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Five-Year Survival of Patients Treated with Minimally Invasive Direct Coronary Artery Bypass (MIDCAB) Compared with the General Swiss Population

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Abstract

Background To evaluate the midterm follow-up and 5-year survival outcome of the minimally invasive direct coronary artery bypass (MIDCAB) procedure compared with the survival of the general Swiss population.

Methods Retrospective study on preoperative data, intraoperative data, and postoperative outcome of patients who underwent MIDCAB surgery between June 2010 and February 2019. To assess validity of this surgical therapy, outcomes were compared with survival data of a gender- and age-matched cohort of the general Swiss population taken from the database of the Swiss Federal Statistical Office.

Results A total of 88 patients were included. Median (interquartile range [IQR[) age was 66 (56–75) years, and 27% ($n = 24$) were female. The median (IQR) length of the in-hospital stay was 7 (6–8) days. No postoperative stroke occurred. The 30-day mortality was 1.1% ($n = 1$). Reintervention for failed left internal mammary artery was needed in 1.1% ($n = 1$). The median (IQR) ejection fraction was 58% (47–60) preoperatively and remained stable during follow-up. The median (IQR) follow-up period was 3 (1.1–5.2) years. Five years postoperatively, 83% (confidence interval, 69–91) of the patients were alive, showing an overlap with the range of survival of the matched subcohort of the general Swiss population (range, 84–100%).

Conclusion Though suffering from coronary heart disease, patients after MIDCAB show almost equal survival rates as an equivalent subcohort corresponding to the general Swiss population matched on age and gender. Thus, our data show this treatment to be safe and beneficial.

Keywords
- ► minimally invasive direct coronary artery bypass
- ► left internal mammary artery
- ► left anterior descending artery
- ► cardiac surgery
- ► off-pump
- ► coronary heart disease

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Introduction

Surgical treatment of patients with coronary artery disease is considered highly efficient, but also notably invasive.[1,2] This is especially due to the sternal access, which is the standard approach for coronary artery bypass grafting (CABG), as well as side effects of extracorporeal circulation, aortic cannulation, cross- and side-clamping of the aorta, and usage of cardioplegic solutions. Cardiac surgeons have undertaken extensive efforts to reduce any harms that might result from conventional CABG surgery and, thus, have developed less invasive surgical techniques. Minimally invasive direct coronary artery bypass (MIDCAB) surgery is being applied since the 1990s[3] and combines these methods and allows for the least invasive surgical revascularization approach: the left internal mammary artery (LIMA) is grafted to the left anterior descending artery (LAD) via a small left anterior thoracotomy on the beating heart.

MIDCAB was reported to compare favorably with conventional surgery and stenting in patients with respect to survival, major adverse events, strokes, angina, and quality of life.[4,5] In comparison to conventional CABG, MIDCAB reduced costs due to shorter intensive care unit stay.[6] Compared with off-pump coronary artery bypass (OPCAB) grafting with median sternotomy, MIDCAB was reported to be safer and more effective. However, treatment groups showed slightly different characteristics, so comparability is limited.[7]

In general, MIDCAB is not only appropriate for patients suffering from isolated coronary artery disease of the anterior wall. Our research group identified three potential scenarios for treating patients via MIDCAB technique: (1) significant single-vessel disease of the LAD (eventually the diagonal branch) with potentially further but insignificant impairment of the circumflex or right coronary artery; (2) hybrid revascularization with surgically grafting the LIMA to the LAD and subsequent interventional treatment of coronaries other than the LAD; and (3) accepting incomplete revascularization in the case of severe frailty of patients.

This single-center study presents data of all patients who underwent MIDCAB procedure between June 2010 and February 2019 in our institution, affected by scenario 1 (significant single-vessel disease). In all cases, the Heart Team recommended a surgical technique due to an inappropriate interventional approach based, for example, upon prior in-stent restenosis, total LAD occlusion, or complex anatomical preconditions. The aim of this study was to evaluate the results and outcome of this operation technique in our setting and to compare survival in our study cohort with survival of the general Swiss population matched on age and gender.[8]

Materials and Methods

Patient Enrollment

All patients who were categorized by scenario 1 (significant single-vessel disease of the LAD) and who had a MIDCAB operation in our institution between June 2010 and February 2019 were included. We attained these patients from our prospectively upheld internal clinical quality database (Dendrite, Version 1.7, Build 1710, Dendrite Clinical Systems, Reading, UK), which uses the surgical planning tool as reference and is regularly checked for data completeness and consistency according to a data validation scheme. Preoperative, intraoperative, and early postoperative data were also taken from this system. Follow-up data were acquired from thorough data exchange and interrogation of individual family doctors and caring cardiologists. The study was approved by the Local Ethical Committee of Northwestern and Central Switzerland (BASEC, approval number 2020–01161).

Operation Technique

The MIDCAB procedure was described in detail previously.[3,4] In brief, in our institution the operation was performed under general anesthesia and patients were monitored hemodynamically, and a limb-lead electrocardiogram in conjunction with one precordial lead (V6) was recorded. Single-lung ventilation was achieved by either a double-lumen tube or a bronchus blocker. Patients were positioned supine with a small cushion underneath the left chest and were draped in a sterile manner. The apex of the heart was marked on the skin by using transthoracic echocardiography. The incision was commonly placed in the submammary fold (fifth intercostal space) and the chest was opened by a short 6-cm anterolateral thoracotomy. The chest was retracted with the ThoraTrak retractor (Medtronic, Inc., Minneapolis, Minnesota, United States). The LIMA was dissected in a skeletonized technique to gain sufficient length of the graft. In three cases, the da Vinci telemanipulator (da Vinci, Intuitive Surgery, Sunnyvale, California, United States) was used for endoscopic LIMA grafting. Side branches of the artery were clipped or cauterized. Heparin was administered to achieve an activated clotting time of more than 250 seconds. The pericardium was incised, and retraction sutures were placed. A ventricular pacemaker wire was attached. The coronary arteries were subsequently identified and the level of anastomosis of the LAD was checked. The surgical field was set up with a flexible arm and a soft tissue stabilizer (Hercules Flex, Stable Soft, Terumo Cardiovascular Group, Ann Arbor, Michigan, United States) to enable a motionless situation of the artery during grafting on the beating heart. After incision, a coronary shunt (ClearView, Medtronic, Minneapolis, Minnesota, United States) was placed into the target vessel. The LIMA was grafted to the LAD with Prolene 8–0 by an end-to-side anastomosis. If necessary, the diagonal branch was additionally grafted. Subsequently, inflow was released by removing the bulldog clamp from the LIMA. The median flow (MF) via bypass graft as well as the pulsatility index (PI) was measured and documented (QuickFit TTFM Flowprobe, Medistim, Oslo, Norway). PI was defined as the difference between the peak systolic and end-diastolic flow velocity, divided by the time-averaged flow velocity.[9] We consider 25 to 30 mL/min and $PI < 5$ as acceptable results. Having adequate results, reversion of heparin by protamine followed. Meticulous hemostasis was accomplished. A chest tube was inserted, and the pericardium was approximated. Under direct visualization, the left lung was reinflated to prevent disruption of the bypass graft. Ribs and pectoral muscles were readapted. After an injection of local anesthetics, the incision was sewn with a subcutaneous and intracutaneous suture. Typically, the patient was extubated on the operating table and transferred to the intensive care unit for further surveillance.

Study Outcomes

Primary outcome was all-cause mortality during follow-up, and secondary outcomes were surgical complications. We furthermore evaluated left ventricular ejection fraction (LVEF) in percentage, Canadian Cardiovascular Society (CCS) angina score, New York Heart Association (NYHA) classification, and heart rhythm during follow-up as functional outcomes.

Statistical Analysis

The aim of this observational study was to describe the outcome of patients who underwent MIDCAB surgery. The Kaplan–Meier method was used to analyze and visualize the primary outcome mortality, right-censoring at 5 years after surgery. We derived survival estimates of an age- and gender-matched subcohort of the general Swiss population from year 1 to year 5 from 1-year survival estimates published on the Swiss Federal Statistical Office[8] and superimposed the corresponding range on the Kaplan–Meier plot to allow for visual comparison. We refrained from constructing point estimates with confidence intervals (CIs) for the general Swiss population to avoid heuristics and assumptions with respect to the population and methods used to derive survival estimates. Functional outcomes (LVEF, NYHA, and CCS class) were assessed iteratively and analyzed in two steps, first before versus after surgery, then from first postoperative measurement onward. We used multilevel mixed-effects ordered logistic regressions to evaluate the association of years since surgery with NYHA and CCS class, respectively, and to derive odds ratios (OR) with CIs and *p*-values including time as linear covariate and patient as random effect into the model. The OR indicates the probability for patients to have an increase ($OR > 1$) or decrease ($OR < 1$) with respect to NYHA or CCS class per year. For continuous functional outcome (LVEF), mixed-effects linear regression was used to calculate average change estimates per year and *p*-values, including time as linear covariate and patient as random effect into the model. For these analyses, we clustered all assessments per time interval (6 months, 1 year, and 2, 3, and 4 years) and patient. We selected assessments that best matched this follow-up scheme to avoid overrepresentation of single patients, given the observational origin of the data. Development of LVEF during observation time was shown in boxplots for these time points applying the same selection approach. To investigate whether LVEF development during follow-up is associated with mortality, we furthermore included LVEF as time-varying covariate into the survival analysis with standard errors adjusted for clustering per patient. Continuous variables were shown as median with interquartile ranges (IQRs) and categorical variables were shown as number with percentage. All analyses were performed using Stata 16.0 (College Station, Texas, United States).

Results

Preoperative Data

A total of 88 patients (median [IQR] age, 66 [56–75] years; 27% [$n = 24$] female) underwent MIDCAB surgery between June 2010 and February 2019. Patient characteristics are shown in ►**Table 1**. The median body mass index was 26 (IQR, 24–29). Redo CABG was done in 3 (3.4%) patients. All of these patients were primarily operated between 1994 and 1996 and received a venous graft on the LAD within the initial operation. Extracardiac arteriopathy was diagnosed in 25 (28%) patients, and there were 6 (6.8%) patients that had previous cerebrovascular events. Poor mobility was seen in 5 (5.7%) patients, and 2 (2.3%) patients had a renal disease. The median LVEF was 58% (IQR, 47–60). No history of myocardial infarction (MI) was discovered in 43 (49%) patients. Before surgery, 11 patients (13%) had undergone a percutaneous coronary intervention (PCI) treatment. The median EuroSCORE II was 1.3 (IQR, 0.79–2.6%). All 88 (100%) patients had a significant one-vessel disease (LAD) diagnosed, with insignificant effect on one further vessel in 20 (23%) participants and two further vessels in 25 (28%) patients (scenario 1).

Intraoperative Data

Intraoperative characteristics are shown in ►**Table 2**. An urgent MIDCAB surgery was required in 6 (6.8%) patients due to acute MI and additional criteria such as rhythm disorders or ongoing ischemia. Median duration of the operation was 135 minutes (IQR, 120–150). Eight (9.1%) patients received inotropes at the end of surgery. A single anastomosis was grafted in 86 (97.7%) patients, whereas two distal anastomoses were grafted in 2 (2.3%) cases. The LIMA graft was skeletonized via the anterolateral incision in 85 (97%) cases, and in 3 (3.4%) cases it was skeletonized endoscopically with da Vinci telemanipulator (da Vinci, Intuitive Surgery, Sunnyvale, California, United States). The median PI measured during the operation was 2.2 (IQR, 1.7–2.8) and the MF was 30 mL/min (IQR, 21–40). Blood products had to be transfused in 8 (9.1%) patients.

Postoperative Data

The postoperative in-hospital data are shown in ►**Table 3**. A hemothorax occurred in 1 (1.1%) patient. No infection was detected (0%). The median peak creatine kinase was 508 U/L (IQR, 338–770), median peak creatine kinase myocardial band was 4.8 µg/L (IQR, 3.8–10), and median peak high-sensitivity cardiac troponin T was 63 mg/L (IQR, 39–145). Postoperative stroke did not occur (0%). Postoperative delirium occurred in 5 (5.7%) patients. The median stay on the intensive care unit was 1 day (IQR, 1–2). The median length of hospital stay was 7 days (IQR, 6–8). Sixty-three (72%) patients went into rehabilitation care, 19 (22%) patients went home, 4 (4.5%) patients went into another hospital, and 1

Table 1 Preoperative data

Baseline characteristics	Total ($N = 88$)
Age (y), median (IQR)	66 (56–75)
Female gender, ***n*** (%)	24 (27%)
Body mass index, median (IQR)	26 (24–29)
Hypertension, *n* (%)	77 (88%)
Diabetes, insulin-dependent, *n* (%)	18 (20%)
Dyslipidemia, *n* (%)	68 (77%)
Smoking, *n* (%)	
Current smoker	23 (26%)
Ex-smoker	35 (40%)
Never smoked	30 (34%)
Cardiovascular family history, *n* (%)	32 (36%)
CABG, *n* (%)	3 (3.4%)
Cerebrovascular events, *n* (%)	6 (6.8%)
Extracardiac arteriopathy, *n* (%)	25 (28%)
Poor mobility, *n* (%)	5 (5.7%)
Pulmonary disease, *n* (%)	9 (10%)
Renal disease, *n* (%)	2 (2.3%)
Last preoperative creatinine (µmol/L), median (IQR)	79 (63–96)
Creatinine clearance (mL/min), median (IQR)	86 (59–113)
Pulmonary hypertension, ***n*** (%)	6 (6.8%)
LVEF (%), median (IQR)	58 (47–60)
AP - CCS class, *n* (%)	
0	18 (20%)
I	16 (18%)
II	27 (31%)
III	20 (23%)
IV	7 (8%)
NYHA class, *n* (%)	
I	44 (50%)
II	31 (35%)
III	12 (14%)
IV	1 (1.1%)
Most recent MI, *n* (%)	
No MI	43 (49%)
6–24 h preoperative	1 (1.1%)
1–7 d preoperative	11 (13%)
8–21 d preoperative	5 (5.7%)
22–90 d preoperative	15 (17%)
> 90 d preoperative	13 (15%)
Previous PCI, ***n*** (%)	11 (13%)
EuroSCORE II, median (IQR)	1.3 [0.79 to 2.6]

Table 1 (*Continued*)

Baseline characteristics	Total ($N = 88$)
Number of diseased vessels, ***n*** (%)	
1 VD	43 (49%)
2 VD	20 (23%)
3 VD	25 (28%)

Abbreviations: AP, angina pectoris; CABG, coronary artery bypass grafting; CCS, Canadian Cardiovascular Society; IQR, interquartile range; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; VD, vessel disease.

Table 2 Intraoperative data

Surgery details	Total ($N = 88$)
Urgent surgery, *n* (%)	6 (6.8%)
Duration (min), median (IQR)	135 (120–150)
Inotropes at the beginning, *n* (%)	1 (1.1%)
Inotropic at the end of surgery, *n* (%)	8 (9.1%)
Previous cardiac surgery, *n* (%)	4 (4.5%)
Type of previous surgery, *n* (%)	
CABG	3 (3.4%)
Valve	1 (1.1%)
Number of distal anastomoses, *n* (%)	
1	86 (97.7%)
2	2 (2.3%)
Harvesting, *n* (%)	
Skeletonized	85 (97%)
Endoscopic	3 (3.4%)
PI, median (IQR)	2.2 (1.7–2.8)
PI (mL/min), median (IQR)	30 (21–40)
Blood products transfused, *n* (%)	8 (9.1%)
Number of RCCs, *n* (%)	
1	2 (2.3%)
2	3 (3.4%)
3	1 (1.1%)
Number of FFPs (4), *n* (%)	1 (1.1%)
Number of TCs (4), *n* (%)	1 (1.1%)

Abbreviations: CABG, coronary artery bypass grafting; FFP, fresh-frozen plasma; IQR, interquartile range; PI, pulsatility index; RCC, red cell concentrate; TC, thrombocyte concentrate.

(1.1%) patient died due to rhythmogenic disorder resulting in pulseless electrical activity. Autopsy revealed an open LIMA graft. Thus, the overall 30-day mortality rate was 1.1% ($n = 1$).

Table 3 Postoperative data

Postoperative data during admission	Total ($N = 88$)
Hemothorax, *n* (%)	1 (1.1%)
Infection, *n* (%)	0 (0%)
Wound-healing problems, *n* (%)	3 (3.4%)
Peak creatine kinase (U/L), median (IQR)	508 (338–770)
Peak CK-MB (μg/L), median (IQR)	4.8 (3.8–10)
Peak hs-cTnT (mg/L), median (IQR)	63 (39–145)
Stroke, *n* (%)	0 (0%)
Delirium, *n* (%)	5 (5.7%)
Peak creatinine, median (IQR)	77 (68–104)
Pleural effusion postoperative, *n* (%)	5 (5.7%)
Urinary tract infection, *n* (%)	3 (3.4%)
ICU stay (days), median (IQR)	1.0 (1.0–2.0)
Intubation time > 24 h, *n* (%)	1 (1.1%)
Length of hospital stay (d), median (IQR)	7.0 (6.0–8.0)
Destination at discharge, ***n*** (%)	
Rehabilitation	63 (72%)
Home	19 (22%)
Other hospital	4 (4.5%)
Patient died	1 (1.1%)
30-d mortality, *n* (%)	1 (1.1%)

Abbreviations: CK-MB, creatine kinase myocardial band; hs-cTnT, high-sensitivity cardiac troponin T; ICU, intensive care unit; IQR, interquartile range.

Table 4 Follow-up data

Follow-up data	Total ($N = 88$)
Years of follow-up, median (IQR)	3.5 (1.1–5.2)
Death, *n* (%)	11 (13%)
Angina pectoris, *n* (%)[a]	
CCS 0	74 (84%)
CCS I	5 (5.6%)
CCS II	4 (4.5%)
CCS III	1 (1.1%)
CCS IV	4 (4.5%)
Sepsis with unclear focus, *n* (%)	1 (1.1%)
Acute renal failure with hyperkalemia, *n* (%)	1 (1.1%)
Pleural effusion, *n* (%)	1 (1.1%)
Pericardial effusion, *n* (%)	1 (1.1%)
PCIS manifestations (Dressler syndrome), *n* (%)	1 (1.1%)
Sinus rhythm, *n* (%)	84 (95%)
Atrial fibrillation, *n* (%)	4 (4.5%)

Abbreviations: CCS, Canadian Cardiovascular Society; IQR, interquartile range; PCIS, postcardiac injury syndrome.
[a]Worst assessment per patient during follow-up.

Table 5 Survival: MIDCAB vs average general Swiss population

Years since surgery	Survival estimate % (95% CI)	Average general Swiss population (range), %
1	96 (89–99)	90–100
2	95 (87–98)	89–100
3	91 (81–96)	88–100
4	91 (81–96)	86–100
5	83 (69–91)	84–100

Abbreviation: CI, confidence interval.
Note: The table shows survival up to 5 years after MIDCAB operation and range of survival probabilities of a subcohort of the General Swiss Population matched on age and gender.

Follow-up and Acquisition of Data of General Swiss Population

Follow-up data are summarized in ►**Table 4**. Median observation time was 3.5 years (IQR, 1.1–5.2), yielding 295 patient-years overall. During follow-up, 11 patients died, which correspond to a rate of 0.04 per year (95% CI, 0.02–0.07).

As shown in ►**Table 5** and ►**Fig. 1**, survival of the study cohort 1 year after MIDCAB surgery was 96% (IQR, 89–99), which is in accordance with the range of survival estimates of the corresponding subcohort of the general Swiss population (90–100%). Even in the 5th year after surgery, survival of the MIDCAB group of 83% (95% CI, 69–91) still showed an overlap with the range of survival of the general Swiss population (84–100%).

The course of the LVEF (%) in our study cohort during the follow-up period is shown in ►**Fig. 2**. The preoperative median LVEF was 58% and stayed stable for the entire follow-up period, with an average change of −0.6 (95% CI, −1.4 to 0.3, $p = 0.20$) per year (see ►**Table 6**). The postoperative midterm LVEF (%) was preserved in patients who had been treated with the MIDCAB procedure.

LVEF during follow-up was associated with mortality. Our results showed a hazard ratio of 0.67 (95% CI, 0.55–0.82, $p < 0.001$) by 5% LVEF increase, indicating that the risk of death was on average reduced by one-third in patients having 5% higher LVEF.

After surgery, 95% of our patients were classified as CCS 0, which was a significant improvement compared with preoperative assessments ($p < 0.001$). During years of follow-up, CCS class on average remained the same with an OR for increase of 1.3 (95% CI, 0.9–1.9, $p = 0.14$). NYHA class and sinus rhythm showed similar patterns (see ►**Table 6**).

Discussion

The overall need for bypass surgery is decreasing due to latest success in PCI.[10,11] However, according to the 2018 European Society of Cardiology/European Association for Cardio-Thoracic Surgery (ESC/EACTS) guidelines on myocardial

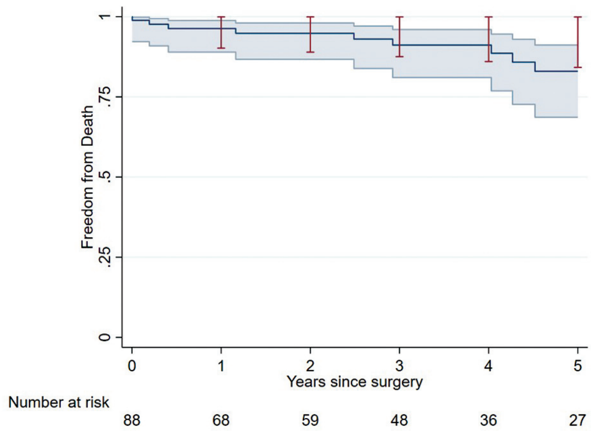

Fig. 1 Survival of patients who underwent MIDCAB surgery with general Swiss population as reference. The *blue line* depicts the Kaplan–Meier estimate and *shaded area* indicates the confidence band of survival after MIDCAB. *Red whiskers* depict the range of survival probability in a subcohort of the general Swiss population matched on age and gender to the MIDCAB cohort.

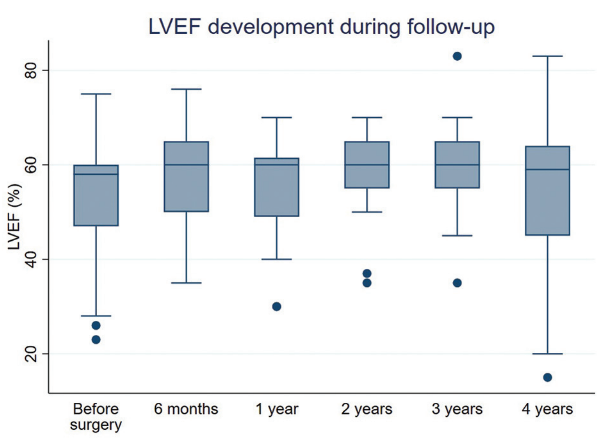

Fig. 2 Median LVEF during follow-up (boxplot). At the time of surgery, median LVEF was 58% and stayed stable for the first year after surgery.

revascularization, there are numerous indications in favor for CABG surgery over PCI.[12,13] If surgery is recommended, MIDCAB surgery is supposed to be an excellent minimal invasive alternative for conventional revascularization in certain clinical settings.[4]

The aim of this study was to evaluate the clinical outcome after MIDCAB surgery and to compare the survival rate with the general Swiss population matched on age and gender. It is of utmost interest that the Kaplan–Meier survival estimates of the study cohort were within the range of the general Swiss population up to 4 years after surgery (►**Fig. 1**); even 5 years after MIDCAB surgery, survival in the study cohort showed a remarkable overlap with the survival of the general Swiss population (83% [95% CI, 69–91] vs 84–100%).[8] Winkler et al reported on survival after conventional CABG with a minimally invasive extracorporeal circulation in a cohort of 2,130 sequential patients who underwent surgery between 2005 and 2010 with baseline characteristics comparable to the characteristics of our study group (mean EuroSCORE II of 2.4 ± 2.7 in our cohort vs 3.0 ± 5.1 in the cohort of Winkler et al).[14] They showed a mortality rate of 9.1% at 6 years, which proved to be comparable with the expected survival of the gender- and age-matched general Swiss population. However, they also reported an increased mortality after CABG within the first postoperative year. This may reflect the fact that there is a procedural risk associated with conventional CABG. In contrast, we could show in the MIDCAB population a survival overlap until 5 years with the general Swiss population and no increased mortality during the first year after surgery. Our data are in good accordance with those of Repossini et al, who reported a 5-year survival of 89.9% (95% CI, 81–92.5) with a mean age of patients of 71 ± 12.5 years.[15] Seo et al reported a survival rate of 85.3 ± 0.09% with a mean age of 69.4 ± 11.1 years. However, there were only 7/66 patients followed at 60 months.[16]

To be able to predict a more specific postoperative 30-day mortality risk, the EuroSCORE II was established. The score is divided into three risk groups: low risk with a EuroSCORE II up to 4%, middle risk from 4 to 9%, and high-risk group with >9%.[17] The EuroSCORE II in this study was in the low-risk section with 1.3% (IQR, 0.79–2.6). We were able to confirm this prediction with a 30-day mortality rate of 1.1%. Furthermore, MIDCAB follow-up studies, with low-risk EuroSCORE II, had similar 30-day mortality rates. Raja et al reported a 30-day mortality of 2%.[18] Holzhey et al reported an early postoperative mortality of 0.8% and Calafiore et al reported 0.6%, and Seo et al reported a 30-day mortality rate of 1.5%.[4,16,19]

It is still controversial whether OPCAB procedures in general reduce the risk for postoperative strokes compared with on-pump techniques. Dominici et al pointed out that patients treated off-pump do have a reduced incidence of postoperative stroke and delirium compared with on-pump heart surgeries.[20] In contrast, Reents et al reported that OPCAB does not necessarily lead to lower stroke rates, possibly due to the complexity of the operation and the various pathomechanisms that trigger postoperative stroke.[21] Since MIDCAB is an even further advanced OPCAB strategy with a totally no-touch technique to the aorta, thus avoiding even side-clamping for proximal anastomoses, we expected additional neurological benefit from this technique. Indeed, in our patient cohort there was no patient (0%) suffering from stroke or neurological complications and only 5 (5.7%) patients suffered from delirium (►**Table 4**). This again is in good accordance with the results of Seo et al, who published a stroke rate of 0%, and Repossini et al, who found a stroke rate of 0.6%.[15,16] Zhao et al also showed that the rate of stroke was significantly lower for a surgery with a no-touch technique to the aorta compared with other CABG modalities.[22]

Median LVEF was 58% at the time of surgery and remained stable during the first year after surgery (►**Fig. 2**). In the subsequent years, the LVEF (%) increased slightly up to 60% in some patients. We conclude that the postoperative midterm LVEF (%) was preserved in patients who had been treated with the MIDCAB procedure. We included LVEF as time-varying

Table 6 Cardiac function: preoperative, early postoperative, and during follow-up

	Average change through surgery			Average change per year	
	Before, *n* (%)	After, *n* (%)	p^*	OR (95% CI)	p
CCS class			<0.001	1.3 (0.9–1.9)	0.14
0	18 (20)	84 (95)			
I	16 (18)	1 (1.1)			
II	27 (31)	0			
III	20 (23)	0			
IV	7 (8)	2 (2.3)			
NYHA class			<0.001	1.1 (0.9–1.3)	0.48
I	44 (50)	68 (77)			
II	31 (35)	12 (14)			
III	12 (14)	4 (4.5)			
IV	1 (1.1)	1 (1.1)			
Sinus rhythm	84 (95)	82 (93)	0.41	2.5 (0.5–14)	0.29
	Before, mean ± SD	**After, mean ± SD**	p^*	**Coefficient (95% CI)**	p
LVEF, %	53 ± 12	55 ± 11	0.21	−0.6 (−1.4 to 0.3)	0.20

Abbreviations: CCS, Canadian Cardiovascular Society; CI, confidence interval; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; OR, odds ratio; SD, standard deviation.
$^*p$ for nonlinear trend.

covariate into the survival analysis to investigate whether LVEF development during follow-up might be associated with mortality. Our results showed that, indeed, higher LVEF was associated with lower mortality. Specifically, we found a hazard ratio of 0.67 (95% CI, 0.55–0.82, $p < 0.001$) by 5% LVEF increase, indicating that the risk of death was on average reduced by one-third per 5% increase of EF. Also, Xu et al state that patients treated with MIDCAB for coronary heart disease preserve a stable LVEF (63.75 ± 8.83 preoperatively vs 62.16 ± 9.97 postoperatively). Therefore, Xu et al advocate MIDCAB surgery for treating coronary artery disease.[7]

LIMA patency grafted to the LAD is the most important determinant for survival and angina pectoris (AP)– and event-free survival after coronary revascularization.[23] Holzhey et al reported the rate of relief from AP symptoms after 5 years was 83.3% (IQR, 79.0–87.5).[4] In our study, 84 (95%) patients did not have any AP symptoms during the follow-up (►**Table 6**). We had 1 (1.1%) patient with the need of a reintervention for an anastomotic stenosis in the LIMA–LAD graft during the follow-up. This patient needed an OPCAB grafting 1 year after the MIDCAB surgery. No interventional revision was required. This is similar or even lower compared with other studies who reported a reintervention rate for anastomotic stenosis of 1.5%[16] and 3.3%.[4]

Even though sternotomy is avoided, few wound-healing problems occurred among 3 (3.4%) patients. These three patients were treated with a secondary wound closure using a vacuum-assisted closure (VAC) therapy. A single change of the VAC was sufficient in 2 (2.3%) patients, while the third patient (1.1%) needed a total of 4 VAC changes. Two (2.3%) of these patients were suffering from insulin-dependent diabetes, the main risk factor for wound-healing problems. Lapierre et al confirmed that MIDCAB is associated with fewer wound infections (1.3%) than conventional coronary revascularization (6%), mainly due to the lack of sternotomy.[24]

Median operation time was 135 minutes (IQR, 120–150), indicating a narrow range of procedural time. Seo et al reported a range of 75 to 405 minutes, with a median length of operation duration of 167 minutes reflecting possible unexpected procedural difficulties, such as complicated mammary harvesting or arduous target artery determination.[16] Calafiore et al noted a median time of 120 minutes (±72) with a vast range.[19] We believe that in our patient population this may be due to the fact that most of the operations in this cohort have been performed by one surgeon (O. R.) leading to a vast experience in MIDCAB surgery.

During surgery, PI and MF were measured over the LIMA graft. Median PI in our cohort was 2.2 (IQR, 1.7–2.8) and median MF was 30 mL/min (IQR, 21–40), reflecting an excellent graft patency. Xu et al reported an MF of 29.25 mL/min (±18.21) and a PI of 2.51 (±1.04) for MIDCAB patients and 29.43 mL/min (±16.58) and a PI of 2.63 (±1.17) for OPCAB patients. Xu et al showed that MIDCAB, though technically more challenging, reaches the same values for PI and MF as OPCAB without the need for sternotomy and can provide superior blood flow in the bypass graft.[7]

The median length of hospital stay was 7 days (IQR, 6–8). Xu et al reported an in-hospital stay of 13.86 (±7.35) days for MIDCAB patients and 21.46 (±10.92) days for OPCAB patients, whereas Ruel et al published a median length of hospital stay of 4 days.[7,25] Though data regarding length of stay are often dependent on country-specific regulations, patients who underwent surgery without sternotomy have a shorter stay in the hospital and are able to start the rehabilitation program earlier.

In addition to the above-discussed advantages, MIDCAB procedures also can serve as an important adjunct for the treatment of multivessel disease. As recent advances in stent development have resulted in reduced restenosis rates, the combination of MIDCAB and PCI appears to be an attractive option to combine the better of two worlds: the long-term patency of LIMA to LAD grafts and the interventional approach to treat the circumflex as well as the right coronary artery. Hage et al reported similar short- and long-term outcomes when comparing hybrid coronary revascularization (HCR) with conventional off-pump bypass.[26] Tajstra et al reported the same 5-year survival rates when comparing conventional coronary bypass with HCR in terms of safety and efficacy.[27] Thus, it should be assumed that numbers of HCR procedures will increase in future to reduce the surgical trauma.

This study was a retrospective single-center study. A prospective randomized clinical trial comparing on- versus off-pump surgery with a thoracotomy or a sternotomy could weigh potential advantages and disadvantages. Given the good survival after this surgical approach, quality of life would deserve scientific attention.

In conclusion, our data underline that patients after MIDCAB show almost equal survival rates as the corresponding general Swiss population matched on age and gender. These data are in convincing accordance with the international literature. Though the technique is challenging due to the limited access and the beating heart setting, we could prove convincing results with respect to 30-day mortality, major adverse cardiac and neurological events, midterm survival rate, reduction of AP symptoms and need for reintervention. We think that MIDCAB revascularization could be the fundament for future hybrid revascularization with concomitant PCI.

Limitations

This is a retrospective, single-center study with limited numbers of patients. Though our institution is one of the largest in Switzerland doing MIDCAB operations, the number of patients remains scarce, especially patients available for the 5-year follow-up. During follow-up, yielding 295 patient-years, we encountered 11 deceased patients. Unfortunately, cause of death could not be distinguished between cardiac- and noncardiac-related death.

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

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