Experience, exposure, and attitudes regarding off-pump coronary artery bypass grafting techniques in US cardiothoracic surgical residents: Results of a survey

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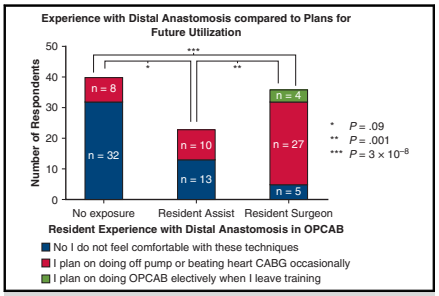
ABSTRACT

Background: We sought to determine the current level of exposure to and interest in off-pump coronary artery bypass and beating heart surgery techniques regarding cardiothoracic surgical residents in the United States.

Methods: An email survey consisting of 6 questions was sent to all cardiothoracic surgery residents of approved cardiothoracic training programs in the United States. The survey was emailed using the Qualtrics XM cloud-based survey platform. When the email responses were received, the answers to the survey questions were tabulated by the Qualtrics software and the resident's institution and year of graduation from their residency was noted.

Results: Of 400 surveys sent, we received 99 responses for a response rate of 25%. A total of 78% of cardiothoracic surgery residents reported that they are at programs that do off-pump coronary artery bypass or beating heart surgery infrequently, noting that these cases are done in less than 5% of the coronary artery bypass graftings to which they are exposed. A total of 51% responded that they do not feel comfortable with off-pump coronary artery bypass grafting under any circumstances. A total of 49% reported some comfort with the technique with most of these respondents noting that they would do off-pump coronary artery bypass or beating heart surgery on a selective basis if the clinical situation arose and 4% plan to do off-pump coronary artery bypass routinely. Exposure to off-pump coronary artery bypass and beating heart surgery significantly correlated with future adoption of the technique by the cardiothoracic surgery residents. Cardiothoracic surgery residents in the lowest, middle, and highest terciles of exposure to off-pump coronary artery bypass and beating heart surgery plan to use these techniques 31%, 86%, and 75%, respectively, in selective cases when they are in independent practice.

Conclusions: Over half of graduating cardiothoracic surgery residents do not feel comfortable with off-pump coronary artery bypass or beating heart surgery techniques. Exposure to these techniques in training correlates with comfort level and plans to use them in independent practice. (JTCVS Open 2022;12:192-200)



A total of 86% of CTSRs who have performed an OPCAB distal anastomosis plan to perform OPCAB as attendings.

CENTRAL MESSAGE

Over half of graduating CTSRs do not feel comfortable with OPCAB or BHS techniques. Exposure to these techniques in training correlates with comfort level and plans to use them in independent practice.

PERSPECTIVE

This is the first survey published of US cardiothoracic surgical residents regarding off-pump CABG in over 20 years. Exposure to OPCAB and BHS significantly correlated with future adoption of the technique by the CTSR. There does appear to be educational value in having an attending surgeon who performs routine OPCAB on the faculty of US training programs in cardiac surgery.

Thirteen percent of coronary artery bypass grafting (CABG) procedures in the United States were done off pump in 2016.[1] After 30 years of debate regarding off-pump CABG (OPCAB), there has been a consensus among US surgeons that the reported long-term decrease in graft patency,[2,3] the tendency toward incomplete revascularization,[4,5] and the technical challenges associated with OPCAB make the technique inferior to on-pump CABG for

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Abbreviations and Acronyms

BHS = beating heart surgery
CABG = coronary artery bypass grafting
CTSR = cardiothoracic surgical resident
OPCAB = off-pump coronary artery bypass grafting
TSDA = Thoracic Surgery Director Association

routine cases.[6] However, the avoidance of an aortic cross-clamp in patients with calcified and atheromatous aortas[7] and the avoidance of cardiopulmonary bypass in elderly patients,[8] patients with carotid disease,[9,10] or patients with elevated creatinine[11] have shown to be of benefit. OPCAB also requires an experienced surgeon who is past the learning curve regarding exposure of target vessels and the use of stabilizers and other adjuncts to provide hemodynamic stability and allow for a technically perfect anastomosis.

In the 1990s and early 2000s, the popularity of OPCAB was at its height, and a survey published by Ricci and associates[12] reported that 98% of cardiothoracic surgical residents (CTSRs) in the United States were interested in performing CABGs off pump. Because of the popularity of the technique at that time, many surgeons trained and performed OPCAB frequently and became proficient in the technique. As these surgeons retire, we wondered whether OPCAB and the techniques associated with it were becoming a "lost art." We designed a survey that we sent to all CTSRs in accredited US programs to assess the level of resident exposure to OPCAB, whether they were being trained in the technique and what they expected their future use of OPCAB would be when they finished training.

MATERIALS AND METHODS

We sent an email survey to 400 CTSRs in accredited US training programs as identified by the Thoracic Surgery Director Association (TSDA) roster. Our Institutional Review Board (IRB) reviewed the study (IRB #52000305, reviewed 8/19/2020) and it was exempt from IRB approval as outlined in federal regulations for protection of human services. The respondents were identified only by their email addresses; however, the institution and level of training for each respondent were used as data points for our study. The survey is listed in Table 1 and was sent out in February of 2021, and included recent graduates who finished training in June of 2020. I-6 and residents in 4/3 programs who were in the third year of training or above were also sent the survey.

The survey was emailed using the Qualtrics XM cloud-based survey platform. Thoracic track residents were not identified as such on the TSDA roster and therefore were not excluded. The survey consisted of 6 questions regarding the experience and exposure the CTSR had to OPCAB and beating heart surgery (BHS) during their training. When the email responses were received, the answers to the survey questions were tabulated by the Qualtrics software and the resident's institution and year of graduation from their residency was noted. In March of 2021, we sent out the survey out again to nonresponders with corrected email addresses for as many CTSRs as we could determine. Several program coordinators were emailed to get correct addresses if no resident from a particular training program responded.

The Qualtrics XM software allowed us to tabulate and graph the responses to questions 1 to 6. The "R Studio" software package[13] allowed us to analyze the CTSR responses regarding their exposure and experience with OPCAB and BHS and how that correlated with their expected future use and adoption of these techniques. "R package ggplot2" software[14] was used to generate stacked bar plots that correlated the reported exposure of the CTSR to OPCAB with the future use of these techniques. Chi-square analysis was used when comparing 2 groups, and Fisher exact test was used when comparing 3 or more groups.

RESULTS

Of 400 surveys sent, we received 99 complete responses. A total of 51 of 75 training programs had at least 1 resident respond to our survey so that 68% of US cardiothoracic training programs were represented in the survey by at least 1 respondent. The training programs that had at least 1 resident respond to our survey are listed in Table 2.

The postgraduate level of training of the CTSR who responded is depicted in Table 3. A total of 32% and 36% of respondents, respectively, were in the last 1 or 2 years of their training and 16% had already completed their training.

A total of 78% of CTSRs reported that they are at programs that perform OPCAB or BHS infrequently, noting that these cases are done in less than 5% of the CABGs that they are exposed to. A total of 14% of CTSRs were at programs where 10% to 25% of cases were done off pump, and 9% of the respondents were exposed to greater than 25% of CABGs off pump. As depicted in Figure 1, *A*, we named these group A (low exposure to OPCAB), group B (medium exposure to OPCAB), and group C (high exposure to OPCAB).

Figure 1, *B* shows that approximately half of CTSRs (48%) had no attendings at their training program who performed OPCAB or BHS routinely. A total of 29% of CTSRs reported 1 attending surgeon available to mentor them with regard to off pump cases. A total of 23% of the survey respondents had 2 or more attendings surgeons who performed OPCAB.

Question #3 asked "If you are exposed to OPCAB do you perform the distal anastomosis?" The results are shown in Figure 2, *A*. A total of 40% of CTSRs report no exposure to OPCAB and 23% have been exposed but have not performed a distal anastomosis off pump, indicating that they only assisted the cases. A total of 17% sometimes perform the distal anastomosis in an OPCAB case, and 19% usually perform the distal anastomosis or routinely act as primary surgeon.

Figure 2, *B* shows the responses to Question #4 regarding the teaching of the techniques for exposure of the target vessels off pump. Most of the CTSRs who responded (54%) were taught exposure techniques for the circumflex and posterior descending arteries off pump, and 46% were not.

Survey Question #5 asked the CTSRs about their experience with patients who had heavily calcified or

TABLE 1. Survey questions

1. What percentage of CABGs in your training were done either off pump or beating heart with pump assist? a. 0 b. <5% c. Approximately 10% d. 10%-25% e. 26%-50% f. >50%
2. How many attending surgeons, with whom you train, perform off-pump or beating heart CABG routinely? a. 0 b. 1 c. 2 d. >2
3. If you are exposed to OPCAB, are you performing the distal anastomosis? a. I am not exposed to OPCAB techniques b. I am exposed but do not perform the distal anastomosis c. Sometimes I do the distal anastomosis d. Most of the time I perform the distal anastomosis e. I stand on the surgeon's side and I am the primary surgeon on OPCABs
4. Have you been taught the techniques for exposure of various targets including the PDA and circumflex branches? a. No, I have not been taught b. I have been taught but I only assist c. I have been taught and done several cases as primary surgeon
5. Do the attending surgeons use off-pump techniques and equipment either with or without cardiopulmonary bypass (stabilizers, CO2 blowers, proximal anastomotic devices) when they encounter calcified or atheromatous aortas during a CABG when a crossclamp might be contraindicated? a. Never, I have not been exposed b. We do OPCAB or beating heart if the ascending aorta or arch is hostile c. One or more of my attendings do OPCAB routinely
6. Do you expect to do OPCAB as an attending when you leave your training program? a. No, I do not feel comfortable with these techniques b. I plan on doing off-pump or beating heart CABG occasionally, in selected cases c. I plan on doing OPCAB electively when I leave training

CABG, Coronary artery bypass grafting; *OPCAB*, off-pump coronary artery bypass grafting; *PDA*, posterior descending artery.

atheromatous ascending aortas and whether they were exposed to OPCAB or BHS using stabilizers, CO2 blowers, or proximal anastomotic devices. As shown in Figure 2, *C*, 31% of respondents have not been exposed to any alternative CABG techniques during their training that might avoid an aortic crossclamp. A total of 40% of CTSRs noted that they do use off-pump techniques when the aorta is "hostile," whereas 28% of CTSRs noted that CABG cases are routinely performed off pump at their training program.

Figure 2, *D* shows that when asked whether the CTSRs plan to perform OPCAB as attending surgeons (Question #6) when they leave training, 51% responded that they do not feel comfortable with off-pump CABG under any circumstances, 49% reported some comfort with the technique with most of these respondents noting that they would perform OPCAB or BHS on a selective basis if the clinical situation arose, and 4% plan to perform OPCAB routinely.

Figure 3, *A* compares the CTSR assigned to groups A, B, and C based on their training programs reported use of OPCAB and the respondents' answers to Question #6. A total of 31% of CTSRs in group A (low exposure to OPCAB) plan to use OPCAB in selective circumstances as attendings, whereas 86% of CTSRs in group B (medium exposure) and 87% of group C (high exposure) plan to use OPCAB and BHS in the future. As shown in Figure 3, *A*, the CTSRs in groups B and C had a significantly higher planned adoption rate of OPCAB in the future when compared with group A, which reported less OPCAB exposure. All the CTSRs who reported that they planned to do OPCAB routinely when they finished their cardiothoracic residency (4/99) were in group C, the high exposure group.

Figure 3, *B* shows how the effect of mentoring reflects the eventual adoption of OPCAB or BH techniques. When there is no surgeon on the faculty of the training program, only 23% of CTSRs plan to perform OPCAB or BHS in the future compared with 75% of residents who have at least 1 mentor for the technique. The presence of a mentor on the faculty is a significant predictor of future OPCAB use ($P < .0001$).

TABLE 2. Participating institutions

Allegheny General Hospital	Baylor University Medical Center
Brigham and Women's Hospital	Case Western Reserve University
Cleveland Clinic Foundation	Duke University
East Carolina Medical Center at ECU/Vidant Medical Center	Emory University
Icahn School of Medicine at Mount Sinai	Johns Hopkins University
Loma Linda University	Loyola University Medical Center
Massachusetts General Hospital	Mayo Clinic
Memorial Sloan Kettering Cancer Center	Montefiore Medical Center
NY Presbyterian Hospital - Columbia	Newark Beth Israel Medical Center
Ohio State University Hospital	Oregon Health and Science University
Rush University Medical Center	Stanford University
Texas Heart Institute/Baylor College of Medicine	Tufts Medical Center
University of Alabama Medical Center	University of California, Los Angeles
University of California, San Diego	University of California, San Francisco
University of Cincinnati	University of Colorado
University of Florida	University of Iowa Hospitals and Clinics
University of Michigan	University of Minnesota
University of North Carolina Memorial Hospital	University of Pennsylvania
University of Pittsburgh	University of Rochester
University of Southern California	University of Texas Health Science Center, San Antonio
University of Texas, Southwestern Medical Center	University of Utah
University of Virginia Medical Center	University of Washington
University of Wisconsin	Vanderbilt University Medical Center
Washington University School of Medicine	West Virginia University School of Medicine
Yale-New Haven Medical Center	Zucker School of Medicine at Hofstra/Northwell

TABLE 3. Participant demographics

Variable	N	(%)
Responding residents per program		
1	16	31.4
2	25	49.0
3	7	13.7
4	3	5.9
Level of training		
4 + 3 Resident	3	3.0
5 + 2 Resident	55	55.6
I-6 Resident	25	25.2
Alumnus	16	16.2
Years until graduation		
1	32	32.3
2	36	36.4
3	8	8.1
4	5	5.0
5	2	2.0
Alumnus	16	16.2

Thirty six percentage of the CTSRs in our survey reported they had performed at least 1 distal anastomosis off pump as surgeon and 23% reported exposure to OPCAB cases (assistant) without performing a distal anastomosis. Figure 4 shows that 89% of the surgeon group and 39% of the assistant group plan to use OPCAB techniques in the future compared with only 20% of CTSRs who are unexposed to OPCAB, indicating that operative experience is a significant determinant of the future adoption of the technique.

DISCUSSION

This is the first survey published of US CTSRs regarding off-pump CABG in over 20 years. We designed the survey to be a short 6 questions and optimized the survey for handheld devices so that it could be completed in less than 5 minutes. We sent out multiple emails to nonresponders and even emailed some Program Directors to try to encourage participation with the survey. We were disappointed with the 25% participation, which is lower than the 53% response rate reported among physicians with other surgical surveys.[15] Although we did have at least 1 response from 68% of the US training programs, the 25% participation rate in our survey makes it hard to draw accurate conclusions regarding the overall exposure and comfort level of current CTSRs training in the United States.

The attitudes regarding OPCAB that we report are markedly different from those Ricci and colleagues[12] reported in 1999. In their study, 98% of CTSRs had some interest or great interest in OPCAB compared with the 50% of CTSRs who stated they had no interest in performing OPCAB in our study. In 1999, the respondents reported that 93% had

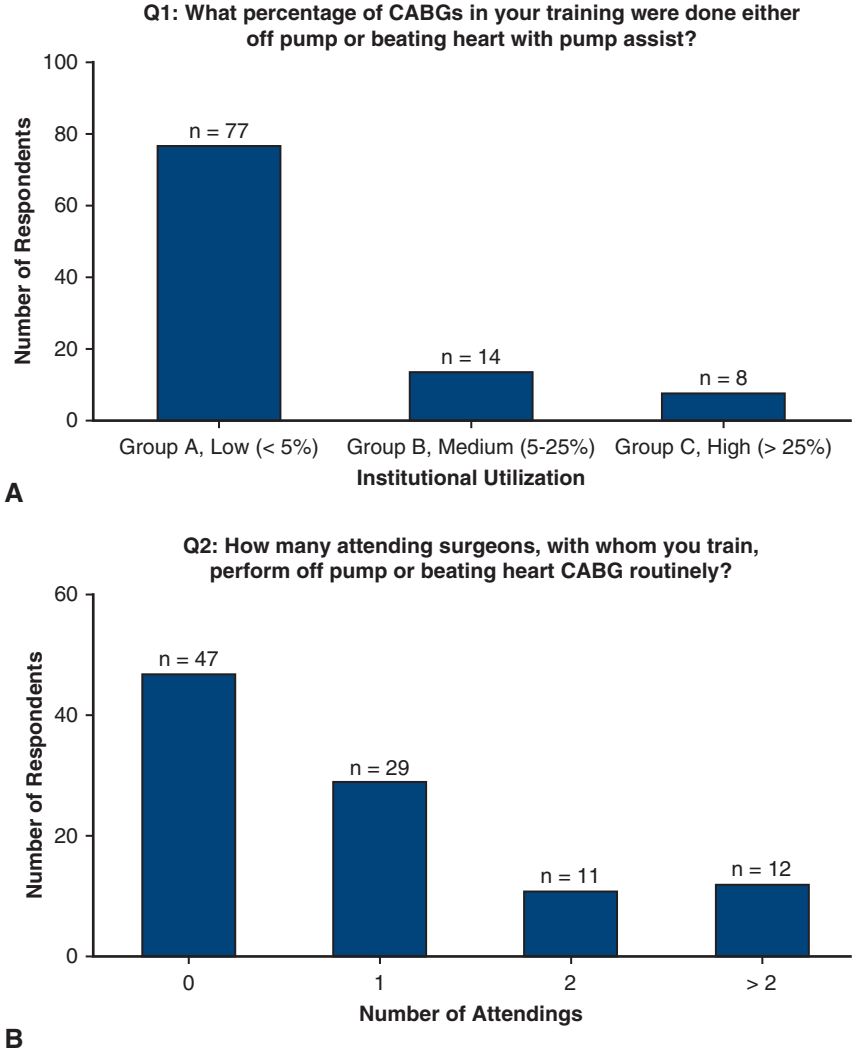

FIGURE 1. A, Group A residents were at programs that had low exposure to OPCAB (<5% of CABG off pump). Those in group B where 10% to 25% of cases were done off pump were considered medium exposure to OPCAB, and the residents who reported exposure to more than 25% of CABGs off pump were in Group C and considered to have high exposure. B, Approximately half of the CTSRs who responded have no attending surgeon who performs OPCAB routinely, and 52% have at least 1 attending who performs OPCAB. *CABG*, Coronary artery bypass grafting.

at least 1 attending surgeon interested in OPCAB,[12] whereas in 2020 only 52% reported exposure to a mentor. Twenty years ago, 88% of CTSRs expected to be performing OPCAB[12] in their practice, whereas only 44% in our survey would use OPCAB selectively and another 4% would use it routinely. We asked the residents specifically about their CABG experience with calcified and atheromatous aortas and found that most had received some training with avoiding an aortic crossclamp or using alternative anastomotic techniques, but 37% of respondents indicated that they had absolutely no off-pump or beating heart experience in their training. Surprisingly, 21% of these residents, with no exposure to BHS, answered survey Question 6 that they would use OPCAB or beating heart techniques in selective circumstances as attendings, indicating a gap in their case experience during residency.

Study Limitations

The main limitation of our study is the low response rate. We sent the survey to all the US residents who we could identify from the TSDA email list regardless of whether the resident was in the cardiac or thoracic track. Although most responses were from residents within 2 years of completing their training (84%), we did not exclude respondents in the thoracic track. We presume that noncardiac track residents and junior residents who had minimal operative experience with cardiac cases were among the 75% of CTSRs who did not participate in the survey, but we have no

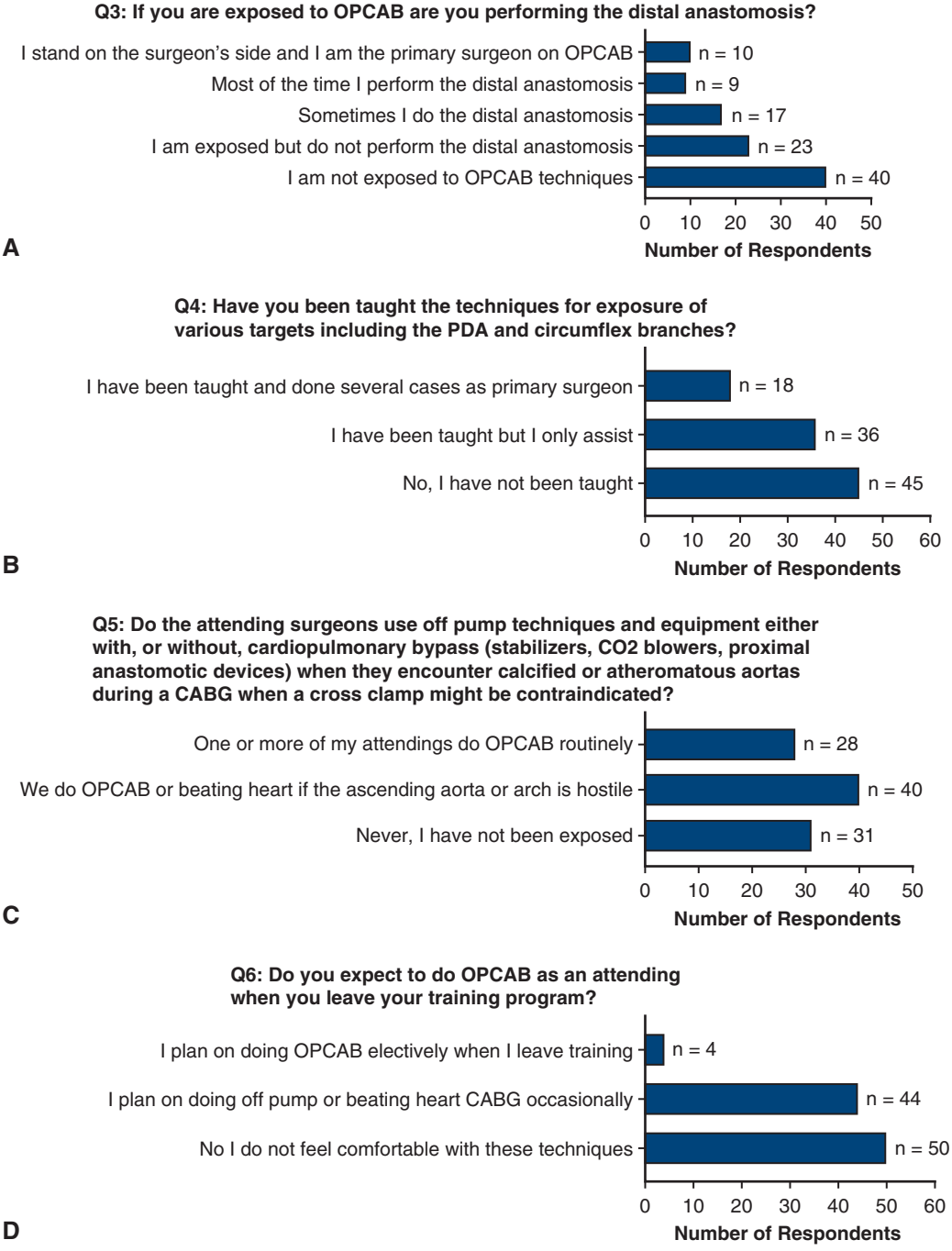

FIGURE 2. A, Question #3: 40% of CTSRs reported zero exposure in their residency to OPCAB. 23% of the respondents have assisted on OPCAB but have not performed a distal anastomosis off pump. A total of 19% of respondents perform the distal anastomosis for OPCAB routinely in their training program. B, Question #4: 18% of the respondents reported they not only had been taught the techniques for exposure of the circumflex branches and posterior descending artery, but also had acted as the surgeon in OPCAB cases. 36% of CTSRs were taught the techniques but only assisted, whereas 46% were not taught these techniques for OPCAB. C, Question #5: 31% of CTSRs reported no exposure to OPCAB at all, whereas 28% have routine exposure. 40% of respondents are exposed to OPCAB in selective situations. D, Question #6: 51% of respondents do not feel comfortable with OPCAB and do not plan to use the technique in their practice as attendings. 45% of CTSRs do plan to use OPCAB selectively in the future, whereas 4% of CTSRs plan on performing OPCAB routinely as attendings. *OPCAB*, Off-pump coronary artery bypass grafting; *PDA*, posterior descending artery; *CO2*, carbon dioxide; *CABG*, coronary artery bypass grafting.

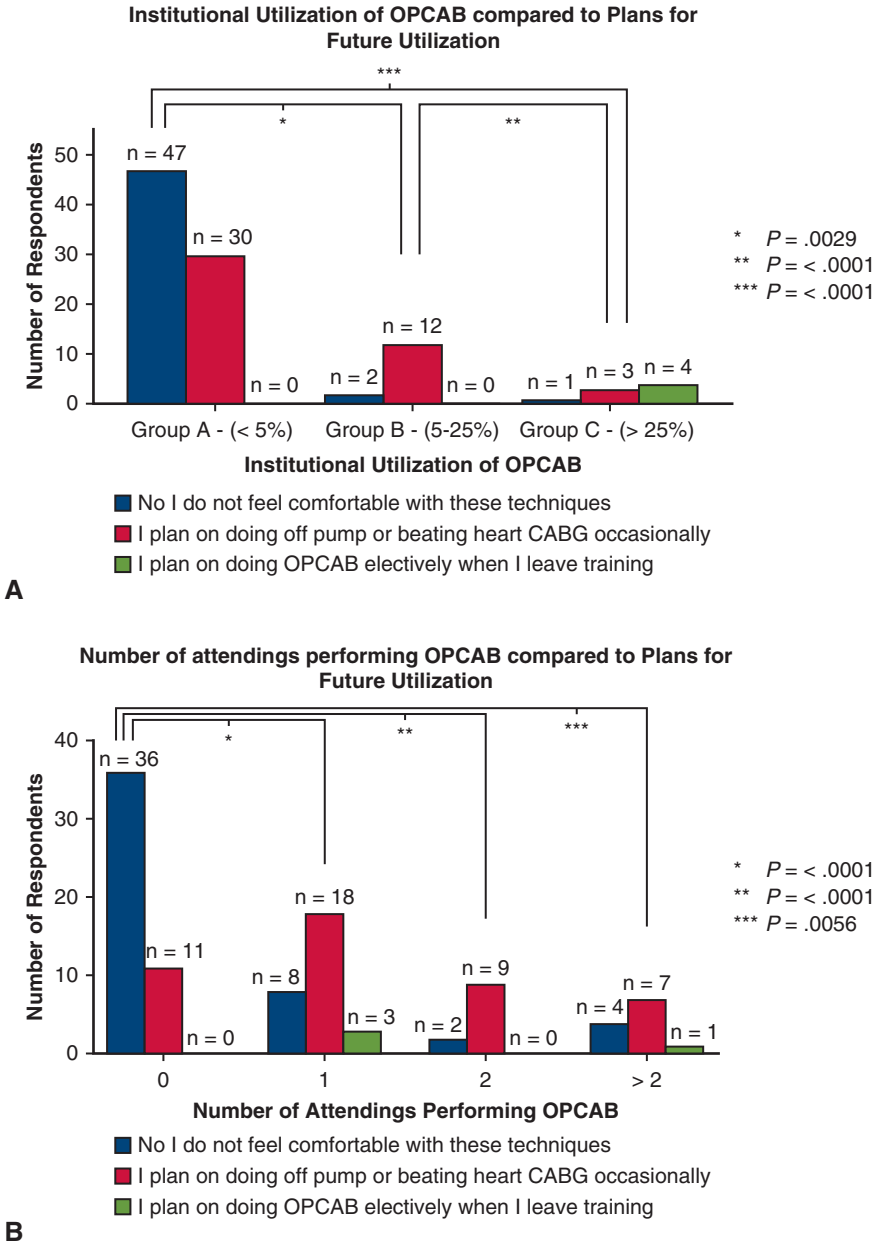

FIGURE 3. A, 39% (30/77) of CTSRs in group A plan to perform OPCAB as attendings. 86% (12/14) of the CTSRs in group B (medium exposure) plan OPCAB selectively, and 87% (7/8) of group C (high exposure) plan on doing OPCAB. 50% of group C plan routine OPCAB. B, When the training programs have at least 1 attending performing OPCAB routinely, 73% of residents plan to use OPCAB selectively in the future compared with only 23% of CTSRs without a mentor in their program. *OPCAB*, Off-pump coronary artery bypass grafting; *CABG*, coronary artery bypass grafting.

way of verifying this. A total of 15% of respondents had 3 or more years until completion of their residency (Table 3), implying that they were not likely to perform any distal anastomoses or be taught off-pump techniques. Because half of the survey questions dealt with mentoring and teaching, as well as the training programs' overall experience with off-pump surgery, we think that the small number of junior residents who answered the survey does not affect the validity of our findings.

The survey was conducted in February 2021 just as the Covid vaccinations were offered to the general population in the United States and 9 months after the nadir of cardiac surgical case volumes that occurred in April of 2020. Nguyen and associates[16] have documented a 51.2% decrease in isolated CABG cases in the United States in April 2020, but volumes increased back up to 87% of pre-pandemic levels by July of 2020. We think that this brief but dramatic decrease in case volumes had little effect on the

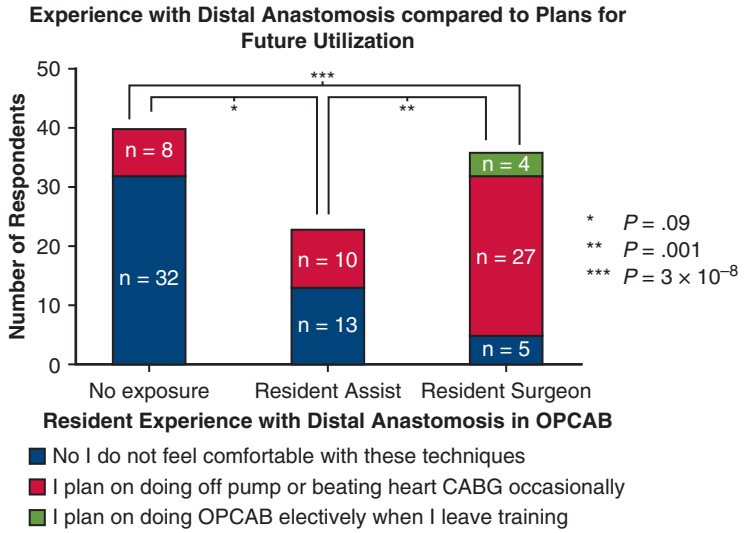

FIGURE 4. A total of 86% of residents who have acted as surgeon on an OPCAB distal anastomosis plan on performing OPCAB as attendings. This is significantly more than the 43% who have only assisted and the 20% who had no exposure. *CABG*, Coronary artery bypass grafting; *OPCAB*, off-pump coronary artery bypass grafting.

overall CABG experience and the exposure to off-pump CABG of our respondents during this time.

CONCLUSIONS

Much has been written in the previous decade regarding teaching OPCAB to residents so that they are proficient in the technique[17] and perform OPCAB safely.[18] These articles outline a gradual progression of the resident performing distal anastomosis on the left anterior descending and diagonal vessels initially. As they gain experience, residents perform the distal anastomosis to the vessels on the inferior wall and finally the circumflex branches, which are the most challenging to expose.[19] Over half the respondents in our survey report that they were exposed and taught these techniques with 19% of the residents acting as primary surgeon on these cases.

Not surprisingly, our stacked bar plot analysis did show that the CTSRs who were exposed to off-pump surgery in their residency programs were more comfortable with the technique (Figure 3, *A*). Half (4/8) of the residents from programs that reported performing more than 25% of the CABGs off pump expected to perform OPCAB routinely as attendings. Analysis of the survey data showed that CTSRs who had at least 1 attending to mentor them in OPCAB techniques and who had performed a distal anastomosis as a surgeon were significantly more likely to use OPCAB in the future as an attending compared with others (Figures 3, *B* and 4).

Our study suggests that half of the current CTSRs in the United States have minimal exposure to OPCAB or BHS and do not plan to use these techniques in their future practices. Approximately 50% of CTSRs in the United States in 2021 are being taught OPCAB techniques and have a mentor at their training program. Approximately one-third of CTSRs have performed a distal anastomosis off pump, and approximately 20% of the residents who responded to this survey have acted as primary surgeon on an OPCAB case. This would suggest that OPCAB in the United States will continue to be performed at least at the current level and that US cardiothoracic residency programs are training some graduates to perform OPCAB without the need for additional surgical revascularization fellowships. There does appear to be educational value in having an attending surgeon who performs routine OPCAB on the faculty of US training programs in cardiac surgery. Perhaps offering more exposure during their cardiothoracic residency to the 50% of CTSRs who are unexposed to OPCAB might minimize the need for additional postgraduate training for off-pump CABG.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. D'Agostino RS, Jacobs JP, Badhwar V, Fernandez FG, Phone G, Warmuth DW, et al. The Society of Thoracic Surgeons Adult Cardiac Surgery database: 2018 update on outcomes and quality. *Ann Thorac Surg*. 2018;105:15-23.
2. Hattler B, Messenger JC, Shroyer AL, Collins JF, Haugen SJ, Garcia JA, et al. Off-pump coronary artery bypass surgery is associated with worse arterial and saphenous vein graft patency and less effective revascularization: results from the VA Randomized On/Off Bypass (ROOBY) trial. *Circulation*. 2012;125:2827-35.

3. Zhang B, Zhou J, Li H, Liu Z, Chen A, Zhao Q. Comparison of graft patency between off-pump and on-pump coronary artery bypass grafting: an updated meta-analysis. *Ann Thorac Surg*. 2014;97:1335-41.
4. Magee MJ, Hebert E, Herbert MA, Prince SL, Dewey TM, Culica DV, et al. Fewer grafts performed in off pump bypass surgery: patient selection or incomplete revascularization? *Ann Thorac Surg*. 2009;87:113-8.
5. Bennedetto U, Caputo M, Patel NN, Fiorentino F, Bryan A, Angelini GD, et al. Long term survival after off- pump versus on- pump coronary artery bypass graft surgery. Does completeness of revascularization play a role? *Int J Cardiol*. 2017;246:32-6.
6. Gaudino M, Angelini GD, Antoniades C, Bakaeen F, Benedetto U, Calafiore AM, et al. Off-pump coronary artery bypass grafting: 30 years of debate. *J Am Heart Assoc*. 2018;7:1-15.
7. Mishra M, Malhotra R, Karlekar A, Mishra Y, Trehan N. Propensity case-matched analysis of off pump versus on-pump coronary artery bypass grafting in patients with atheromatous aorta. *Ann Thorac Surg*. 2006;82:608-14.
8. Khan H, Uzzaman M, Benedetto U, Butt S, Raja SG. On or off pump coronary artery bypass grafting for octogenarians: a meta- analysis of comparative studies involving 27,623. *Int J Surg*. 2017;47:42-51.
9. Halkos ME, Puskas JD, Lattouf OM, Kilgo P, Guyton RA, Thourani VH. Impact of preoperative neurologic events on outcomes after coronary artery bypass grafting. *Ann Thorac Surg*. 2008;86:504-10; discussion 510.
10. Zembala MO, Filipiak K, Ciesla D, Pacholewicz J, Hrapkowicz T, Knapik P, et al. Surgical treatment of left main disease and severe carotid stenosis: does the off-pump technique provide a better outcome. *Eur J Cardiothorac Surg*. 2013;43:541-8; discussion 548.
11. Kim HJ, Kim JB, Jung S-H, Choo SJ, Lee JW, Chloe HC. Coronary artery bypass grafting in patients with severe chronic kidney disease: a propensity score- weighted analysis on the impact of on-pump versus off-pump strategies. *Eur J Cardiothorac Surg*. 2017;52:937-44.
12. Ricci M, Karamanoukian HL, D'Ancona G, DeLaRosa J, Karamanoukian RL, Choi S, et al. Survey of resident training in beating heart operations. *Ann Thorac Surg*. 2000;70:479-82.
13. RStudioTeam (2020). RStudio: integrated development for R Studio, PBC, Boston MA. Accessed February 1, 2021. http://www.studio.com
14. Wickham H. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag; 2016.
15. Meyer VM, Benjamens S, El Moumni M, Lange JFM, Pol RA. Global overview of response rates in patient and health care professional surveys in surgery. *Ann Surg*. 2022;275:e75-81.
16. Nguyen TC, Thourani VH, Niessen AP, Shahian DM, Jacobs JP, Badhwar V, et al. The effect of Covid-19 on adult cardiac surgery in the United States in 717,103 patients. *Ann Thorac Surg*. 2022;113:738-46.
17. Murzi M, Caputo M, Aresu G, Duggan S, Angelini GD. Training residents in off-pump coronary artery bypass surgery: a 14-year experience. *J Thorac Cardiovasc Surg*. 2012;143:1247-53.
18. Smith TA, Asimakopoulos G. How safe is it to train residents to perform off-pump coronary artery bypass surgery? *Interact Cardiovasc Thorac Surg*. 2015;20:658-62.
19. Halkos ME, Puskas JD. Teaching off pump coronary artery bypass surgery. *Semin Thorac Cardiovasc Surg*. 2009;21:224-9.

Key Words: cardiopulmonary bypass, coronary artery bypass grafting, off-pump coronary artery bypass grafting, surgical education, surgical myocardial revascularization