beating heart group; *N-B group*, nonbeating heart group.

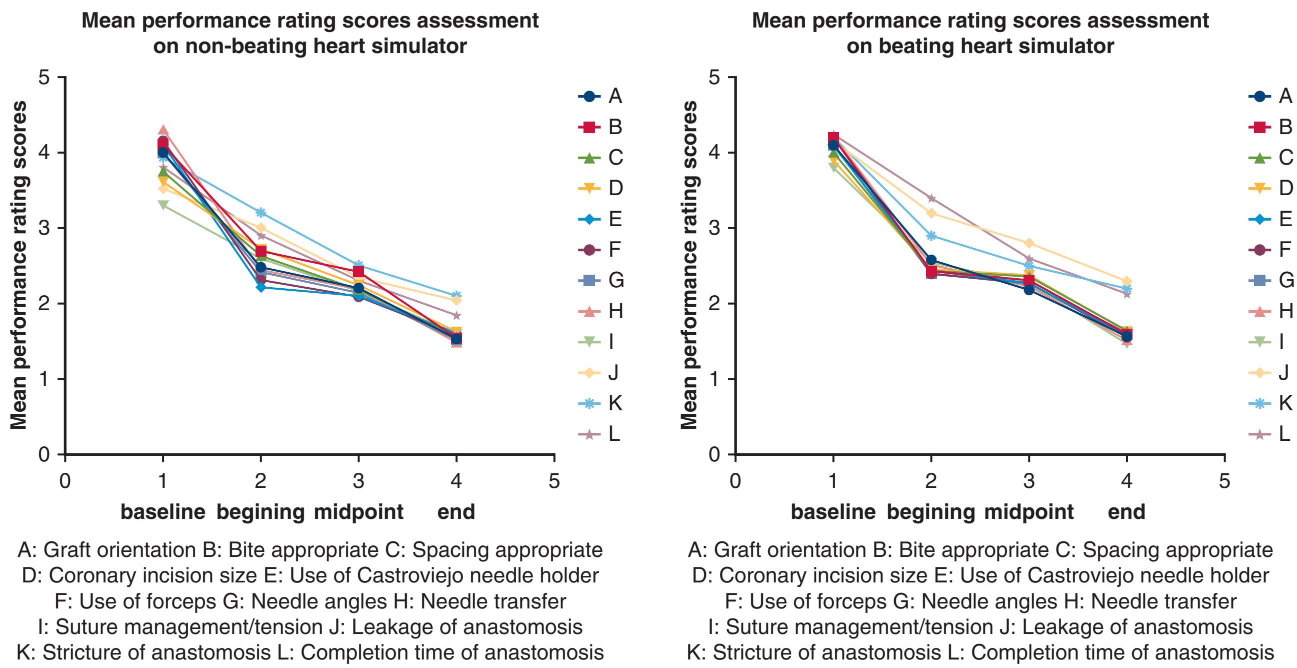


FIGURE 4. The trainees in the beating heart simulator training group notably improved their performance of coronary artery anastomosis. This spaghetti graph of their mean performance rating scores based on assessment of 2 kinds of simulator, at the beginning (after 1 month), midpoint (after 2 months), and at the end of assessment (after 3 months).

approximately straight line from baseline to end point. On the beating heart simulator test, the slope showed the largest change from baseline to beginning point (index items A, B, C, D, E, F, G, H, and I) and the slope decreases significantly on the spaghetti graph. The slope of evaluation index items J, K, and L was an approximately straight line from baseline to end point. The trainees made remarkable progress in the performance of microsurgical instruments after 1 month of training on the beating heart simulator. They were more comfortable with the use of microsurgery instruments when facing the static heart and target blood vessels on the nonbeating heart simulator, and the evaluation index related to the proficiency of the microsurgical instruments was also significantly improved. During the next 2 months, their evaluation indexes related to microsurgical instruments proficiency entered a relatively stable stage, rather than the previous rapid progress. This was similar to the phenomenon we encountered in clinical practice.[18,19] There was a learning curve that could explain the change of slopes in the spaghetti chart. All these reminded us that junior cardiac surgeons should pay attention to strengthening their training on the use of microsurgery instruments, and this training might be long-term.

Most educators agree about the critical limitations of simulation-based training. Simulation may never mimic the feel of living human tissue, the complexity of human physiology, or all the psychosocial nuances of real patient care.[20-23] Simulation training was not designed to eliminate the need for genuine patient interaction and real operating room experience, but rather to serve as a crucial adjunct or bridge for the safer transition to independent patient care and continued practice.[24-26] In practice, we found that beating heart simulation training did not require complex equipment and specialized laboratories, and it was very convenient for clinicians to be trained in the their spare time. It could basically simulate the scene of OPCABG and help trainees to perform coronary artery bypass grafting on an actual beating heart. After using this beating heart simulators, participants reported confidence in their ability to perform OPCABG.

Limitations

One limitation was that simulators could not reproduce the tissue responses observed in human pathology. Other limitations of any simulation training are that a simulator might not mimic the unstable fluctuations of circulation during an actual operation on a patient, the influence of the psychological pressure and emotional changes of the operator on the operation, and the cooperation between surgeons and anesthesiologists.

CONCLUSIONS

Our research results showed that the effect of our uniquely developed beating heart simulator training was better than those of nonbeating heart simulator training for residency OPCABG and ONCABG training. So we speculate that we might directly use the beating heart simulator to train young surgeons, instead of the traditional nonbeating simulator first and then the beating heart simulator. Directly using beating heart simulators might improve training efficiency and training effect, which could shorten the training cycle and the learning curve for cardiac surgeons.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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