

Process Review of a Departmental Change from Conventional Coronary Artery Bypass Grafting to Totally Arterial Coronary Artery Bypass and Its Effects on the Incidence and Severity of Postoperative Stroke

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ABSTRACT

Background: We evaluated the process of changing from conventional coronary artery bypass grafting (CABG) to totally arterial off-pump coronary artery bypass (TOPCAB) at a single heart center in Germany.

Methods: We (1) used multivariate statistical methods to assess real-time monitoring of OPCAB effects, (2) conducted a case review to assess preventable deaths and identify areas of improvement, (3) conducted a team survey, and (4) evaluated benchmarking results.

Results: All surgeons and assistants (n = 18) at this center were involved and were guided by the department head and one of the consultants, who was trained in this procedure in 2004 at the Leuven OPCAB school. The frequency of OPCAB operations increased abruptly in 2005 from 5% to 43% and then increased gradually to 67% (n = 546) by 2008 (total, 1781 OPCAB cases and 1563 on-pump cases). The in-hospital and 30-day mortality rates for OPCAB surgeries (n = 10 [0.6%] and 21 [1.2%], respectively) were lower than for on-pump surgeries (n = 27 [1.7%] and 26 [1.7%], respectively). Stroke rates were also lower for OPCAB surgeries (7 cases [0.4%] versus 15 cases [1%]). The lower risk of stroke in the OPCAB group was significant ($P < .05$) after risk adjustment. Monitoring curves and case reviews demonstrated a preventable death percentage of at least 30%. The attitude of the team was mostly positive because of the promising results (eg, fewer strokes, increasing TOPCAB popularity, and a top national rank).

Conclusions: The change from conventional CABG to TOPCAB was effective in decreasing the incidence and severity of stroke, in developing a team routine and a positive team attitude, and in producing excellent benchmarking results.

Received July 21, 2010; received in revised form September 12, 2010; accepted October 13, 2010.

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The presence of a training and communication deficiency at the beginning of the study suggested an area for further improvement. After 6 years TOPCAB had largely replaced conventional CABG.

INTRODUCTION

Use of off-pump coronary artery bypass surgery (OPCAB) offers the opportunity to reduce early mortality and the incidence of postoperative stroke [Sergeant 2004]. The use of arterial grafts is known to increase the longevity of bypass grafts compared with the use of venous grafts. Thus, our department in 2005 wanted to shift its strategy from conventional coronary artery bypass grafting (CABG) to totally arterial OPCAB (TOPCAB). The entire team was involved, and the process was guided by the department head and one of the consultants, who was trained in this procedure at the Leuven OPCAB school in 2004. The purpose of this study was to evaluate the new strategy with regard to possible application rates, the different methods of internal quality control, benchmarking data derived from national quality control, and the subjective attitudes of team members. In this report, we describe our use of a process review that allowed us to experience how the difficulties evolved and were eliminated over the various stages of converting to TOPCAB. These stages were initiation, implementation, ramp-up, and, finally, integration [Szulanski 2000].

MATERIALS AND METHODS

OPCAB Strategies

The data set includes 3344 patients with coronary artery disease who underwent either CABG procedures with extracorporeal circulation (n = 1563) or OPCAB procedures (n = 1781) at the Heart Institute Lahr/Baden between March 2005 and December 2008. OPCAB (primarily TOPCAB) became the procedure of choice for the department head and the retrained consultant, and it represented 90% of all CABG procedures during this time. At the same time, a number of the surgeons in the team were put on a schedule of a gradual learning curve (ie, expanding the

Table 1. Selection of Preoperative, Procedure-Related, and Outcome Data*

Variables	Entire Group	OPCAB Group	On-Pump Group	P
Preoperative data				
Age, y	66.8 ± 9.6	66.5 ± 9.7	67.3 ± 9.5	.013
Female sex, %	25.3	23.1	27.8	.001
Insulin-dependent diabetes, %	13.1	21.1	14.1	NS
Carotid stenosis, %	20.3	20.1	20.6	NS
History of stroke, %	10.1	10.3	10.0	NS
Dialysis, %	0.9	1.0	0.8	NS
EuroSCORE (additive)	4.5 ± 3.0	4.2 ± 2.9	5.0 ± 3.1	<.001
Ejection fraction, %	59 ± 28	59 ± 14	59 ± 38	NS
Hyperthyroidism, %	6.9	7.2	6.6	NS
Hypothyroidism, %	4.6	5.4	3.8	.02
Leukocyte count, ×10 ⁹ /L	8.0 ± 5.5	7.95 ± 6.7	7.98 ± 3.7	NS
Operative data				
Emergency cases, %	4.1	2.0	6.5	<.001
Multivessel disease, %	91.1	88.6	94.0	<.001
No. of anastomoses	3.0 ± 1.0	2.9 ± 0.97	3.1 ± 0.92	<.001
Use of bilateral IMAs, %	45.6	56.6	33.1	<.001
Operation time, min	188 ± 52	185 ± 50	191 ± 54	.001
Postoperative data				
Arrhythmias, %	33.7	31.3	36.5	.001
Psychosyndrome, %	4.0	2.9	5.3	.001
Infarct, %	1.8	1.7	1.9	NS
CKMB maximum, U/L	44 ± 72	33 ± 54	57 ± 87	NS
Dialysis, %	4.5	4.0	5.1	NS
In-hospital mortality, %	1.1	0.6	1.7	.001
30-Day mortality, %	1.4	1.2	1.7	NS
Strokes (including RINDs), %	0.7	0.4	1.0	.04
Strokes (excluding RINDs), %	0.5	0.2	1.0	.002

*Data are presented as the mean ± SD where indicated. OPCAB indicates off-pump coronary artery bypass; NS, not statistically significant; IMA, internal mammary artery; CKMB, creatine kinase isoenzyme MB; RIND, reversible ischemic neurologic defect.

surgeon-technique spectrum) [Song 2003]. Thus, the propensity toward the OPCAB approach was clearly a biased one. Finally, the strategy of the surgical team was to use bilateral internal mammary arteries (IMAs) in performing OPCAB surgery and to use composite arterial grafting (ie, TOPCAB). Patients in a critical preoperative state (as defined by the EuroSCORE) and redo CABG procedures were excluded from the study.

Surgical Technique

OPCAB was performed in a standardized fashion according to the techniques of the Leuven OPCAB school ([Albert 2006; Peck 2007], <http://www.opcab-training.eu>). The key feature of this technique is the division of the OPCAB procedure into distinct components from the surgical and

anesthesiologic procedural points of view. The routine use of a pericardial sling and an apical suction device for positioning and the use intracoronary shunts play a major role. Automated ST-segment analysis, readings of central venous and pulmonary artery pressures, and intermittent cardiac output measurements (Swan-Ganz catheter) are used for hemodynamic monitoring. We applied modifications of the Leuven TOPCAB techniques in different aspects of the procedure. These aspects included IMA harvesting (use of skeletonized IMAs), the grafting sequence (use of proximal T-graft anastomoses before the first distal anastomoses) [Albert 2008], use of a blower, and routine use of flow measurements for all CABG procedures. On the other hand, the on-pump CABG approach included the use of blood cardioplegia and a single-clamp technique.

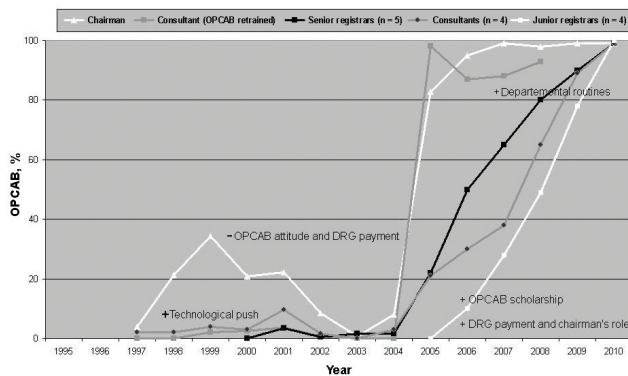


Figure 1. Departmental rates of off-pump coronary artery bypass (OPCAB) application according to professional group. The major stimulating (+) and restraining factors (-) for implementation of the new technology are shown. Data from 2009 and 2010 are included in this figure. DRG indicates diagnosis-related group.

Internal Quality Control

Data Set. For each patient included in the presented study, 49 preoperative characteristics were used from the consolidated database of our data mart system [Arnrich 2004]. The data were based on the anesthesiologic and cardiosurgical quality-assurance data and clinical chemistry laboratory data. Table 1 summarizes the data set. All variables included in the analysis had a missing-data rate of <5%. For missing values, we used the mean for continuous variables and the most frequent event for categorical variables.

Follow-up. Mortality within 30 days was assessed meticulously (data >99% complete) by means of a specific procedure that we have performed routinely since 1996. This procedure is based on questionnaires and phone calls to the patients after discharge. Patients with any neurologic dysfunction before and after surgery underwent routine evaluations by neurologists. These evaluations included brain computed tomography scans and have been described previously [Albert 2003].

Real-Time Monitoring. For real-time monitoring of in-hospital mortality, we created online variable life-adjusted displays (VLADs) based on a database updated daily, as described previously [Albert 2004]. Multiple VLAD types may thus be selected according to type of procedure, individual surgeon, or time period.

Multiple Regression Models. To adjust for confounding variables, we estimated the impact of OPCAB on in-hospital mortality by logistic regression analysis. Statistical analysis was performed with the SPSS software package (SPSS, Chicago, IL, USA). For the selection of variables, we minimized the Akaike information criterion. To further account for imbalances in the distribution of risk factors between patients who underwent OPCAB or the on-pump technique, we calculated a saturated propensity score by logistic regression, irrespective of the factors' significance levels. We then calculated the propensity score for every patient and forced it into the model.

Case Conferences. We conducted routine case conferences to evaluate all adverse events. During these meetings

we also performed chart reviews to determine the preventability of adverse events. This evaluation was carried out by identifying problems with processes of care and then judging whether these problems contributed to the poor outcome. On the basis of these results, we rated preventability retrospectively by increasing strength of preventability ("none," "slight," "modest," "strong," and "certain"). This evaluation was carried out according to a previously described method [Guru 2008], and areas of improvement were discussed.

External Quality Control

The data of the Deutsche Gesellschaft für Thorax-, Herz-, und Gefäßchirurgie (DGTHG) (<http://www.dgthg.de>) and the national quality assessment by the BQS Institute (<http://www.bqs-outcome.de>) provide comparisons of hospital-specific data and national averages with respect to case mixes, performed procedures, and risk-adjusted mortalities (all annual reports since 1995 are published on the MediClin Herzzentrum Lahr/Baden Web site (<http://www.mediclin.de/herzzentrum-lahr/desktopdefault.aspx>) at BQS/AQUA-Bundesauswertung and Jahresberichte under the Qualität tab.

Surveys of Team Attitudes

We enrolled 38 team members in the study from January to February 2008 (18 surgeons, 8 anesthesiologists, 3 physicians from the intensive care unit, and 9 scrub nurses). Data were collected via questionnaires. The collected data included current and previous attitudes regarding OPCAB benefits, technical issues, and proposals for improvement. Additional questions assessed the subjective evaluation of OPCAB results (mortality, stroke, myocardial infarction, graft occlusion, bleeding, and wound infections) and patients' and cardiologists' attitudes toward OPCAB.

RESULTS

Application Rates

The rate of OPCAB application in the department increased abruptly from 5% ($n = 41$) in 2004 to 43% ($n = 371$) in 2005 and increased progressively thereafter until 2008, when the rate was 67% ($n = 546$). The cumulative total was 1781 cases (Figure 1). The rate of use of both IMAs increased concurrently. Approximately 60% of OPCAB procedures involved the use of bilateral IMAs (TOPCAB), whereas use of bilateral IMAs occurred in only 35% of on-pump cases. Table 1 compares procedure-rated data for OPCAB and on-pump surgeries.

Internal Quality Control

Case Conference of OPCAB Patients. Of 11 OPCAB patients who died in the hospital, 6 were obviously high-risk patients (emergencies, critical preoperative state, ejection fraction <30%, age >80 years). Another 10 OPCAB patients died after discharge but within 30 days. Seven of the OPCAB patients developed a stroke, and the occurrence of stroke was delayed in all patients but one, who had undergone partial clamping of the aorta (Table 2). Residual symptoms of

Table 2. Patients Who Developed a Focal Neurologic Deficit during Their Hospital Stay*

Patient No.	Year	Clinic	Onset	Localization	Residuals	Partial Clamping	Age, y	Risk Factors
1	2005	Stroke	Delayed	Internal capsule	Slight	No	83	History of stroke
2	2005	Stroke	Delayed	Brain stem	Slight	No	73	Aortic atheromatosis (grade V, Turnik classification)
3	2006	RIND	Delayed	Unclear	No	No	73	Postoperative AF
4	2007	RIND	Delayed	Posterior cerebral artery	No	No	80	Postoperative AF
5	2007	Stroke	Delayed	Multiple infarcts	Severe	No	82	Postoperative AF, left carotid artery occlusion, right carotid artery stenosis, left vertebral artery occlusion
6	2008	RIND	Delayed	Left hemisphere	Slight	No	75	Postoperative AF
7	2008	RIND	Early	Thalamic syndrome	No	Yes	73	No

*RIND indicates reversible ischemic neurologic defect; AF, atrial fibrillation.

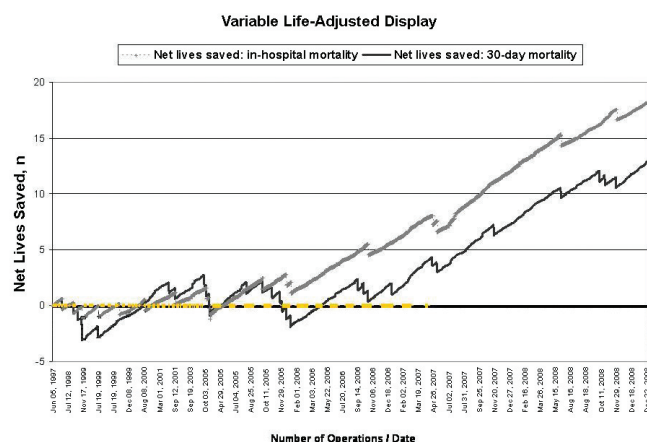


Figure 2. Multiple variable life-adjusted display (VLAD) charts, which was created automatically and updated daily by input from our database [Albert 2004]. OPCAB performance data since 1995 are illustrated. The number of operations is indicated by the thickness of the small yellow bars on the x-axis. To estimate the death rate within 30 days, we derived the items and additive weights from the simple EuroSCORE to calculate the expected mortality (EM) for our patients [Roques 1999]. For all patients the EM was in the range of 0.002 to 0.1. VLADs were created by continuous display of operative results. In the case of a successful operation, the curve goes up by the EM value for this patient; if the patient dies, the curve decreases by the value of 1 EM. If the patient was at a high risk of perioperative death, the surgeon's mortality figures are not unduly penalized, but mortality figures are penalized when a low-risk patient dies. The cumulative results for every patient display the overall performance. The expected cumulative mortality minus the actual cumulative mortality is the net lives saved.

reversible ischemic neurologic defects (RINDs) after discharge were severe in 1 patient, slight in 3 patients, and absent in 3 patients.

Online Monitoring of Surgical Performance (VLADs).

Both VLAD curves indicated positive OPCAB performance, compared with both the internal references and the EuroSCORE reference (Figure 2). Obviously, an accumulation of unfavorable events occurred in the years before the change process, as well as during 2005.

Risk-Adjusted Effect of OPCAB on Mortality. The in-hospital and 30-day mortalities were 11 patients (0.6%) and 21 patients (1.2%), respectively, for the OPCAB group. The corresponding mortalities for the on-pump group were 27 patients (1.7%) and 26 patients (1.7%). The risk-adjusted difference in in-hospital mortality and 30-day mortality for the OPCAB approach was not significant after correcting for propensity and event-related variation.

Risk-Adjusted Effect of OPCAB on Stroke. The incidence of stroke before discharge was 7 patients (0.4%) for the OPCAB group and 15 patients (1%) for the on-pump group. The 60% non-risk-adjusted difference in prevalence with the OPCAB approach was significant in the univariate analysis, but this difference lost statistical significance after correction for propensity and event-related variation (see Model 1 in Table 3: c index, 0.818; chi-square, 12.886; $P = .117$, Hosmer-Lemeshow test). When the RIND cases were excluded, the difference between the OPCAB and on-pump groups (0.2% versus 1.0%) remained significant in the multivariate analysis (see Model 2 in Table 3: c index, 0.84; chi-square, 15.559; $P = .049$, Hosmer-Lemeshow test).

External Quality Control

Application Rates of OPCAB (Annual Reports of the DGTHG). The number of OPCAB procedures performed in Germany did not change significantly from 2005 to 2008 (5264, 5199, 5036, and 5362 cases, respectively). The proportion of OPCAB cases increased only slightly during this period, from 9.7% to 10%. A few departments (18, 17, 13, and 14 departments for the years 2005 to 2008, respectively) performed >100 OPCAB procedures per year. Since 2005, our department performed the highest numbers of such procedures in Germany (2005, 371 cases; 2006, 426 cases; 2007, 438 cases; 2008, 546 cases).

Rates of Totally Arterial Revascularization. The use of bilateral IMAs for complete revascularization more than doubled, from 20% in 2005 to 47% in 2008. TOPCAB was used in 58% of the patients (some surgeons used this technique for >90% of their patients). In Germany, the percentages of CABG procedures with 2 arterial grafts were 16.8% in 2008 and 18.3% in 2007.

Table 3. Effect of Off-Pump Coronary Artery Bypass (OPCAB) on All Strokes and on Complete Strokes Only with Residuals after Discharge (Excluding Reversible Ischemic Neurologic Defects)*

Variable	Model 1: All Strokes		Model 2: Complete Strokes Only	
	Estimate	P	Estimate	P
Saturated propensity score	−3.859	.01	−4.815	.003
Noncardiac comorbidity				
Higher WBC	1.20	.007	1.124	.023
Peripheral artery disease	1.662	.001	1.730	.001
History of stroke	2.074	.001	2.088	<.001
OPCAB effect	−0.552	.257	−1.346	.040

*Multivariate regression analysis; c index values are 0.81 and 0.84 for models 1 and 2, respectively. WBC indicates white blood cell count.

Hospital Comparison of Non-Risk-Adjusted and Risk-Adjusted In-Hospital and 30-Day Mortality. Table 4 summarizes the annual outcome data for all CABG procedures (including reoperations) in our department, compared with the national averages. The department ranked second, third, fourth, or fifth (national CABG ranking by the BQS Institute) in the years 2005 to 2007 (<http://www.mediclin.de/herzzentrum-lahr/desktopdefault.aspx>; see under Qualität tab). The 2008 rankings were the worst because of the worse results for the on-pump group (the in-hospital mortality rate for elective OPCAB patients was 0%; the 30-day mortality rate was 3 of 546 patients, 0.6%).

Surveys of Staff Attitude. Eighty-five percent of the team members considered OPCAB beneficial for all patients, 73% of the team members anticipated a reduction in the incidence of postoperative stroke, and 41% anticipated a reduction in postoperative mortality. Attitudes toward the OPCAB technique differed among the different groups of hospital staff (Figure 3).

All of the physicians, however, considered the technological pull (patient demand) for this newly introduced technique to be a positive factor in stimulating the use of OPCAB (78% of anesthesiologists, 93% of surgeons, and 75% of intensivists). The majority of the surgeons and intensivists noticed the bias of the referring physicians toward OPCAB and the TOPCAB technique.

The scrub nurses complained predominantly that OPCAB is time-consuming (100%) and that there were noticeable individual differences between surgeons in performing OPCAB surgery. They argued for a more competent selection of the surgical team (67%). Anesthesiologists, surgeons, and scrub nurses believed the incidence of hemodynamic instability during the procedure to be approximately 50%, 15%, and 40%, respectively ($P = .004$). Fifty-eight percent of the anesthesiologists believed that hemodynamic instability is a major problem of this procedure; however, none of the surgeons believed this.

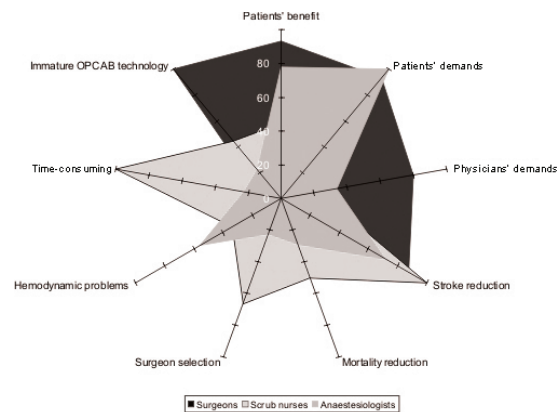


Figure 3. Survey of staff attitudes.

DISCUSSION

Approximately 6 years passed before conventional CABG was largely replaced by the new TOPCAB technique. Various factors stimulated the implementation process: (1) It was initiated by a modification in the national diagnosis-related group (DRG) payment system in 2005 that abolished any difference in reimbursement between on-pump and OPCAB procedures (see “payment system” [Banta 1993]). (2) The department head made an explicit commitment to move the department toward performing TOPCAB procedures. This decision was based on his perception of the relative advantages of the procedure and therefore of a need to have superior expertise in this technique to compete with other surgical centers (see “competition” [Poulsen 1998]). (3) The 1-year fellowship at the Leuven OPCAB school for the retrained consultant provided the required information, technical skills, enthusiasm, belief, and strong motivation to endorse TOPCAB as a set technique for all CABG patients (see “Leuven OPCAB school” [Albert 2006] and “surgical training” [Wanzel 2002]).

The retrained consultant implemented the Leuven OPCAB technique overnight in the new environment as the procedure of first choice. The consultant provided evidence that the knowledge to be transferred was robust and that the source was reputable [Szulanski 2000]. The prompt adoption of this technique by the head of the department, established that this standardized procedure is teachable. The continuous 1-year intensive training program for the retrained consultant produced a more stable process of knowledge transfer than, for example, the 3-day Leuven OPCAB courses [Albert 2006]. The intensive training provided the opportunity for deliberate practice, facilitated expert feedback [Wanzel 2002], and led to a more stable process of knowledge transfer, all of which were due to the experiences shared with the Leuven OPCAB team (see “shared experience” [Nonaka 1994]).

The role of the department head was of utmost importance, not only during the initiation and implementation stages but also during the ramping-up stage. He provided psychological support and safety, which facilitated a healthy learning environment [Edmondson 1999]. Additional factors that

Table 4. Risk-Adjusted (Logistic EuroSCORE) Comparison of Mortalities in Heart Institute Lahr/Baden versus the National Average*

Year	In-Hospital Mortality			30-Day Mortality†		
	Dead/Total, n	O/E Lahr versus National Average	Rank	Dead/Total, n	O/E Lahr versus National Average	Rank
2005	13/819	0.23 versus 0.51	3	18/819	0.31 versus 0.53	4
2006‡	8/689	0.19 versus 0.52	2	12/689	0.28 versus 0.57	3
2007	7/797	0.08 versus 0.40	2	11/795	0.12 versus 0.45	4
2008§	17/841	0.21 versus 0.41	8	22/840	0.27 versus 0.42	22

*See <http://www.bqs-outcome.de> and <http://www.mediclin.de/herzzentrum-lahr/desktopdefault.aspx> (see under Qualität tab). O indicates observed mortality; E, expected mortality (by logistic EuroSCORE).

†Follow-up rates at Heart Institute Lahr/Baden were 100% (2005), 100% (2006), 99.7% (2007), and 99.9% (2008). National average follow-up rates were 72.14% (2005), 75.21% (2006), and 72.9% (2007).

‡In 2006, all EuroSCORE variables were exported for only 689 of 806 patients because of a change in the hospital information system.

§Only 2 of the 17 in-hospital deaths and 3 of the 22 deaths occurring within 30 days were in the off-pump coronary artery bypass group. The other deaths were for conventional coronary artery bypass grafting (CABG) or redo CABG operations.

allowed an optimal climate for the positive diffusion of the newly implemented technique [Poulsen 1998; Albert 2006] were the following: the rich database; the closed recording and different measures of internal quality control, including online monitoring of surgical performance [Albert 2004; Arnrich 2004]; various debriefing activities; data transparency and the positive benchmarking results (see “debriefing activities” [March 1975]), which enhanced team attitudes toward OPCAB (see “attitude” [Dirksen 1996]); the competitive attitude of the working team; specialization (in the cardiac field); and the adequate existing collection of surgical skills. Our plan involved including all coronary patients, without exclusion, because shifting back and forth between conventional and OPCAB techniques increases the challenges to participants because of the risk of not developing habitual routines [Hackman 1990].

In contrast, the factors that restrained TOPCAB implementation were the high number of surgeons and trainees who had different OPCAB attitudes and skills and who had been performing CABG procedures routinely. Furthermore, the different interests of the various consultants and the different heart surgery specialties led to a lack of interest and a reluctance to change [Albert 2006]. Therefore, a number of the surgeons in the team were placed on a schedule that involved a gradual learning curve (ie, expanding the surgeon-technique spectrum [Song 2003]).

The procedure is now fully institutionalized. This stage of integration is characterized by a progressive development of routine, which is incipient in every recurring social pattern. With respect to the complex interaction between performance improvements and future adoption, there may be virtuous and vicious cycles at work. Early adoption of the technique and initial successes may lead to an interest in performing more cases. This positive feedback leads to a growing volume of cases, which in turn may stimulate further performance improvements. The commitment of the recipient to specific practices will become evident during the integration stage, because each time complications occur, the appropriateness of the new practice can be explicitly questioned [Szulanski 2000].

According to the present study, the most important effect of TOPCAB implementation (beside the significant increase in arterial revascularization) has been a significant reduction in the incidence and severity of stroke. In the multivariate analysis, a preference for OPCAB with respect to the occurrence of stroke and RINDs was not identifiable; however, the subgroup analysis (only strokes with residuals) suggested a significant preference. Of note is that we had a limited ability to prove some of the crucial points of debate because of a lack of statistical power, low event rates, selection bias, a short observation period, and problems with subgroup analysis. We conclude from our data that TOPCAB leads to a relevant decrease in the incidence and severity of postoperative stroke. The results in the literature regarding the neurologic benefit of the OPCAB procedure vary [Raja 2005]. In our experience, the necessary preconditions for achieving an OPCAB benefit are (1) elimination of the risk of intraoperative embolism by avoiding any manipulation of the aorta and (2) application of appropriate OPCAB techniques by a well-trained team to ensure hemodynamic stability during the entire procedure. Noteworthy is that all but one the stroke patients in our series emerged from their operations without focal neurologic deficits. This patient was one of a very few patients who had undergone partial clamping for a proximal anastomosis. This finding suggests that avoiding partial clamping during the OPCAB procedure produces better results and abolishes the iatrogenic trigger for the occurrence of a neurologic deficit [Lev-Ran 2005]. Most obviously, postoperative de novo atrial fibrillation was the cause of delayed strokes in the OPCAB patients.

An OPCAB benefit with respect to in-hospital or 30-day mortality was not evident after risk adjustment. First, the analysis was not statistically powered to identify a mortality difference for these periods of time. Second, although the risk profile of the OPCAB sample (mean $\pm$ SD, 4.1% $\pm$ 0.1%) exceeds the risk profile of the EuroSCORE data set (mean, 3.3% $\pm$ 2%), it was still less than that of the on-pump group (mean, 4.9% $\pm$ 0.1%). This selection bias has probably decreased the possibility to detect significant differences. Third, by using only 30 days instead of a longer observation

interval, we may have missed events that could have affected statistical accuracy. In our experience with CABG follow-up between 2000 and 2004, we identified an additional 30% of the events by extending the follow-up from 30 days to 3 months (1.4% versus 2.1%, unpublished data). Fourth and most importantly, the deficit in outcomes due to learning effects is included in the analysis. An accumulation of unfavorable events in 2005 was detected by the use of VLADs, which indicated preventable deaths.

In this process of drastic change, it is mandatory from the very beginning to closely follow up the possible causes of preventable death and their effects on the statistical outcome of this experience and to try to eradicate the causative factors. Preventable deaths are more likely to be identified for patients with a low operative risk (according to a heuristic understanding of risk [Guru 2008]). High-risk patients, however, are particularly susceptible to problems with the OPCAB procedure, such as periods of low output or low systemic pressure). In our study, 4 (36%) of the 11 in-hospital deaths were judged to have been preventable (“strong” or “certain”). This percentage is similar that of a previous multicenter study [Guru 2008]. In another 6 high-risk patients, we encountered a “slight” or “modest” preventability. In contrast to the preliminary OPCAB experience (before 2004), when the OPCAB technique itself was deficient [Albert 2004; Hassanein 2005], we have now identified other areas for improvement, including intraoperative communication problems, quality assurance, and retraining. One in-hospital death was “certainly” preventable. In this operation, the OPCAB procedure was converted to an on-pump procedure too late in the procedure, and a prolonged situation of low cardiac output caused multiorgan failure. In this case, 2 problems were identified as areas for improvement—insufficient OPCAB retraining (hence indicating conversion) and inadequate communication between the surgeons and anesthesiologists (hence delaying conversion). Such communication problems were also involved in 2 other “slightly” or “modestly” preventable deaths. The surgeon and the anesthesiologist have different points of view with respect to patient management. The anesthesiologist (“accommodator”) maintains the patient’s hemodynamics under operative conditions, which requires immediate and flexible reactions to encountered acute problems. The surgeon, on the other hand, performs an operation with a specific technical procedure in mind, much as engineers use patterns or blueprints [Baker 1985]. Human cognitive tunnels could be the reason for the differences in the views of surgeons and anesthesiologists toward an operation; such cognitive tunnels are probably important human behavioral risk factors [de Leval 2000].

The views of the different professional groups involved could be seen vividly in our attitude survey. The surgeons focused on the minute technical details (intracoronary shunt placement) and ignored the time factor and hemodynamic instability. The anesthesiologists, however, tended to be alarmed by a patient’s instability and the nurses’ lack of interest and continuous criticism. A trial to minimize the communication problem would be to set a fixed team. Such a program would facilitate the building of mutual trust among members and would accelerate the creation of an implicit

common perspective by the members because of shared tacit knowledge [Nonaka 1994; Edmondson 2003]. Some of the anesthesiologists and the majority of the scrub nurses emphasized the need for surgeon selection for OPCAB. Indeed, surgeon retraining in OPCAB procedures was identified as an improvement area in the preventable death.

CONCLUSION

The different methods of assessing this process of change varied during the different stages of the changeover to OPCAB, and they were either active or passive. These methods were also the initiating and motivating factors that permitted the existence and continuation of this live process. This change involving the application of routines and standardization, which an entire department experienced over a period of time, facilitated optimization and the perfection of performance. Could this technique be the method to achieve the goal of the zero strokes in bypass surgery? We are convinced that if there is any way to avoid stroke totally during the surgical approach to myocardial revascularization, this method would probably be the way.

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