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Unilateral left-sided thoracoscopic ablation of atrial fibrillation concomitant to minimally invasive bypass grafting of the left anterior descending artery

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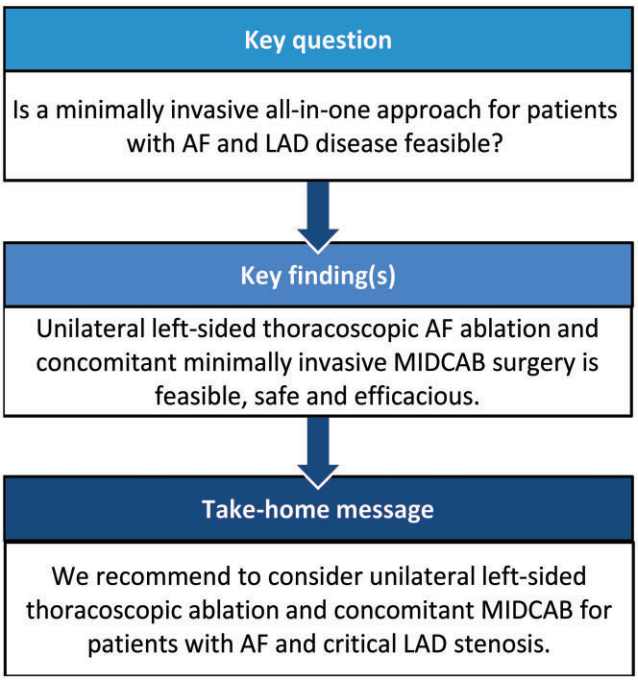

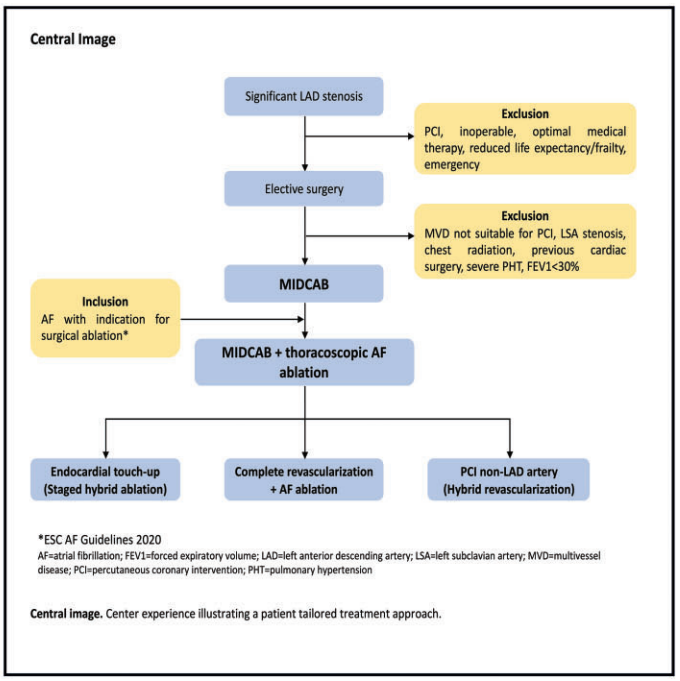

Abstract

OBJECTIVES: Thoracoscopic ablation for atrial fibrillation (AF) and minimally invasive direct coronary artery bypass (MIDCAB) with robot-assisted left internal mammary artery (LIMA) harvesting may represent a safe and effective alternative to more invasive surgical approaches via sternotomy. The aim of our study was to describe the feasibility, safety and efficacy of a unilateral left-sided thoracoscopic AF ablation and concomitant MIDCAB surgery.

METHODS: Retrospective analysis of a prospectively gathered cohort was performed of all consecutive patients with AF and at least a critical left anterior descending artery (LAD) stenosis that underwent unilateral left-sided thoracoscopic AF ablation and concomitant off-pump MIDCAB surgery in the Maastricht University Medical Centre between 2017 and 2021.

RESULTS: Twenty-three patients were included [age 69 years (standard deviation = 8), paroxysmal AF 61%, left atrial volume index 42 ml/m^2 (standard deviation = 11)]. Unilateral left-sided thoracoscopic isolation of the left (n = 23) and right (n = 22) pulmonary veins and box (n = 21) by radiofrequency ablation was succeeded by epicardial validation of exit- and entrance block (n = 22). All patients received robot-assisted LIMA harvesting and off-pump LIMA-LAD anastomosis through a left mini-thoracotomy. The perioperative complications consisted of one bleeding of the thoracotomy wound and one aborted myocardial infarction not requiring intervention. The mean duration of hospital stay was 6 days (standard deviation = 2). After discharge, cardiac hospital readmission occurred in 4 patients (AF n = 1; pleural- and pericardial effusion n = 2, myocardial infarction requiring the percutaneous intervention of the LIMA-LAD n = 1) within 1 year. After 12 months, 17/21 (81%) patients were in sinus rhythm when allowing anti-arrhythmic drugs. Finally, the left atrial ejection fraction improved postoperatively [26% (standard deviation = 11) to 38% (standard deviation = 7), P = 0.01].

CONCLUSIONS: In this initial feasibility and early safety study, unilateral left-sided thoracoscopic AF ablation and concomitant MIDCAB for LIMA-LAD grafting is a feasible, safe and efficacious for patients with AF and a critical LAD stenosis.

Keywords: Minimally invasive • Thoracoscopic ablation • Atrial fibrillation • Minimally invasive direct coronary bypass grafting

ABBREVIATIONS

AF	atrial fibrillation
LA	left atrial
LAA	LA appendage
LAD	left anterior descending artery
LAEF	Left atrial ejection fraction
LIMA	left internal mammary artery
LMWH	low molecular weight heparin
MIDCAB	minimally invasive direct coronary artery bypass graft
pAF	paroxysmal AF
persAF	persistent AF
PCI	percutaneous coronary intervention
PV	pulmonary vein
PVI	PV isolation
SR	sinus rhythm

INTRODUCTION

Over the past years, complex cardiac procedures have evolved into minimally invasive alternatives. In the treatment of atrial fibrillation (AF), minimally invasive thoracoscopic AF ablation has been recommended as a successful strategy for patients with symptomatic and drug-refractory AF to lower the burden of AF symptoms [1]. In coronary artery bypass surgery, minimally invasive direct coronary artery bypass (MIDCAB) grafting with left internal mammary artery (LIMA) harvesting for single-vessel revascularization via a small left thoracotomy is a well-established alternative to a standard sternotomy approach, resulting in a shorter hospital stay due to fast recovery [2].

While both stand-alone thoracoscopic AF ablation and MIDCAB have been shown to be safe and effective as separate procedures [3], cohort data on unilateral left-sided thoracoscopic AF ablation and concomitant MIDCAB have never been reported. Here, we describe our experience with additional unilateral left-sided thoracoscopic AF ablation during MIDCAB procedures.

METHODS

Patients and study design

In this single-centre cohort study, a retrospective analysis of a prospectively gathered cohort was performed. All consecutive patients with AF and at least a critical left anterior descending artery (LAD), and possibly also a diagonal artery stenosis and multivessel disease, which underwent a unilateral left-sided thoracoscopic AF ablation and concomitant off-pump MIDCAB surgery between September 2017 and June 2021 in the Maastricht University Medical Centre were analysed. Clinical data were collected from the electronic patient records of the hospital.

Ethics statement

This study was approved by the Institutional Review Board (IRB) and Ethics Committee (METC 2019–1430) and analysed in accordance with IRB guidelines. Informed consent was waved due to the retrospective character of the study. The study complies with the ethical principles of the Helsinki Declaration.

Surgical procedure

The absence of thrombus in the left atrial appendage (LAA) was confirmed by trans-oesophageal echocardiogram and a double lumen endotracheal tube was inserted, allowing selective right lung ventilation. The unilateral left-sided thoracoscopic ablation procedure has been described elsewhere in detail [4]. In brief, 3×5 mm trocars were introduced in the second, fourth and sixth left intercostal space in the midaxillary line. Left and right pulmonary vein (PV) isolation was performed using a biparietal bipolar radiofrequency clamp (Isolator, AtriCure Inc., Cincinnati, OH, USA) and ablation of a roof and inferior line was performed (Coolrail, AtriCure Inc.) to create the box lesion. Next, epicardial exclusion of the LAA (Atriclip Pro, AtriCure Inc.) was performed. Finally, the epicardial entrance and exit block of the PVs and the box was evaluated. Patients who were still in AF after epicardial ablation were electrically converted to sinus rhythm (SR). Hereafter, exit and entrance blocks were validated on the PVs and box by sensing and

pacing at 20 mA at least 20 beats/s above the heart rate using the Isolator Transpolar Pen (MAX 5, AtriCure Inc.). The right superior PV was only tested if adequately reachable.

Subsequently, thoracoscopic trocars were exchanged for robotic trocars and LIMA harvesting was performed using the Da Vinci Robot (Intuitive Surgical, Inc., Sunnyvale, California, United States). A soft tissue retractor (Alexis, Applied Medical) was inserted through an anterior small thoracotomy of ~5–7 cm in the 4–5th intercostal space for the exposure of the LAD and if necessary the diagonal artery. A rib spreader was mainly used to mount the minimally invasive stabilizer (Octopus Evolution, Medtronic, MN, USA) for local immobilization of the LAD and if necessary the diagonal artery. Consequently, the LIMA-LAD anastomosis was performed manually on the beating heart. To assess the patency and the quality of the graft, intraoperative transit-time flow measurement was used.

Outcomes

The primary outcome was the procedural feasibility and safety up and until 12 months of follow-up. Feasibility was assessed by the number of patients where complete isolation of both PVs and the box, confirmed by the epicardial entrance and exit block, and a successful LIMA-(D)-LAD anastomosis could be performed as planned. As described in the central image, all patients underwent MIDCAB and unilateral left-sided thoracoscopic AF ablation. In patients with unintentional incomplete AF ablation, a staged endocardial touch-up was performed (staged hybrid AF ablation). Patients in the hybrid revascularization group underwent a percutaneous coronary intervention (PCI) of a non-LAD artery after the surgical procedure, as planned. Safety was evaluated by the incidence of perioperative complications including conversion to sternotomy; bleeding requiring transfusion, drainage or reoperation; cardiac tamponade; infection requiring prolongation of hospitalization; mortality; myocardial infarction; pacemaker implantation; pericarditis requiring drainage; phrenic nerve injury; pneumothorax or pleural effusion requiring intervention (after removal of chest tubes); readmission to the intensive care unit; respiratory insufficiency requiring reintubation, stroke and cardiac rehospitalization.

The secondary outcome was the efficacy of both procedures, defined as freedom from AF and freedom from myocardial infarction and/or percutaneous interventions until 12 months of follow-up. AF recurrence was defined as an (a)symptomatic episode of any supraventricular arrhythmia ≥30 s, detected by continuous rhythm monitoring (24-h, 48-h or 7-days Holter) or a 12-lead ECG according to the ESC AF 2020 Guidelines [1], and the number of unscheduled AF reinterventions including electrical cardioversion or endocardial touch-up via catheter ablation, after a 3 months blanking period. Myocardial infarction was defined conform the definition used in the Netherlands Heart Registration [5] as an increase or decrease in cardiac biomarkers with at least one of the following: symptoms suspicious for ischaemia; new significant ST-segment, T-wave alterations or a new bundle branch block; pathological Q-waves; loss of viable myocardial tissue or new regional wall motion dysfunction based on imaging; identification of intracoronary thrombus during angiography or autopsy.

Left atrial contractility

Minimal and maximal left atrial (LA) volumes were calculated by tracing the endocardial border of the LA, with the exclusion of the LAA and the PVs, by 2D echocardiography in both the apical 2-chamber and 4-chamber views in end-systole and end-diastole. Consequently, the left atrial ejection fraction (LAEF) was calculated, blinded for preoperative AF type, using the biplane modified Simpson method.

Perioperative management

Direct oral anticoagulants were discontinued 2 days prior to surgery. After surgery, the patient received low molecular weight heparin (LMWH). On the day of discharge, LMWH was discontinued and direct oral anticoagulants were restarted. In patients using a vitamin-K antagonist, oral anticoagulants were discontinued at least 3 days before surgery until an international normalized ratio of <1.5 was reached. Postoperatively, the vitamin-K antagonist was restarted on the third postoperative day and the patient received LMWH until an adequate international normalized ratio was obtained. For all patients, preoperatively discontinued oral anticoagulants therapy was only bridged with LMWH in case of a CHA_2DS_2-VASc Score of ≥8 or with a high risk of thrombo-embolic events. After discharge, all patients were invited to the outpatient clinic after 3 and 12 months for regular check-up using a 12-lead ECG and 24-h Holter monitoring. In case of AF recurrence, patient-tailored treatment followed conform routine care. Monitoring for cardiac ischaemia due to myocardial infarction was performed by a 12-lead ECG and routine determination of cardiac enzymes after 6, 9 h and the next morning. Further control of enzymes took place after 72 h or when indicated, as part of standard care. In case of symptoms suspicious for cardiac ischaemia, further diagnostics to evaluate myocardial ischaemia by ECG and, if necessary, a coronary angiography was performed and treated conform standard care. Furthermore, all data, including late myocardial infarction and/or coronary intervention, were prospectively entered in the Netherlands Heart Registration (NHR) for prospective analyses.

Statistical analysis

Continuous variables were expressed as mean (standard deviation) if normally distributed or median and interquartile range (not-normally distributed), while categorical variables as count and relative frequencies. A paired *T*-test was used to compare continuous variables (such as LAEF) at 2 different time points for the same subject, while a Student's *T*-test was used to compare continuous variables between groups. A Kaplan–Meier survival curve was plotted to estimate the probability of being free from AF recurrences over the course of 1 year. Analyses were performed using SPSS version 25.0 (SPSS Inc., Chicago, IL, USA) and R version 4.1.2.

RESULTS

Study population

Between September 2017 and June 2021, 23 patients underwent unilateral left-sided thoracoscopic AF ablation and concomitant MIDCAB surgery. Patients were on average 69 years old (SD = 8), 22% was female, the mean body mass index was 29 kg/m^2 (SD = 4) with a median CHA_2DS_2-VASc Score of 3 [2–4] (Table 1). Furthermore, 5 patients (17%) were known with chronic

Table 1: Baseline characteristics

Clinical characteristics and risk profile	All patients ($n = 23$)
Age (years)	69 (8)
BMI (kg/m^2)	29 (4)
CHA_2DS_2-VASc score	3 [2 - 4]
COPD	4 (17%)
Diabetes mellitus (%)	4 (17%)
EuroSCORE-II	2.5 (2.0)
Female (%)	5 (22%)
Hypertension (%)	22 (96%)
Ischaemic cardiomyopathy	1 (4%)
OSAS	5 (22%)
Polycythemia vera	1 (4%)
Stroke	2 (9%)
AF	
Duration (months)	59 (78)
Previous ECV	10 (43%)
Previous endocardial PVI	2 (9%)
Type	
Paroxysmal	14 (61%)
(longstanding) persistent	9 (39%)
Coronary artery disease	
Previous myocardial infarction	5 (22%)
Previous PCI	2 (9%)
Stenting of the RCA	1 (4%)
Stenting of the RCx	1 (4%)
Single-vessel disease	19 (83%)
Multivessel disease	4 (17%)
Echocardiographic measurements	
LA diameter (mm)	39 (5)
LA volume (ml)	84 (21)
LAVI (ml/m^2)	42 (11)
LVEF (%)	57 (7)

Data are presented as mean (standard deviation), median (interquartile range) or frequencies: *n* (%).

AF: atrial fibrillation; BMI: body mass index; COPD: chronic obstructive pulmonary disease; LA: left atrial; LAVI: left atrial volume index; LVEF: left ventricular ejection fraction.

obstructive pulmonary disease and/or obstructive sleep apnoea, one (4%) had ischaemic cardiomyopathy and one (4%) was diagnosed with polycythaemia vera. The mean preoperative EuroSCORE-II was 2.5 (SD = 2.0). Moreover, 61% of all patients had paroxysmal AF (pAF) and 39% had (longstanding)-persistent (pers) AF. Two (9%) underwent previous catheter PV isolation (PVI) and 10 (43%) underwent one or more electrical cardioversions. The mean duration of AF history was 59 months (SD = 78). Furthermore, 5 patients (22%) had a previous myocardial infarction of which 2 (9%) had a previous PCI with stenting of the right coronary artery ($n = 1$) or circumflex artery ($n = 1$). More patients were known with single-vessel disease (83%) compared to multivessel disease (17%). Overall, the left ventricle ejection fraction was preserved (mean left ventricle ejection fraction = 57%, SD = 7) and the left atrial volume was severely enlarged (mean left atrial volume index = 42 ml/m^2, SD = 11; Table 1).

Primary outcome

Feasibility. All procedures were carried out by 2 experienced cardiac surgeons (B.M. and P.S.). The mean surgical procedure operation time was 224 min (SD = 38) and the duration of hospital stay was 6 days (SD = 2; Supplementary Material, Table S1). Of all patients with paroxysmal AF (pAF; $n = 14$), 12 (86%) had single-vessel disease of which 10 (71%) received isolation of the PVs and box (Fig. 1). In 9 of them (64%), epicardial mapping was performed which confirmed entrance and exit block, but in one patient (7%) a very antral PVI was performed and therefore epicardial validation of the box was impossible. Furthermore, in one patient (7%) only a left PVI could be performed due to abundant epicardial adipose tissue. For safety reasons, and considered the fact that this patient was only recently diagnosed with pAF, no bilateral approach was performed. As such, the patient was referred for an endocardial touch-up procedure as part of a staged hybrid procedure within the 3 months blanking period. Consequently, endocardial validation demonstrated transmural isolation of the left PVs, whereafter a wide antral circumferential ablation of the right PVs was performed along with successful cavotriscuspid isthmus ablation. The last patient in this group of single-vessel disease and pAF (7%) presented with a very small LA, had only recently diagnosed pAF and therefore received left and right PVI only. Of the patients with pAF and multivessel disease ($n = 2$), all received a complete isolation of the PVs and box, confirmed by epicardial mapping (100%). One patient (50%) underwent an elective PCI of the right coronary artery and one (50%) patient was referred for PCI of a (small) obtuse marginal artery in the case of symptoms during follow-up.

Of all patients with (longstanding)-pers AF ($n = 9$), 7 (78%) had single-vessel disease whom all received PVI and box isolation, thus a full AF ablation. The box could not successfully be isolated in 1 patient (11%) due to too much epicardial adipose tissue, where a staged hybrid ablation was only opted in case of symptoms. The isolation of the right superior pulmonary vein could not be evaluated in 2 patients (22%) and one of them experienced AF recurrence. A redo-catheter ablation was performed where endocardial mapping confirmed isolated left PVs but no isolation of the right PVs. Subsequently, a successful wide area circumferential ablation of the right PVs was achieved. As the voltage map still showed a low voltage area in the LA, combined with a registered atypical flutter, an anterior mitral isthmus line with bidirectional block was created. The patients with (longstanding)-persAF and multivessel disease ($n = 2$) all received PVI and box isolation and LIMA-LAD anastomosis. Considered the fact that in both patients a stenosis of a small right descending posterior was present with a dominant left system, no intervention of the right descending posterior was performed. An epicardial left ventricle lead was placed in one patient who suffered from ischaemic cardiomyopathy and this patient was referred for an elective cardiac resynchronization therapy device implantation, as the left ventricle ejection fraction did not restore. This was also the only patient who received grafting of the diagonal artery (Supplementary Material, Table S1, Fig. 1).

Safety. Perioperative complications were bleeding from the thoracotomy wound (requiring drainage, transfusion and re-thoracotomy; $n = 1$) and myocardial infarction based on increased cardiac biomarkers with new significant ST-segment elevation ($n = 1$). In the latter patient, the coronary angiography showed a patent LIMA-LAD anastomosis and no intervention was required. Within 30 days after discharge, one patient was readmitted due to recurrent AF treated with digoxin, one patient

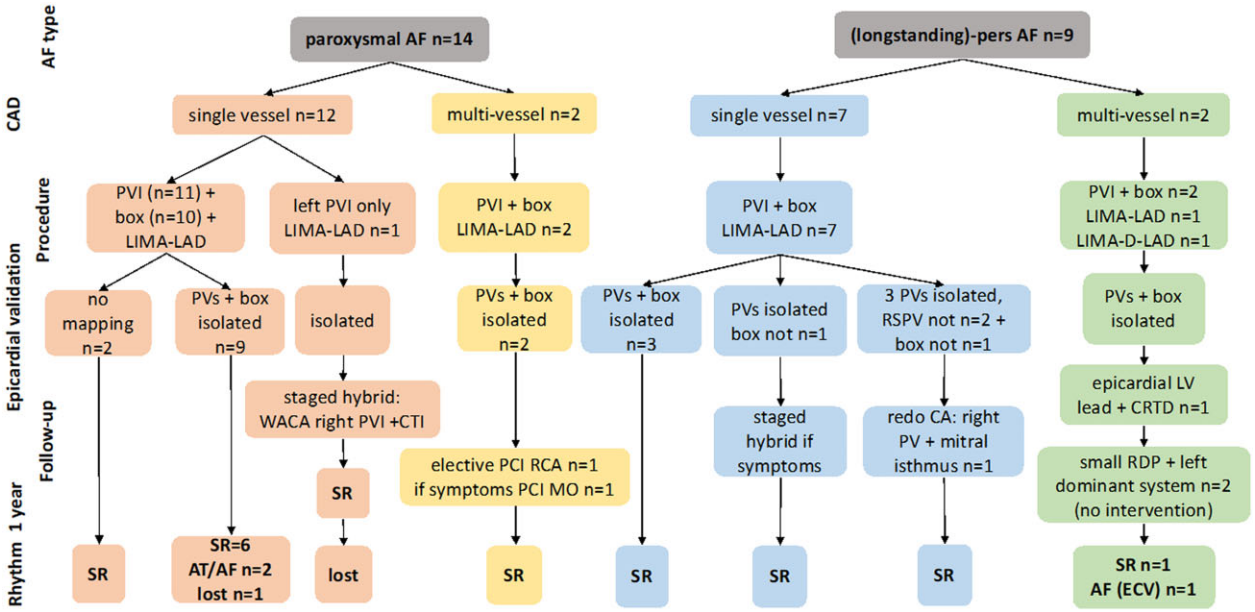

Figure 1: Flowchart representing patient individualized treatment strategies and outcomes. AF: atrial fibrillation; AFL: atrial flutter; AT: atrial tachycardia; CA: catheter ablation; CAD: coronary artery disease; CRT-D: cardiac resynchronization therapy-defibrillator; CTI: cavo-triscupid isthmus; ECV: electrical cardioversion; iCMP: ischaemic cardiomyopathy; LIMA-LAD: left internal mammary artery–left anterior descending artery; LV: left ventricle; NSTEMI: non-ST elevated myocardial infarction; PCI: percutaneous coronary intervention; PV: pulmonary vein; PVI: PV isolation; RCA: right coronary artery; RSPV: right superior pulmonary vein; SR: sinus rhythm; WACA: wide antral circumferential ablation.

with polycythaemia vera had a myocardial infarction requiring PCI of the LIMA-LAD and 2 patients with pleural- and pericardial effusion requiring drainage. There was no conversion to sternotomy, cardiac tamponade, pericarditis, respiratory insufficiency, stroke, phrenic nerve injury or mortality (Supplementary Material, Table S1 and Table 2).

Secondary outcome

Efficacy. The secondary outcome was to evaluate the efficacy of both procedures up to 12 months of follow-up. Until now, 21 (87%) patients completed 1-year follow-up, as 2 patients only reached 6 months of follow-up (Table 2). Freedom from any supraventricular tachyarrhythmia ≥30 s occurred in 17/21 patients (81%), of which 8 were off anti-arrhythmic drug (Fig. 2). For logistical reasons, their anti-arrhythmic drugs were not discontinued after the ablation, even though there were no AF-related complaints and Holter monitoring showed SR. As mentioned earlier, one patient unintentionally received an incomplete AF ablation and therefore underwent a staged hybrid procedure within 3 months. This patient was in SR after 12 months of follow-up. In total, 4 patients experienced a recurrence of a supraventricular tachyarrhythmia after the 3 months blanking period, of which 2 patients underwent a successful electrical cardioversion, one received a redo-catheter ablation and one patient preferred to receive no additional therapy due to being asymptomatic. Concerning the revascularization efficacy outcome, all patients received a full revascularization, of which one patient underwent a staged hybrid revascularization with a planned PCI of the right coronary artery. Furthermore, 2 patients experienced a myocardial infarction; one during hospitalization and one within 30 days postoperative as described earlier.

Table 2: Follow-up

12 months of follow-up	All patients ($n = 23$)
Complications after discharge	
Cardiac hospital readmission	4 (17%)
AF	1 (4%)
Myocardial infarction requiring PCI LIMA-LAD	1 (4%)
Pleural and pericardial effusion	2 (9%)
Staged hybrid ablation >30 days, <3 months	1 (4%)
Wound infection	0 (0%)
12 months follow-up reached	21 (91%)
Recurrence of AF/AT >3 months	4 (19%)
Electrical cardioversion	2 (9%)
Expectative	1 (4%)
Redo catheter ablation	1 (4%)
Mortality	0 (0%)
Stroke	0 (0%)
Rhythm outcome until 12 months	
SR allowing AADs	17 (81.3%; 95% CI: [66.3–99.7%])
SR off AADs	9 (43%)

Data are presented as frequencies: *n* (%).
AADs: anti-arrhythmic drugs; AF: atrial fibrillation; CI: confidence interval; SR: sinus rhythm.

Left atrial contractility

Of all 23 patients, 13 patients (5 persAF, 8 pAF) had a postoperative transthoracic echocardiography (TTE) in SR (median time of postoperative TT was 11 months [6–21]). Mean postoperative LAEF was 38% [7]. Of those 13 patients, 11 (3 persAF, 8 pAF) patients also had a preoperative TTE in SR. After analysis of pre- and postoperative TTE in those 11 patients, mean LAEF increased

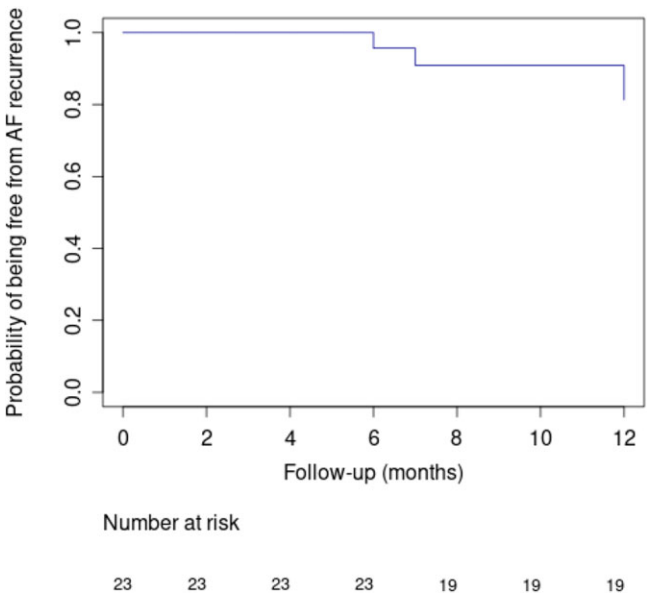

Figure 2: Kaplan–Meier survival curve representing the probability of being free from atrial fibrillation recurrences. AF: atrial fibrillation.

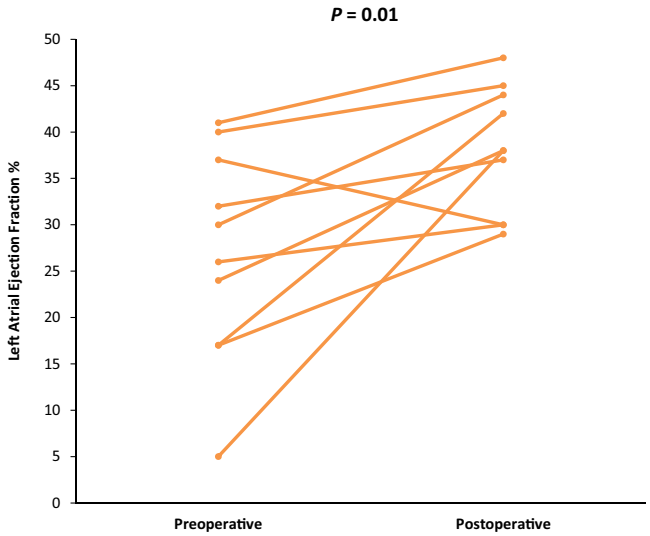

Figure 3: Left atrial ejection fraction at baseline and after surgery.

(26% [11] to 38% [7], $P = 0.01$, see Fig. 3). Furthermore, postoperative mean LAEF was significantly higher in patients with paroxysmal AF ($n = 8$) compared to patients with persAF ($n = 5$; 40% [6] vs 31% [4] respectively, $P = 0.05$). Although we did not have echocardiographic data in all patients, our analysis clearly shows that postoperative electrical freedom of AF also results in restoration (in patients in AF during preoperative TTE) or improvement (in patients in SR during preoperative TTE) of atrial contractility.

DISCUSSION

To the best of our knowledge, this is the first study that describes the feasibility, safety and efficacy of patients undergoing a unilateral left-sided thoracoscopic AF ablation and concomitant robot-assisted MIDCAB grafting procedure for a critical LAD (and if necessary the diagonal artery) stenosis. We found that this all-in-one minimally invasive approach is safe, feasible and efficacious with satisfactory results at 12 months of follow-up.

Minimally invasive atrial fibrillation ablation

Thoracoscopic AF ablation targeting the PVs, LA posterior wall and exclusion of the LAA, with or without endocardial touch-up, is an effective and safe treatment for patients with pAF or persAF and has been associated with better rhythm outcomes than non-surgical treatment options such as catheter ablation [6–8]. Although a minimally invasive procedure, thoracoscopic AF ablation is still more invasive with higher risks for complications and longer hospitalization than percutaneous alternatives [7]. According to the ESC 2020 AF Guidelines, a stand-alone thoracoscopic approach should therefore be considered preferentially in patients with previously failed catheter ablation or when a high chance of success following surgical ablation is expected [1]. This is especially true for patients with persAF, as success rates in more persistent forms of AF are higher following surgical ablation than catheter ablation [9]. In our population, where patients with pAF as well as persAF were included, the heart team could have opted for conservative alternatives including catheter ablation. However, for concomitant cardiac procedures, surgical AF ablation should be considered in symptomatic and asymptomatic patients when the benefits of freedom from AF and the risk of recurrence (LA dilatation, comorbidities) outweigh the minimal additional risk of the ablation [1, 10], as was the case in our patients. While concomitant AF ablation has a class IIA recommendation [1], surgical AF ablation is associated with an improvement in quality of life after both stand-alone and concomitant procedures [11]. Moreover, thoracoscopic AF ablation is still feasible after MIDCAB, but comes with a higher risk of complications due to pericardial adhesions. Furthermore, the LAAOS-III trial demonstrated that concomitant LAA closure in patients with AF who also undergo cardiac surgery is a safe therapy to reduce ischaemic strokes (4.8% stroke after LAA occlusion vs 7.0% without LAA occlusion, $P < 1.000$) [12]. All of our patients received clipping of the LAA, which may attribute to the fact that no strokes were reported during follow-up.

Minimally invasive coronary bypass grafting

In patients with a critical LAD stenosis, several treatment strategies including PCI, on- or off-pump CABG and MIDCAB have been reported. Minimally invasive surgery is associated with less coronary reinterventions than PCI to achieve revascularization of the anterior wall of the left ventricle [13, 14] and surgical intervention of the proximal LAD has a class IA recommendation [15]. Moreover, MIDCAB surgery with LIMA harvesting via a small thoracotomy, either video or robot-assisted, has shown to be a safe and effective treatment compared to conventional on- and off-pump procedures through sternotomy for single-vessel disease [16]. The potential advantages of a minimally invasive approach compared to on/off-pump approaches via sternotomy are less bleeding, fewer wound infections and faster recovery [17]. In our study, we experienced one bleeding and no wound infection.

In certain patients with multivessel disease, a staged hybrid coronary revascularization strategy combining minimally invasive LIMA-LAD anastomosis with PCI of non-LAD vessels can represent a good alternative to CABG [15, 18]. In our study, one

patient with multivessel disease was referred for a successful staged hybrid revascularization approach and for one patient, the staged hybrid revascularization was opted, but the patient remained asymptomatic. A potential restriction of minimally invasive revascularization through a small thoracotomy is the inability of single lung ventilation in patients with very severe chronic obstructive pulmonary disease, the risk of incomplete identification of the LIMA (due to pleural adhesions) or the LAD (due to a large amount of epicardial adipose tissue) possibly necessitating sternotomy [18]. In our study, all patients received an LIMA-LAD anastomosis without conversion to sternotomy, which may be attributed partly to the careful patient selection in a dedicated heart team.

Combining minimally invasive minimally invasive direct coronary artery bypass graft with thoracoscopic atrial fibrillation ablation in one procedure

In regular practice, the surgical options for a patient with LAD disease and AF are limited to either a minimally invasive procedure without surgical AF treatment (MIDCAB), or a concomitant procedure via sternotomy. In an earlier report, we presented an all-in-one minimally invasive approach that overcomes these shortcomings [19]. In the current cohort study, we confirm the feasibility, safety and efficacy of adding a unilateral left-sided thoracoscopic AF ablation to MIDCAB in a small patient population.

In terms of feasibility and efficacy, as mentioned earlier, an LIMA-LAD through a small left thoracotomy could be performed in all patients. Due to our existing centre experience in robotic- and video-assisted surgery for MIDCAB and AF surgery, all patients received robot-assisted MIDCAB surgery and video-assisted thoracoscopy for the AF ablation. Adding thoracoscopic ablation for AF to the MIDCAB procedure was not only feasible but also effective, as almost all patients received a complete PVI and box lesion set with good 1-year rhythm outcomes (81% allowing anti-arrhythmic drugs). These results are comparable with previously reported results following stand-alone thoracoscopic ablation for pAF and persAF [9]. Importantly, left atrial contractility was regained or even improved after the procedure (Fig. 3). Patients with persAF are believed to have an AF substrate that is far more complex than in patients with pAF. Accordingly, we found that the postoperative LAEF was higher in patients with pAF compared to persAF. Be that as it may, patients with pAF did show a significant improvement in postoperative LAEF compared to baseline. This can be explained by reversed contractility remodelling in this group [20]. These results are in line with the results of La Meir *et al.* [21], where the LAEF improved significantly after surgical AF ablation.

Totsugawa *et al.* [22] described in a case report a technique combining surgical AF ablation and LAD revascularization. There are 2 important differences between their technique and the technique described in the current manuscript: surgical AF ablation was performed via unilateral thoracoscopy compared to bilateral anterolateral thoracotomy and LIMA harvesting was robot-assisted compared to under direct vision. Furthermore, Totsugawa *et al.* did not report on outcomes. To date, there are no other reports to compare our results to. The possible advantage of a unilateral left-sided approach is that it avoids right-sided complications, such as bleeding, right phrenic nerve injury and right-sided postoperative pain. In terms of safety, the complication rate perioperatively and after discharge was low. The mean surgical procedure time for both the MIDCAB and the thoracoscopic ablation was 224 min (SD = 38), which may be longer than a LIMA-LAD and concomitant AF ablation through sternotomy, but is still less than a CABG and full Cox-maze IV procedure and does not require the need for cardiopulmonary bypass.

Limitations

First, our results are based on a single-centre experience in a small patient population. Secondly, all surgeries were performed by a skilled team in a centre of excellence with high volume of stand-alone MIDCAB procedures and stand-alone thoracoscopic AF ablation. As these procedures require advanced skills and training in robot-assisted surgery and thoracoscopy, the generalizability and external validity of our results may be reduced. Moreover, calculating LA volumes on 2D echocardiography might under- or overestimate LAEF and postoperative echocardiography data were not available in all patients. Finally, 24-h Holter monitoring may be a potential study limitation, as well as the absence of a control group.

CONCLUSION

In this initial feasibility and early safety study, combining unilateral left-sided thoracoscopic AF ablation and concomitant robot-assisted MIDCAB surgery for LIMA-(diagonal artery)-LAD grafting is feasible, safe and efficacious and improves left atrial contractility post-procedure. In patients with an incomplete thoracoscopic AF ablation or revascularization, a staged hybrid ablation or revascularization can be considered to deliver a patient-oriented and personalized treatment. Future studies should compare the efficacy and safety of this minimally invasive approach with CABG and concomitant AF ablation via sternotomy. Given the success of the current combination, future perspectives could be to combine more cardiac minimally invasive procedures that each has proven their efficacy and safety as a stand-alone procedure, and study their added value in patients.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

Conflict of interest: Bart Maesen is consultant for Atricure and Medtronic.

Data Availability Statement

Data are available on request.

Author contributions

Claudia A.J. van der Heijden: Conceptualization; Data curation; Methodology; Validation; Visualization; Writing—original draft. **Patrique Segers:** Data curation; Writing—review & editing. **Anna Masud:** Data curation. **Vanessa Weberndörfer:** Conceptualization; Project administration. **Sevasti-Marisevi Chaldoupi:** Writing—review & editing. **Justin G.L.M. Luermans:** Writing—review & editing. **Geertruida P. Bijvoet:** Investigation. **Bas L.J.H. Kietselaer:** Investigation. **Sander M.J. van Kuijk:** Methodology; Validation; Writing—review & editing. **Paul Barenbrug:** Data curation. **Jos G. Maessen:** Supervision. **Elham Bidar:** Writing—review & editing. **Bart**

Maesen: Conceptualization; Supervision; Validation; Visualization; Writing—review & editing.

Reviewer information

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