# Cardiac Surgery Trainees as "Skin-to-Skin" Operating Surgeons: Midterm Outcomes

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*Background.* We have previously demonstrated that cardiac surgery trainees can safely perform operations "skin-to-skin" with adequate attending surgeon supervision.

*Methods.* We used 100 consecutive cases (82 coronary artery bypass grafts, 9 aortic valve replacements, 7 coronary artery bypass grafts plus aortic valve replacements, 2 others) performed by residents (group R) to match 1:1 by procedure to nonconsecutive cases done by a single attending surgeon (group A) from July 2014 to October 2016. Patients were stratified based on whether the attending surgeon or trainee performed every critical step of the operation skin-to-skin. Outcomes included death, major morbidity, and readmission.

*Results.* Patients in the two groups were similar with respect to demographic characteristics and comorbidities. The median follow-up time for patients in this study was 28 months (interquartile range: 23 to 35 months). There were seven deaths (3.5%; four in group A, three in group R, $p = 0.7$). Of the 43 patients (21.5%) who were readmitted during the study term, 27 patients (13.5%) were readmitted for causes related to the operation (11 in group A, 16 in group R, $p = 0.02$). The most common reasons for readmissions related to the operation were chest pain (n = 11), pleural effusion that required drainage (n = 8), pneumonia (n = 4), and unstable angina that required percutaneous coronary intervention (n = 3). No statistically significant differences were found in reasons for readmission between group A and group R.

*Conclusions.* The equivalence of postoperative outcomes previously demonstrated at 30 days persists at midterm follow-up. Our data indicate that trainees can be educated in operative cardiac surgery under the current paradigm without sacrificing outcome quality. It is reasonable to expect academic programs to continue providing trainees with experience as primary operating surgeons.

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EDUCATION

Cardiac operations are among the most studied procedures in the world. They are technically demanding, unforgiving of error, and require precision, which in turn makes them inherently difficult to teach. Whether through traditional fellowship, joint 4+3, or fully integrated pathways (I-6), the ability of cardiothoracic training programs to produce independently autonomous surgeons remains an important topic of conversation on a national scale [1–3]. Furthermore, the best teaching method or methods to accomplish this goal remain widely debated [4, 5].

In our earlier study to strictly define "skin-to-skin" procedure criteria, we previously demonstrated that cardiac surgery trainees can safely perform operations in their entirety, without compromising short-term hospital outcomes [6]. Despite expectedly longer operative times, patients receiving operations by trainees versus attending surgeons showed no difference in 30-day mortality, stroke, or hospital length of stay. Beyond the index hospitalization, however, the effects of this discrepancy in operative speed and lack of attending direct technical involvement remain unknown. Given the established long-term benefit of coronary bypass surgery in both survival and symptomatic relief compared with medical management or percutaneous approaches, it is of utmost importance to ensure that this benefit is preserved when the operation is executed by a trainee under direct attending supervision [7].

We sought to further demonstrate the safety and efficacy of skin-to-skin surgical training past the 30-day mark by comparing midterm outcomes of cases done entirely by trainees with cases done entirely by a single attending surgeon. The primary end points for this study were readmission and death.

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## Patients and Methods

This study was approved by the Partners Human Research Committee's Institutional Review Board for human research to meet ethical and legal requirements. The methods for the original study were published elsewhere [6]. From July 2014 to December 2016, Dr Tolis completed a total of 642 pump cases as either teaching or primary surgeon. A prospective longitudinal database was created to capture comprehensive data for all patients undergoing cardiac operations by Dr Tolis at our institution. Consecutive cases done skin-to-skin by the resident surgeon (group R) during the study period with attending supervision were matched 1:1 by specific operative procedure with cases done skin-to-skin by the same attending surgeon (group A). Matched cases were analyzed for differences in outcomes, and all cases were performed at the Massachusetts General Hospital main campus. The case mix is shown in Table 1.

### *Training*

The cardiothoracic training program at Massachusetts General Hospital consists of rotating general surgery residents, 4+3 integrated and full-time cardiothoracic residents who have completed general surgery training. All cases done skin-to-skin by resident surgeons were done so by the eight full-time cardiothoracic residents who rotated with Dr Tolis during the study period. Before being allowed to perform an operation skin-to-skin, the residents displayed competency in performing each individual step of the operation during the earlier part of their training (eg, opening, harvesting conduits, cannulating, constructing distal and proximal anastomoses). Our training method uses the apprenticeship model, wherein each trainee spends three consecutive months with a single attending surgeon.

### *Definitions*

Cases were considered skin-to-skin if the operating surgeon, attending, or resident completed each of the following steps of the operation from the right side of the operating table.

*Table 1. Case Mix of Operations Performed Skin-to-Skin by the Attending Surgeon or the Resident Surgeons*

| Procedure | Attending Surgeon (n = 100) | Resident Surgeons (n = 100) |
|---|---|---|
| CABG | | |
| × 2 | 34 | 34 |
| × 3 | 34 | 34 |
| × 4 | 10 | 10 |
| × 5 | 4 | 4 |
| AVR | 10 | 10 |
| AVR/CABG | 7 | 7 |
| MVR/CABG × 3 | 1 | 1 |

Values are n.

AVR = aortic valve replacement; CABG = coronary artery bypass graft; MVR = mitral valve replacement.

COMMON STEPS.

1. Opening of skin, soft tissues, sternum, and pericardium
2. Cannulation for cardiopulmonary bypass (CPB)
3. Placement of aortic cross-clamp (ACC)
4. Completion of the procedure specific steps (in sections below)
5. Decannulation and separation from CPB
6. Achieving hemostasis and closure of sternum, soft tissues, and skin

SPECIFIC STEPS FOR CORONARY ARTERY BYPASS GRAFT.

1. Harvesting the arterial conduit or conduits
2. Identification, dissection, and opening of coronary arteries
3. Completion of both proximal and distal anastomoses for every bypass graft

SPECIFIC STEPS FOR AORTIC VALVE REPLACEMENT/MITRAL VALVE REPLACEMENT.

1. Performing the aortotomy/atriotomy
2. Resection/reconstruction of native valve
3. Placing every annular suture
4. Tying every knot
5. Closing the aortotomy/atriotomy

If the attending surgeon had to intervene and complete any of these steps, the case was excluded from our analysis. Several cases were intended to be resident cases but were converted to mixed (attending and resident cases) because the attending surgeon had to intervene at some point during the operation. Typical reasons that this scenario would occur were (1) dense pericardial adhesions that made cannulation and identification of coronary arteries difficult, (2) excess annular calcium in a mitral or aortic valve procedure that necessitated attending involvement, (3) leaking of a distal or proximal anastomosis that required takedown of the anastomosis and reconstruction, or (4) distorted anatomy of the heart and great vessels that made it technically difficult to perform a standard cannulation. None of the "mixed" cases described above are included in our present study, and our original data do not reveal any complications from these cases (eg, death, stroke, wound infection) that we could directly attribute to attending conversion.

### *Statistical Analysis*

All statistical analysis was performed with Stata/SE 12.1 (StataCorp, LP, College Station, TX). Continuous data, which were normally distributed, were expressed as means with SDs, and nonnormally distributed data were expressed as medians with interquartile ranges (IQRs). Categorical data were expressed as numbers and percentages. Student's $t$ test and Wilcoxon rank sum tests were used when appropriate for continuous variables, and the $\chi^2$ test was used when appropriate for categoric variables. Analysis of variance testing was used to analyze the between-group differences. All tests were performed in a two-sided fashion. Normality of data was assessed

with the use of histograms, skewness, kurtosis, and the Shapiro–Wilk test.

## Results

Patients in the two groups were similar with respect to demographic characteristics and comorbidities (Table 2). No statistically significant differences were found in age, sex, body mass index, American Society of Anesthesiologists score, left ventricular ejection fraction, or diabetes mellitus. Patients in the attending group (group A) had higher Society of Thoracic Surgeons predicted mortality scores than patients in the resident group (group R) (1.55% versus 1.22%, $p = 0.04$). This difference was largely because of three predictors: age older than 66 years (64% versus 49%, $p = 0.03$), use of intraaortic balloon pump (10% versus 4%, $p = 0.1$), and case status (elective [23% versus 39%], urgent [74% versus 60%], and emergent [3% versus 1%], $p = 0.04$]. Residents in group R were further along in training than residents in group A (postgraduate year [PGY] 7.2 versus 5.7, $p < 0.001$). This was not surprising, given our established system of earned autonomy. Table 3 shows the case mix and operating times by PGY for cases done by the resident surgeons. Although most cases were done by the second- and third-year residents (50% and 33%, respectively), first-year residents did 17% of the skin-to-skin cases. When comparing total operative, CPB, and ACC times, only minor differences were found between PGY years. As shown in Figure 1, operations performed by the attending surgeon were significantly shorter in total operative, CPB, and ACC times than operations performed by the resident surgeons. Despite this increase in operative times, we did not find any associated outcome differences at 30-day follow-up.

The midterm outcomes data are shown in Table 4. There were seven deaths (3.5%) in the study population with a median follow-up time of 28 months (IQR: 23 to 35 months). Four deaths occurred in the attending group, and three in the resident group ($p = 0.7$). Cause of death was able to be determined for 2 patients in the resident group and three patients in the attending group. All but one death was due to unrelated causes (esophageal cancer, interstitial lung disease, sepsis from osteomyelitis, and hypoxemic respiratory failure). One patient in the attending group died from cardiogenic shock; however, on autopsy, all grafts were patent. Of the 43 patients (21.5%) who were readmitted during the study term, 27 patients (13.5%) were readmitted for causes related to the operation (11 in group A, 16 in group R, $p = 0.3$). The

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*Table 2. Preoperative Characteristics for Operations Performed Skin-to-Skin by the Attending Surgeon or the Resident Surgeons*

| Variable | Attending Surgeon (n = 100) | Resident Surgeons (n = 100) | *p* Value |
|---|---|---|---|
| Age, years | | | |
| Mean ± SD | 69.2 ± 10.4 | 67 ± 9.3 | 0.1 |
| Range | 43–91 | 47–89 | |
| Female | 20 (20) | 19 (19) | 0.9 |
| Body mass index, kg/m$^2$ | | | |
| Mean ± SD | 28.6 ± 5.3 | 29.5 ± 5.7 | 0.2 |
| Range | 17.3–47.1 | 18.7–55.2 | |
| American Society of Anesthesiology score | | | |
| Median | 3 | 3 | 0.7 |
| IQR | 3–4 | 3–4 | |
| Ejection fraction, mL/min | 55.9 ± 13.9 | 58 ± 12.9 | 0.3 |
| Diabetes mellitus | 30 (30) | 39 (39) | 0.2 |
| STS predicted mortality, % | | | |
| Median | 1.55 | 1.22 | 0.04 |
| IQR | 0.9–3.2 | 0.5–2.2 | |
| Intraaortic balloon pump | 10 (10) | 4 (4) | 0.1 |
| Inserted preoperatively | 9 (90) | 1 (25) | 0.02 |
| Inserted intraoperatively | 1 (10) | 3 (75) | 0.02 |
| Inserted postoperatively | 0 | 0 | |
| Age > 66 years | 64 (64) | 49 (49) | 0.03 |
| Case status | | | |
| Elective | 23 (23) | 39 (39) | 0.04 |
| Urgent | 74 (74) | 60 (60) | 0.04 |
| Emergent | 3 (3) | 1 (1) | 0.04 |
| Postgraduate year of trainee | 5.7 ± 1.4 | 7.2 ± 0.7 | <0.001 |

Values are n (%) or mean ± SD unless otherwise specified.

IQR = interquartile range; STS = The Society of Thoracic Surgeons.

*Table 3. Distribution of Case Mix and Operating Times by Postgraduate Year for Operations Performed Skin-to-Skin by the Resident Surgeons*

| Procedure | PGY 6 | PGY 7 | PGY 8 | Total | *p* Value |
|---|---|---|---|---|---|
| CABG × 2 | 5 (14.7) | 16 (47.1) | 13 (38.2) | 34 | |
| Operative time, hours | 3.9 (3.8–4) | 4 (3.5–4.6) | 3.9 (3.9–4.2) | | 0.6 |
| CPB time, minutes | 67 (65–69) | 76 (68–77) | 68 (59–72) | | 0.04 |
| ACC time, minutes | 54 (46–55) | 57 (52–59) | 50 (47–53) | | 0.2 |
| CABG × 3 | 6 (17.7) | 17 (50) | 11 (32.4 | 34 | |
| Operative time, hours | 4.7 (4.4–5.2) | 4.7 (4.3–5.1) | 4.8 (4.4–5.5) | | 0.9 |
| CPB time, minutes | 102 (97–104) | 91 (77–100) | 98 (87–110) | | 0.1 |
| ACC time, minutes | 83 (77–86) | 74 (63–82) | 81 (66–92) | | 0.2 |
| CABG × 4 | 2 (20) | 4 (40) | 4 (40) | 10 | |
| Operative time, hours | 5.8 (5.1–6.4) | 6.3 (6.1–6.5) | 5.2 (4.5–5.6) | | 0.4 |
| CPB time, minutes | 119 (96–142) | 147 (109–179) | 107 (103–114) | | 0.3 |
| ACC time, minutes | 101 (80–122) | 120 (93–149) | 90 (84–95) | | 0.3 |
| CABG × 5 | 0 | 2 (50) | 2 (50) | 4 | |
| Operative time, hours | | 6.3 (6.1–6.5) | 5.4 (5.4–5.5) | | 0.05 |
| CPB time, minutes | | 143 (129–157) | 144 (142–145) | | 1 |
| ACC time, minutes | | 103 (95–111) | 122 (119–125) | | 0.2 |
| AVR | 0 | 9 (90) | 1 (10) | 10 | |
| Operative time, hours | | 3.9 (3.5–4) | 4.3 | | 0.5 |
| CPB time, minutes | | 103 (100–118) | 129 | | 0.3 |
| ACC time, minutes | | 89 (84–96) | 100 | | 0.3 |
| AVR/CABG | 3 (42.9) | 2 (28.6) | 2 (28.6) | 7 | |
| Operative time, hours | 5.9 (3.1–6.4) | 4.7 (3.6–5.8) | 5.8 (4.7–6.8) | | 0.8 |
| CPB time, minutes | 151 (113–154) | 119 (116–122) | 137 (103–171) | | 0.7 |
| ACC time, minutes | 133 (98–133) | 100 (96–103) | 117 (88–145) | | 0.6 |
| MVR/CABG × 3 | 1 (100) | 0 | 0 | 1 | |
| Total cases | 17 (17) | 50 (50) | 33 (33) | 100 | |

Values are n (%) or median (IQR).

ACC = aortic cross-clamp; AVR = aortic valve replacement; CABG = coronary artery bypass graft; CPB = cardiopulmonary bypass; IQR = interquartile range; MVR = mitral valve replacement; PGY = postgraduate year.

most common reasons for readmissions related to the operation were chest pain (n = 11), pleural effusion that required drainage (n = 8), pneumonia (n = 4), and unstable angina that required percutaneous coronary intervention (n = 3). No statistically significant differences were found in the reasons for readmission between group A and group R.

## Comment

The results of this study suggest that midterm outcomes of cardiac operations are not worsened when performed skin-to-skin by resident trainees versus attending surgeons, despite marked increases in operative, CPB, and ACC times. During a median follow-up period of 28

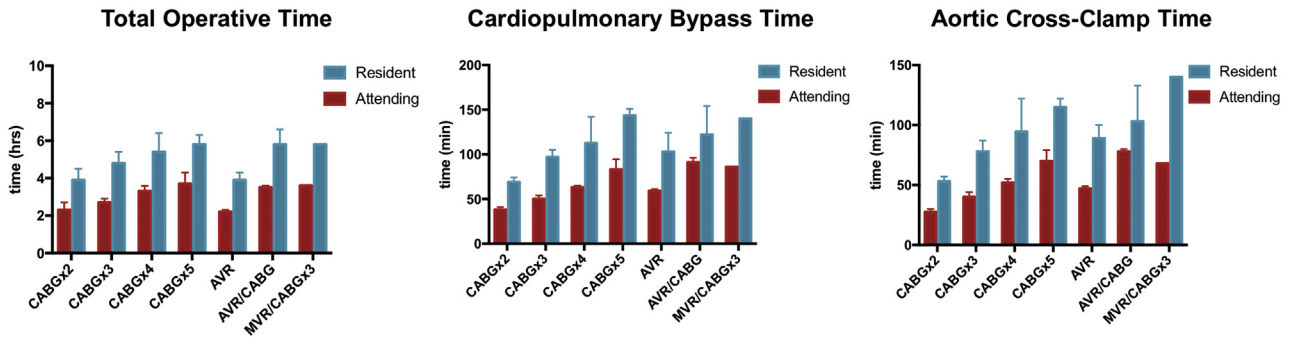


*Fig 1. Comparison of cardiopulmonary bypass time and aortic cross-clamp time between resident and attending groups. (AVR = aortic valve replacement; CABG = coronary artery bypass graft; MVR = mitral valve replacement.)*

*Table 4. Midterm Outcomes for Operations Performed Skin-to-Skin by the Attending Surgeon or the Resident Surgeons*

| Variable | Attending Surgeon (n = 100) | Resident Surgeons (n = 100) | *p* Value |
|---|---|---|---|
| Death | 4 (4) | 3 (3) | 0.7 |
| Readmission | | | |
| Related to the operation | 11 (11) | 16 (16) | 0.3 |
| Chest pain | 3 (3) | 7 (7) | 0.2 |
| Heart failure | 4 (4) | 3 (3) | 0.7 |
| Pleural effusion that required drainage | 5 (5) | 3 (3) | 0.5 |
| Wound infection | 2 (2) | 1 (1) | 0.56 |
| Hospital-acquired pneumonia | 1 (1) | 3 (3) | 0.31 |
| Unstable angina that required PCI | 0 | 3 (3) | 0.08 |

Values are n (%).

PCI = percutaneous coronary intervention.



months, no statistically significant differences were found in mortality or readmissions for causes related to the operation, most commonly chest pain, pleural effusion that required drainage, pneumonia, and unstable angina that required percutaneous coronary intervention.

Learning how to perform complex tasks is accomplished by first mastering the requisite smaller components, then combining those skills into the entire procedure [5]. Athletes, musicians, and pilots must acquire a multitude of skills early in their training before performing in the game, concert, or flight. After the individual skills have been repetitively practiced and mastered, the aforementioned groups must engage in scrimmage, dress rehearsal, and simulation in which the learned skills can be assimilated into a timed, synchronous, and harmonious performance. The education of present and future surgeons is no different, and, although methods vary among educators, hospitals, and countries, the product must be a technically skilled, practice-ready surgeon who has repetitively practiced and mastered all aspects of a full operation with individual autonomy.

Although the technical skill of the operating surgeon is a major factor in the outcome and durability of a cardiac operation, the exact timepoint of an outcomes difference based on the technical quality of the operation is not known [8, 9]. Purely technical errors that will present early in the postoperative period include cardiac tamponade due to poor hemostasis, ischemia due to coronary graft occlusion, and pump failure due to paravalvular leak [10]. Other errors, however, may take more time to manifest, such as excessive sternal retraction that leads to sternal complications, minor imperfections in a coronary anastomosis that lead to delayed graft dysfunction, and inadequate myocardial protection that leads to myocardial infarction or heart failure.

The experience of performing entire operations skin-to-skin is crucial to the development of competent and practice-ready surgeons in any specialty. For many cardiac surgery trainees, however, this critical benchmark is now more sparingly offered in the current climate of heavily scrutinized and financially tied public outcomes reporting. In particular, readmissions after index surgeries are costly to both patients and institutions, the fear of which may drive increasing degrees of attending/resident overlap, even from the left side of the table [11]. At present, our data reveal no major differences in readmissions of any cause among residents as true skin-to-skin operating surgeons. These findings are especially important because coronary artery bypass grafting is advocated as the treatment of choice for multivessel coronary artery disease because of its better long-term outcomes compared with percutaneous approaches [7]. We believe that it is exceedingly important to make sure that these outcomes can also be secured if the operations are performed by trainees rather than by the attending surgeons. Our data remain consistent with the idea that resident autonomy can be safely cultivated in cardiothoracic training programs and further corroborate this philosophy beyond the 30-day outcomes mark in case-matched patient cohorts undergoing unambiguously defined skin-to-skin operations by residents and attending surgeons, respectively. Programs and educators should strive to provide this experience for their trainees.

As discussed in our original article, there are several limitations to our study [6]. Our effort to provide residents with superb training is supported by the institution, with nursing and ancillary staff willing and expected to work late into the day and to accept the inefficiencies associated with our training philosophy. In all resident cases, the attending surgeon was present for the critical parts of the operation, as recommended by the Commonwealth of Massachusetts Department of Health and mandated by our institutional policy. This is a challenge to resident autonomy and practice readiness, because, despite best efforts, attending presence inevitably augments the procedure.

As stated, patients in the resident group were similar to those in the attending group. That said, there were some differences and the sicker patients were done by the attending. Although this represents clear selection bias, it is not necessarily deleterious. Knowing how to select patients who are appropriate for resident education and who can tolerate longer operative times with appropriate

myocardial protection is critical to educating residents using our methods. This is solely the job of Dr Tolis and his methods for determining an appropriate teaching case are discussed elsewhere [12].

Finally, although we are delighted that these midterm outcomes reinforce the safety of our methods, we know that the true durability of these operations has likely not been fully tested with 28-month follow-up data. We look forward to further studying the method with longer term data and larger numbers to contribute more robust conclusions. Our data set currently includes more than 400 patients, and we are actively working on new analyses to further solidify the safety and efficacy of teaching cardiac surgery skin-to-skin.

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## INVITED COMMENTARY



In every cardiothoracic surgery trainee's career, there comes a day when he or she is "promoted" to the right side of the table. For trainees, this promotion is followed by a series of "firsts": the first sternotomy, the first aortic cannulation, the first distal anastomosis. For the attending on the left side of the table, these moments represent opportunities for education balanced with the great responsibility of entrusting key portions of an incredibly complex operation to amateur hands. As the trainee masters his or her series of "firsts," the question inevitably becomes: when to turn over an entire case? And when you do, how will patients be affected?

Bloom and colleagues[1] are to be commended for a well-written article in this issue of *The Annals of Thoracic Surgery* that attempts to address these questions in a rigorous and scientific way, offering an important perspective on a relevant topic in cardiothoracic surgical training. Building on their earlier work,[2] the authors have demonstrated that cardiac surgery procedures can be performed entirely ("skin-to-skin") by residents without sacrificing outcome quality, not only immediately postoperatively but also over a midterm follow-up period. As such, this article has established that graduated responsibility and resident autonomy do not adversely affect patient safety.

It has been demonstrated elsewhere that the current public reporting climate presents a new challenge for cardiothoracic surgery trainees and attendings alike, because intense scrutiny over surgeon-specific outcomes may affect the degree of resident autonomy allowed.[3] In this climate, selection of "appropriate" teaching cases will become increasingly more important, as the authors have demonstrated here. Although high-risk patients may not be suitable for resident education, particularly in earlier stages of training, more straightforward, elective cases offer invaluable opportunities for resident training with attending supervision and instruction.

With the advent of new, integrated pathways for cardiothoracic surgery training, the questions addressed here will become more and more relevant, particularly as residents and attendings work in tandem at earlier stages of postgraduate training. Of paramount importance is the development of a system that results in technically outstanding, autonomous surgeons without



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