E-ISSN 2148-9211

CVSI

CARDIOVASCULAR SURGERY *and* INTERVENTIONS

Official Electronic Journal of the Turkish Society of Cardiovascular Surgery

Turkish Society of Cardiovascular Surgery
1988

Volume: 5 / Number: 1 / March 2018

E-ISSN 2148-9211

Cardiovascular Surgery and Interventions

Volume 5 - Number 1 - March 2018

Cardiovascular Surgery and Interventions is the official and periodical journal of the Turkish Society of Cardiovascular Surgery. It is published three times a year.

Executive office:
Türk Kalp ve Damar Cerrahisi Derneği
Ataşehir Mah., Ataşehir Bulvarı, 48 Ada,
Mimoza 2/2, K: 2, D: 6,
34758 Ataşehir, İstanbul, Turkey
Tel: +90 216 - 456 14 54
Fax: +90 216 - 456 14 54
e-mail: info@tkdcd.org
URL: http://www.tkdcd.org

Editorial Contact Person
Suat Nail Ömeroğlu, MD.
e-mail: suatnail@gmail.com

Publisher
Bayçınar Tıbbi Yayıncılık ve Reklam Hiz. Tic. Ltd. Şti.
Örnek Mah., Dr. Suphi Ezgi Sok., Saray Apt., No: 11, D: 6,
34704 Ataşehir, İstanbul, Turkey
Tel: +90 216 - 317 41 14
Fax: +90 216 - 317 63 68
e-mail: info@baycinartibbiyayincilik.com

Type of publication: Periodical
Publication date: April 24, 2019

The control of conformity with the journal standards and the typesetting of the articles in this journal, the control of the English abstracts and references and the preparation of the journal for publishing were performed by Bayçınar Medical Publishing.

Contents

ORIGINAL ARTICLE

CASE REPORT

REVIEW

LETTER TO THE EDITOR

Cardiovasc Surg Int 2018;5(1):1-8
http://dx.doi.org/DOI: 10.5606/e-cvsi.2018.684
www.e-cvsi.org

Cardiovascular Surgery and Interventions

Original Article Open Access

Does thyroid dysfunction affect early mortality and morbidity after coronary artery bypass graft surgery?

Özlem Tarçın[1], Gökçen Orhan[2], Ummu Nehir Tandogar[2], Müjgan Mihmanlı[3], Murat Baştopçu[2], İbrahim Yekeler[2]

[1]Department of Endocrinology and Metabolism, Marmara University Medical School, Istanbul, Turkey
[2]Department of Cardiovascular Surgery, Dr. Siyami Ersek Heart and Thoracic Surgery Training and Research Hospital, İstanbul, Turkey
[3]Department of Biochemistery, Dr. Siyami Ersek Heart and Thoracic Surgery Training and Research Hospital, İstanbul, Turkey

Received: February 04, 2018 ***Accepted:*** February 12, 2018 ***Published online:*** April 24, 2019

ABSTRACT

Objectives: This study aims to evaluate to effect of thyroid dysfunction on early mortality and morbidity in patients undergoing coronary artery bypass grafting (CABG).

Patients and methods: Between April 2008 and December 2010, a total of 37 patients (20 females, 17 males; mean age 54.9±10.2 years; range, 26 to 76 years) with thyroid dysfunctions who underwent CABG and 11 patients (2 females, 9 males; mean age 46.9±15.5 years; range, 26 to 65 years) without thyroid dysfunction who underwent on-pump CABG as the control group were included in the study. Patients were divided into groups as overt and subclinical hypothyroidism, overt hyperthyroidism, and subclinical hyperthyroidism according to the thyroid function test results. The European System for Cardiac Operative Risk Evaluation (EuroSCORE) scores were evaluated and the Gensini severity scores were calculated according to coronary angiographies. All patients were followed for seven days after surgery. The duration of endotracheal intubation, inotropic support, cardiac complications, duration of stay in the intensive care unit (ICU) and hospital were recorded.

Results: There were no statistically significant differences between the groups in terms of the duration of intubation, need of inotropic support, and duration of stay in the ICU and hospital. Arrhythmia was more frequent in the overt hyperthyroid group than in the overt hypothyroid group postoperatively. Thyroid-stimulating hormone (TSH) levels remained unchanged after surgery, whereas free T_3 decreased and free T_4 increased, which was compatible with postoperative euthyroid sick syndrome. The EuroSCORE scores were positively correlated with pre- and postoperative TSH levels, duration of intubation, and duration of ICU and hospital stay, but was negatively correlated with free T_3.

Conclusion: Subclinical or overt thyroid dysfunctions do not seem to affect early mortality after CABG. However, overt hyperthyroidism is associated with postoperative arrhythmia complications. Euthyroid sick syndrome may also occur after surgery in certain cases. Pre- and postoperative TSH and free T_3 levels may be useful to identify mortality and morbidity risk in patients undergoing CABG.

Keywords: Coronary artery bypass grafting, morbidity, mortality, thyroid dysfunction.

The preoperative thyroid status in patients undergoing coronary artery bypass grafting (CABG) may alter morbidity and mortality during or after surgery by affecting cardiovascular condition and recovery of myocardial function. Potential complications during cardiac surgery due to overt hyperthyroidism and hypothyroidism are well known and well-studied. Hyperthyroidism increases cardiovascular mortality risk due to high rate of supraventricular dysrhythmias, high cardiac output, tachycardia, and decreased systemic vascular resistance.[1,2] Hypothyroidism is another serious risk factor for coronary heart surgery complications[3] which prolongs the cardiac action potential and QT interval, leading to an increased risk of ventricular arrhythmias.[4] Surgery in the setting of overt hyperthyroidism and hypothyroidism should be avoided, if possible, until the patient achieves euthyroid status to prevent peri- and postoperative complications.

Subclinical thyroid dysfunctions have not been widely studied in cardiac surgery patients. In accordance

Corresponding author: Özlem Tarçın, MD. Marmara Üniversitesi Pendik Eğitim ve Araştırma Hastanesi Endokrinoloji ve Metabolizma Hastalıkları Anabilim Dalı, 34899 Pendik, İstanbul, Turkey.
Tel: +90 216 - 450 51 44 e-mail: ozlemtarcin@yahoo.com

Citation:
Tarçın Ö, Orhan G, Nehir Tandogar U, Mihmanlı M, Baştopçu M, Yekeler İ. Does thyroid dysfunction affect early mortality and morbidity after coronary artery bypass graft surgery? Cardiovasc Surg Int 2018;5(1):1-8.

with the current consensus, authors have advocated that subclinical thyroid dysfunction is not a causative factor of surgical complications or mortality. However, no case-controlled study has been reported on the effects of overt or subclinical thyroid dysfunctions on mortality and morbidity after cardiac surgery.

In the present study, we aimed to evaluate early mortality and morbidity in patients with overt and subclinical thyroid dysfunction undergoing CABG.

PATIENTS AND METHODS

Between April 2008 and December 2010, a total of 37 patients (20 females, 17 males; mean age 54.9±10.2 years; range, 26 to 76 years) with thyroid dysfunctions who underwent CABG and 11 patients (2 females, 9 males; mean age 46.9±15.5 years; range, 26 to 65 years) without thyroid dysfunction who underwent on-pump CABG as the control group were included in the study. A written informed consent was obtained from each patient. The study protocol was approved by the local Ethics Committee of Dr. Siyami Ersek Cardiovascular and Thoracic Surgery Training and Research Hospital. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Thyroid status was established by history and clinical examination and confirmed by preoperative thyroid function tests including free T_3 (fT3), free T4 (fT_4), and thyroid-stimulating hormone (TSH). The patients were divided into groups as overt hypothyroidism (n=8), overt hyperthyroidism (n=8), subclinical hypothyroidism (n=11), and subclinical hyperthyroidism (n=10) according to their thyroid function test results. The European System for Cardiac Operative Risk Evaluation (EuroSCORE) scores were evaluated and the Gensini severity scores were calculated according to coronary angiographies. Adequate premedication was applied to the patients with overt thyroid dysfunction. The patients with subclinical thyroid dysfunction were followed without any medication for the thyroid status. All patients were followed for the first seven days after surgery in the intensive care unit (ICU) and ward. Duration of endotracheal intubation, need for inotropic support longer than six hour after surgery, cardiac complications such as arrhythmia or infection, duration of stay in the ICU and hospital were recorded. Postoperative thyroid function tests were performed in the first week after surgery.

Assessment of thyroid function

Serum TSH, fT_3, fT_4, T_3, and T_4 concentrations were measured by immunochemiluminometric assay using the Siemens ADVIA Centaur analyzer (Siemens Ltd., Bayswater, Victoria, Australia and Penrose, Auckland, New Zealand-Diagnostics Division, Tarrytown, NY, USA). The percentage coefficient of variation (CV%) was 1.7% at TSH concentrations of 0.1-0.5 mIU/L and 2.1% at 5-10 mIU/L. Normal ranges were between 0.55-4.78 mIU/L for TSH; 2.3-4.2 pg/mL for fT3, and 0.59-1.3 ng/dL for fT_4.

Calculation of EuroSCORE and Gensini scores

EuroSCORE

EuroSCORE is a simple, objective, and up-to-date scoring system to predict early mortality based on the objective risk factors in cardiac surgery patients in Europe.[5] The EuroSCORE risk was calculated based on the study of Nashef et al.[6] in all patients. Pointing chart of the scoring system was done according to the risk factors related to the patients and cardiovascular system (CVS) (Table 1). The scoring system was, then, applied to three risk groups. The low-risk group has a score of EuroSCORE 1-2, intermediate-risk group has a score of EuroSCORE 3-5, and the high-risk group has a score of EuroSCORE 6 plus.

Gensini severity scores

Gensini Severity Index was used to evaluate the severity of atherosclerosis according to coronary angiography (CAG) imaging. In the Gensini's coronary artery scoring method,[7] the geometrically increasing severity of lesions, the cumulative effects of multiple obstructions, the significance of their locations, the modifying influence of the collaterals, and the size and quality of the distal vessels are considered. According to the severity of angiographic stenosis, ratings are as follows: 0-25% (1), 25-50% (2), 50-75% (4), 75-90% (8), 90-99% (16), and 100% (32). All these points are multiplied with coefficient factor for each main vessels and segment. The result is calculated by adding all values.

Statistical analysis

Statistical analysis was performed using the InStat-GraphPad version 3.10 (GraphPad Software, Inc., San Diego, CA., USA). Descriptive data were expressed in mean ± standard deviation (SD). Numeric variations were compared using the Student's t-test for

Table 1
Baseline demographic and clinical characteristics of patients

	Subclinical hypothyroid (n=11)	Subclinical hyperthyroid (n=10)	Overt hypothyroid (n=8)	Overt hyperthyroid (n=8)	Control (n=11)	
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	*p*
Age (year)	54.5±11.2	55.6±10.2	51.4±8	58.2±13.8	46.9±15.5	NS
Body mass index	27.5±3	26.3±2.7	27.5±6.2	28.7±5.5	25.5±4.5	NS
Intubation (hour)	11.4±4	16.8±19.2	14.6±8	10.3±1.4	10.3±3	NS
ICU stay (hour)	31.5±29.4	30.7±23	40.6±27.8	37±23	28.8±14.3	NS
Hospital stay (day)	7.9±2.9	7.7±2	7.4±1.4	8.3±1.4	8.4±3.4	NS

SD: Standard deviation; ICU: Intensive care unit; NS: Not significant.

independent samples or by the Mann-Whitney test. The chi-square test or Fisher's exact test, if applicable, were used to compare the groups. The Pearson's correlation analysis was used for the comparison of variables. A p value of <0.05 was considered statistically significant.

RESULTS

The baseline demographic and clinical characteristics of study groups are summarized in Table 2. There was no significant difference in the mean age and body mass index (BMI) between the groups. However, duration of ICU stay was slightly longer in the patients with overt thyroid dysfunction, although not statistically significant. Duration of endotracheal intubation and hospital stay were not significantly different between the groups. Although arrhythmia was more evident in the overt hyperthyroid group than in the overt hypothyroid group postoperatively, there was no significant difference between the groups in terms of the need of inotropic support and postoperative complications such as infection. According to the operation, the patients who underwent concomitant valve and CABG needed more inotropic support postoperatively, as expected, due to the distinct physiopathology of valvular diseases.

When pre- and postoperative thyroid function tests were compared between the groups (Table 3), TSH was not found to change significantly after surgery. However, in patients with subclinical thyroid dysfunctions, fT_3 decreased and fT_4 increased significantly, whereas only fT_3 decreased in the overt hypothyroidism group and only fT_4 increased in the overt hyperthyroid and control groups, suggesting postoperative euthyroid sick syndrome.

Table 2
Pre- and postoperative thyroid function test results

	Preoperative			Postoperative		
	TSH	fT_3	fT_4	TSH	fT_3	fT_4
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Subclinical hypothyroid	7.3±1.6	2.9±0.5*	0.9±0.3*	6.8±3.4	2.5±0.4	1.2±0.3
Subclinical hyperthyroid	0.15±0.1	3±0.6*	1.1±0.3*	0.19±0.2	2.5±0.5	1.3±0.4
Overt hypothyroid	16.5±8.2	2.8±0.7*	0.7±0.2	15.3±10.2	2.1±0.6	0.8±0.3
Overt hyperthyroid	0.03±0.03	3.3±0.6	1.2±0.3*	0.04±0.05	3.5±0.9	1.8±0.6
Control	1.7±0.6	2.9±0.3	1±0.17*	1.7±0.8	2.8±0.4	1.2±0.2

TSH: Thyroid-stimulating hormone; fT_3: Free T_3; fT_4: Free T_4; SD: Standard deviation; * p<0.05 correlated with postoperative values.

Table 3
Correlation of EuroSCORE scores with thyroid function test results (n=48)

	Pearson's correlation coefficient	
	r	*p*
Preoperative TSH	0.42	0.004
Preoperative fT_3	-0.38	0.01
Preoperative fT_4	-0.28	0.06
Postoperative TSH	0.30	0.05
Postoperative fT_3	-0.42	0.006
Postoperative fT_4	-0.26	0.08

TSH: Thyroid-stimulating hormone.

The EuroSCORE and Gensini severity scores were evaluated for all study groups. The mean EuroSCORE score was 2.25 for overt hyperthyroidism, 5.75 for overt hypothyroidism, 3.6 for subclinical hyperthyroidism, 3.81 for subclinical hypothyroidism, and 2.18 for the control group. There was no statistically significant difference between the groups. However, we found a positive and significant correlation of EuroSCORE with preoperative TSH levels (p=0.004; r=0.42), postoperative TSH levels (p=0.05; r=0.30), duration of intubation (p=0.04; r=0.31), ICU stay (p<0.005; r=0.49), and hospital stay (p=0.01; r=0.37), but negatively and significantly correlated with the preoperative fT_3 levels (p=0.01; r= -0.38) and postoperative fT_3 levels (p=0.006; r= -0.42) (Table 4) (Figure 1). Pre- and postoperative fT4 levels were negatively correlated with the EuroSCORE, but were not statistically significant (p=0.06; r= -0.28 and p=0.08; r= -0.26, respectively). The Gensini severity scores were 106.6 for overt hyperthyroidism, 69.5 for overt hypothyroidism, 81.8 for subclinical hyperthyroidism, 62 for subclinical hypothyroidism,

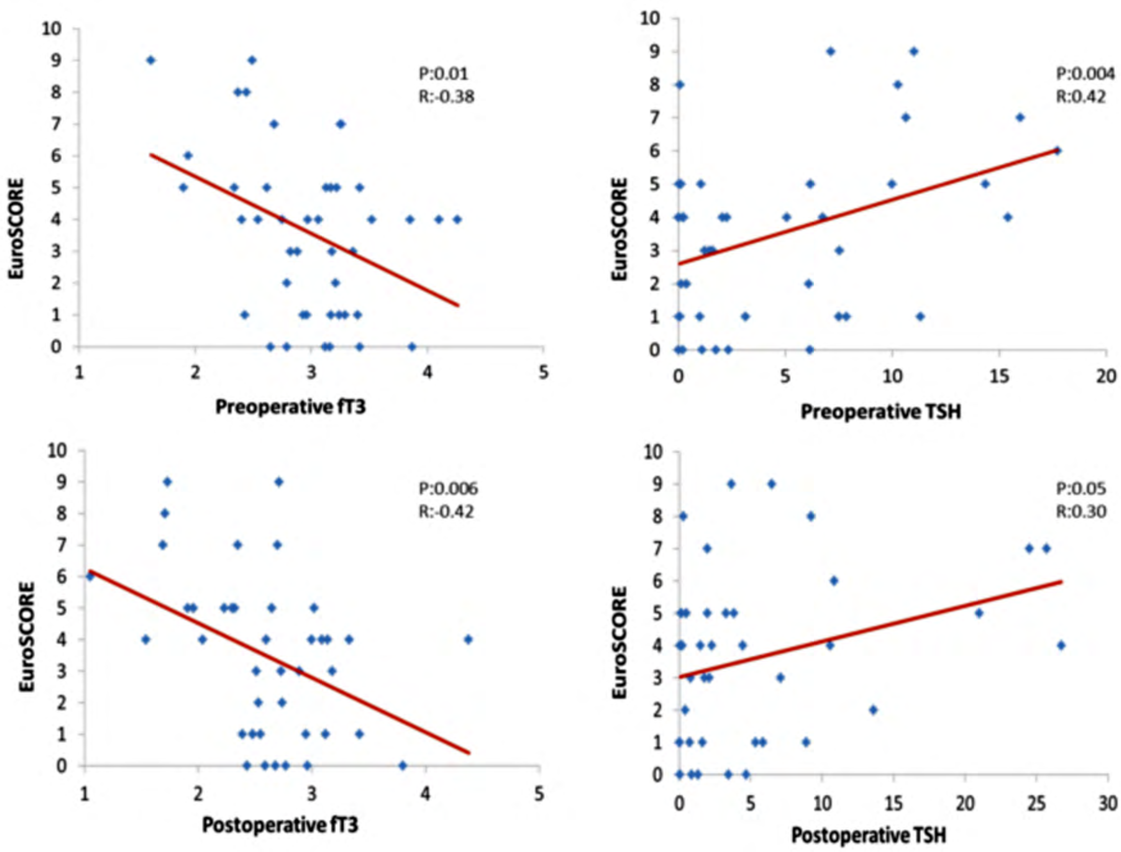

Figure 1. Correlation of EuroSCORE with pre- and postoperative fT_3 and TSH levels.
TSH: Thyroid-stimulating hormone; fT_3: Free T_3.

and 74 for the control group. However, there was no significant difference between the groups and no correlation between the Gensini scores and thyroid function test results or other follow-up parameters.

DISCUSSION

Thyroid hormones have various effects on the CVS which are mediated at both genomic and non-genomic levels.[8] Overt hyperthyroidism has well-known effects on the CVS such as resting tachycardia, arrhythmias (most commonly supraventricular), thromboembolism, and heart failure which may lead to cardiovascular and cerebrovascular mortality, particularly in patients with CVS diseases.[1,2] Most feared perioperative complication is thyroid storm which may occur anytime in the perioperative period with a mortality rate of 10 to 75%.[9] Paroxysmal atrial fibrillation is also a serious complication of hyperthyroidism which may occur at least once in nearly 25% of cases.[10] In addition, the combination of tachycardia and hypertension may precipitate angina or myocardial infarction in patients with underlying coronary artery diseases.[11,12] In particular, untreated Graves' disease, which is more prominent and aggressive, may cause fatal results in these patients.

There are some reported cases with hyperthyroidism undergoing open heart surgery with or without premedication. Onoe et al.[13] reported that, in two patients with known thyrotoxicosis, open heart surgery was successfully performed by preoperative and early postoperative anti-thyroid agents. However, in a recent article, Bish et al.[14] found thyroid storm developing in a patient after urgent CABG caused by Graves' disease which was unknown before surgery and controlled by immediate potassium iodide and thionamides through nasogastric tube, as well as high-dose intravenous hydrocortisone. In our study, we found no increase in the mortality rate in overt hyperthyroid patients, although we observed increased arrhythmia in this patient group after surgery, compared to the hypothyroid group, which was not statistically significant.

Similarly, overt hypothyroidism may cause many of the signs and symptoms associated with heart failure including dyspnea, edema, cardiomegaly, and effusions and increase the risk of coronary artery disease.[3] However, these patients have a lower incidence of angina and myocardial infection, perhaps secondary to the reduction in cardiac metabolic demands. The patients usually have hypertension due to alterations in the peripheral vascular resistance and an increased risk of ventricular arrhythmias.[4] In untreated overt hypothyroidism patients, acute thyroid hormone replacement therapy may worsen myocardial ischemia due to increased myocardial oxygen consumption.[15] There are still conflicting data regarding the safety of CABG in untreated patients. Some authors have reported no adverse effects in patients with untreated mild-to-moderate hypothyroidism undergoing cardiac surgery,[16-18] whereas some others have suggested adverse effects such as severe myxedema after cardiac surgery, leading to significant hemodynamic compromise.[19] Some reports have also shown that percutaneous transluminal coronary angioplasty (PTCA) can be a better choice before CABG in hypothyroid patients who have a higher incidence of complications, if there is no time to render them euthyroid.[20,21] In our study, one patient with overt hypothyroidism who was operated emergently died due to critical coronary obstruction and aortic valve failure. However, the incidence of other complications was not higher in the overt hypothyroid patients, compared to the control group.

Subclinical thyroid diseases continue to be an issue in the preoperative evaluation of patients and are more common than overt thyroid disorders. The prevalence ranges between 2 and 8% in the general population and higher in women over the age of 60.[22] Subclinical thyroid dysfunctions may develop after a contrast agent administration during PTCA or CAG.[23] In a recent study Marraccini et al.[24] reported that thyroid dysfunction was frequent in patients who underwent CAG, and low T_3 syndrome was the predominant feature in these patients. Furthermore, in patients with valvular heart diseases, euthyroid sick syndrome (low T_3 syndrome) is a common problem, particularly who have heart failure and affects mortality.[25,26] Thus, patients with subclinical thyroid dysfunction should be investigated in detail about exposure of the contrast agents, family history of thyroid disea§ses, diseases affecting blood circulation, and the use of inotropic drugs which leads to decreased TSH.

In the literature, there are few studies and case reports which are controversial regarding the safety of cardiac surgery in subclinical thyroid diseases. Mantzoros et al.[27] revealed that subclinical hypothyroidism did not appear to be a risk factor for significant morbidity or increased mortality following PTCA. Ripoli et al.[28] examined the effects of subclinical hypothyroidism on the cardiac pump performance and found that subclinical hypothyroidism decreased the end-diastolic volume and increased systemic vascular resistance, leading to impairment of the cardiac pump performance, compared to healthy subjects. More importantly, the incidence of transient atrial fibrillation after CABG was found to be slightly higher in patients with subclinical hypothyroidism.[29] This finding suggests that the detection of preoperative thyroid dysfunction or the routine assessment of thyroid function may be useful for patients undergoing CABG. In our study, there was no significant difference between the subclinical hypothyroid or hyperthyroid patients and control group in terms of the morbidity and surgery complication rates.

The EuroSCORE is a simple and common risk scoring system for predicting operative mortality.[6,30] Gensini severity scoring system is also commonly used to identify the severity of coronary artery stenosis according to CAG.[7] To the best of our knowledge, correlation of these risk scores and thyroid function test results has not been studied in the literature, yet. In this study, we were unable to find a significant correlation between the Gensini scores and any of the thyroid function test results. However, the EuroSCORE scores were positively correlated with the pre- and postoperative TSH levels and negatively correlated with the pre- and postoperative fT_3 levels and slightly correlated with fT_4 levels. The correlations were more evident for fT_3 and TSH, followed by fT_4, suggesting that mortality increases with high TSH and low fT_3 levels. That is why preoperative thyroid function test should be routinely performed and may be useful postoperatively in predicting mortality, in particular in patients with a known thyroid disease.

Euthyroid sick syndrome and low T_3 syndrome are also well-described after cardiac surgery. In severe stress or major surgery, circulating levels of T3 decrease within two hours which is thought to reflect a reduction in the peripheral conversion of T_4 to T_3.[31,32] The majority of studies investigating thyroid hormone levels in patients undergoing cardiac surgery have demonstrated a well-established reduction in the fT3 levels, particularly under cardiopulmonary bypass.[33-35] Murzi et al.[35] showed a significant reduction in the fT_3 levels with a nadir at 48 h postoperatively and that the levels were still below baseline values at up to six days following surgery. The degree of the decline in the fT_3 levels was higher than the fT_4 levels. Similarly, in our study, we found a decline in the fT_3 levels on postoperative Days 5-7 and reduction of fT_3 levels were more prominent than the fT4 levels. Postoperative low T_3 syndrome decreases cardiac output as in chronic hypothyroidism and systemic vascular resistance increases.[36] Recent studies have mostly addressed into the effects of postoperative T_3 replacement therapy. Previous studies performed in small study groups have shown that T_3 replacement therapy increases cardiac output, decreases the need for inotropic agents and incidence of atrial fibrillation after cardiac surgery.[34,37,38] Although it has been shown that T_3 replacement therapy decreases the incidence of arrhythmia by improving hemodynamic performance, its association with mortality has not been established in large-scale, randomized-controlled studies, yet.[39-41] In a clinical review, Kaptein et al.[41] analyzed 14 randomized-controlled studies involving patients undergoing cardiac surgery and reported that, although cardiac index increased and the need for inotropic agents decreased, particularly in elderly patients with low ejection fraction values with T_3 replacement therapy, there was no significant difference in the mortality rates. On the other hand, there is a limited number of data regarding the duration of stay in the ICU and hospital. In our study, the complication risk did not significantly decrease in the patients, even if the fT_3 levels decreased. The strong association between the EuroSCORE scores and fT_3 and TSH levels suggests that T_3 replacement therapy may have positive effects on mortality. Based on these findings, we suggest that certain patients with low T_3 and high TSH levels in the postoperative period may benefit from T_3 replacement therapy. However, further studies including the mortality endpoint is required to investigate the possible benefits of thyroid hormone replacement.

Most reviewers and authors recommend premedication for overt hyperthyroidism to prevent thyroid storm or other complications during the perioperative period.[42-44] For patients with uncontrolled hyperthyroidism who are candidates for an elective surgery, surgical procedure should be postponed, until they become stable on anti-thyroid therapy. For patients presenting urgent or emergent surgery, the anesthesiologist should be informed about the patent's status to have drugs which block the systematic effects of thyroid hormones such as beta-blockers, iodide, and thionamides ready. Although premedication for hyperthyroidism is clear in general, there is still controversy for hypothyroid patients with known ischemic heart diseases or those who are candidates for coronary revascularization. Rapid treatment of thyroid dysfunction may increase myocardial oxygen demand, leading to ischemia. Currently, the consensus is that, if a patient needs urgent cardiac revascularization, they should undergo the procedure before replacement therapy;[44,46] however, many endocrinologists prefer starting low-dose T_4 treatment in hospitalized patients. In our overt hyperthyroid patients, we started oral thionamides before surgery, although overt hypothyroid patients underwent surgery, particularly those who had critical coronary stenosis. Our common idea was that revascularization is more important than hypothyroidism, as at least four weeks are needed to render those patients in the euthyroid state. Unfortunately, one of our overt hypothyroid patients with severe coronary artery stenosis and aortic valve stenosis who underwent emergent surgery died.

The main limitation of our study is its small sample size. In addition, total thyroid function test was not performed in this study, as free thyroid hormone levels are more reliable in this study population. In our study, for the first time, thyroid function tests were correlated with coronary artery stenosis risk scores and surgical mortality scores such as Gensini and EuroSCORE. Also, subclinical thyroid disorders were evaluated in patients undergoing CABG for the first time in a controlled study. Nonetheless, further large-scale, prospective, randomized-controlled studies are needed to confirm these findings.

In conclusion, CABG seems to be safe in patients with thyroid dysfunction. Overt hyperthyroidism increases the risk of arrhythmia and other potential complications due to hyperthyroidism. Conversely, subclinical thyroid disorders are not associated with any complications and there is no need for premedication before and after CABG. The EuroSCORE scores also increase with low fT_3 and high TSH levels in the perioperative period, suggesting that thyroid hormones may affect open heart surgery-related mortality or morbidity rates and should be, therefore, evaluated before and after surgery. Based on our study findings, T_3 replacement therapy may be useful in patients with low fT_3 and high TSH levels who have a higher mortality risk score, according to the EuroSCORE.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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Cardiovasc Surg Int 2018;5(1):9-11
http://dx.doi.org/DOI: 10.5606/e-cvsi.2018.683
www.e-cvsi.org

Cardiovascular Surgery and Interventions

Case Report Open Access

Spontaneous massive hemothorax related to a neurofibroma: A case report

Slim Charfi[1], Abdessalem Hentati[2], Walid Abid[2], Imed Frikha[2]

[1]Department of Pathology, CHU Habib Bourguiba, Sfax, Tunisia
[2]Department of Cardiovascular and Thoracic Surgery, CHU Habib Bourguiba, Sfax, Tunisia

Received: January 29, 2018 ***Accepted:*** May 21, 2018 ***Published online:*** April 24, 2019

ABSTRACT

A 33-year-old woman was admitted due to sudden-onset dyspnea and right-sided chest pain. Imaging studies revealed a right-sided hemothorax and an hyperdense mass of the posterior mediastinum. A *monobloc* and complete tumor resection was done by thoracotomy. The diagnosis of a neurofibroma was confirmed by the pathological exam. A careful examination of the patient did not suggest any signs of von Recklinghausen's disease. To the best of our knowledge, this is the first case of spontaneous massive hemothorax secondary to a neurofibroma in non-von Recklinghausen's disease.

Keywords: Hemothorax; neurofibroma; neurofibromatosis.

Spontaneous massive intra-thoracic bleeding is rare and life-threatening complication. It usually occurs due to vasculopathy. A concomitant mediastinal neoplasm related to spontaneous hemothorax is a rare finding.[1] Herein, we report a case of spontaneous hemothorax secondary to a neurofibroma of the mediastinum in non-von Recklinghausen's disease.

CASE REPORT

A 33-year-old woman with a non-specific medical history was admitted to our hospital due to sudden-onset dyspnea and right-sided chest pain. Physical examination revealed tachypnea (respiratory rate: 44/min) and decreased breath sounds in the right lung base. No other abnormalities were noted. Laboratory tests showed a low hemoglobin level of 8.6 g/dL. Coagulation tests were normal. A chest radiograph revealed a large amount of right-sided pleural effusion (Figure 1). Thoracic computed tomography (CT) demonstrated a right-sided hemothorax and an hyperdense mass of the posterior mediastinum which was measured 146×126×114 mm in size with an intense contrast enhancement. A collapse of the right lung and a mediastinal shift to the left were noted (Figure 2).

A written informed consent was obtained from the patient and a transfusion of three units of blood was done, followed by a thoracotomy. During operation, an abundant hemothorax was noted with a bleeding

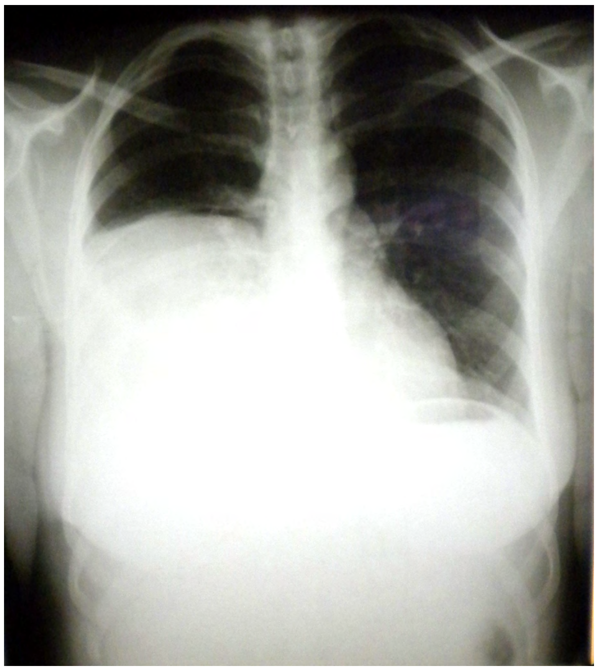

Figure 1. A chest radiograph showing large amount of right-sided pleural effusion.

Corresponding author: Slim Charfi, MD. Department of Pathology, CHU Habib Bourguiba, 3029 Sfax, Tunisia.
Tel: 00216 98 972 756 e-mail: charfislim@gmail.com

Citation:
Charfi S, Hentati A, Abid W, Frikha I. Spontaneous massive hemothorax related to a neurofibroma: A case report. Cardiovasc Surg Int 2018;5(1):9-11.

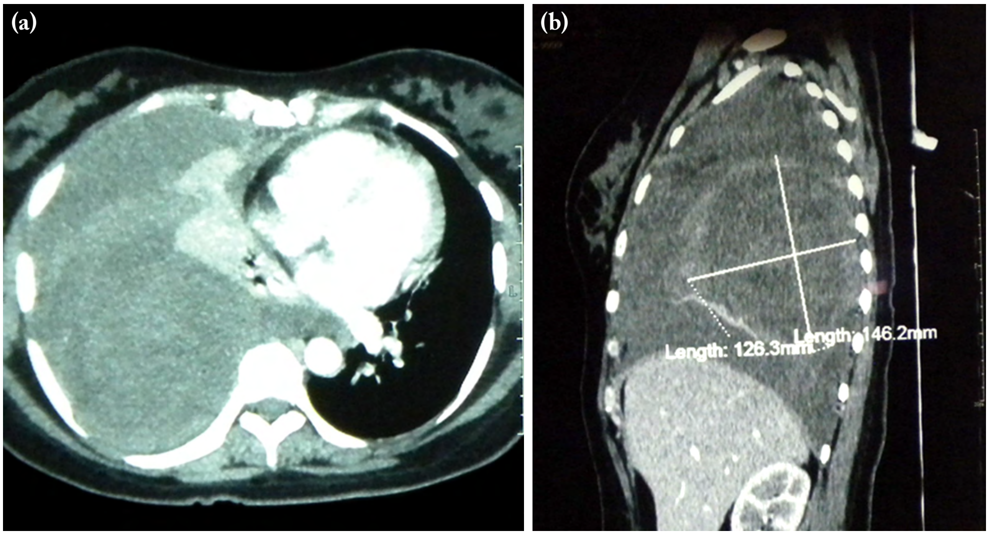

Figure 2. Thoracic computed tomography showing **(a)** massive hemothorax and **(b)** mass of the posterior mediastinum.

mass of the posterior mediastinum which extended through an intervertebral foramen. Therefore, a *monobloc* and complete tumor resection with removal of the pleural hematoma was performed. Pathological examination showed a bilobate and encapsulated mass measuring 14×11×11 cm in size. The cut surface was white-to-yellowish with myxoid and hemorrhagic areas. Histological examination revealed a low cellular spindle cells proliferation with no cellular pleomorphism and mitosis. The stroma was fibrous with myxoid areas. Immunohistochemical study showed that tumor cells were positive for PS100 and vimentin and negative for smooth actin muscle, desmin, and CD34. The diagnosis of a neurofibroma was considered. A careful examination of the patient did not suggest any signs of von Recklinghausen's disease. In addition, there was no café-au-lait spots, hyperpigmented macules, and axillary or inguinal freckles. Also, there was no history of first-degree relative with neurofibromatosis. The patient was discharged on Day 5. The follow-up was unremarkable.

DISCUSSION

Spontaneous massive hemothorax secondary to a neurofibroma is a rare and often lethal complication.[1] Spontaneous massive hemothorax usually occurs secondary to pulmonary infarction, arteriovenous fistula, ruptured aneurysm, and tumors. Numerous benign and malignant tumors have been blamed for the development of spontaneous massive hemothorax including angiosarcoma, chondrosarcoma, fibrosarcoma, peripheral neuroectodermal tumor, teratoma, and neural tumors.[2-6] Neural tumors includes neurofibromas, schwannomas, malignant peripheral nerve sheath tumors, and ganglioneuromas.[6,7] In the literature, all published cases of spontaneous massive hemothorax secondary to a neurofibroma have been shown to be related to von Recklinghausen's disease.[1] In this context, this is the first case of spontaneous massive hemothorax secondary to a neurofibroma in non-von Recklinghausen's disease.

In conclusion, neurofibroma should be considered among neural tumors causing hemothorax even for patients without von Recklinghausen's disease.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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Cardiovasc Surg Int 2018;5(1):12-23
http://dx.doi.org/DOI: 10.5606/e-cvsi.2018.646
www.e-cvsi.org

Cardiovascular Surgery and Interventions

Review Open Access

Coronary revascularization in robotic cardiac surgery

Burak Onan

Department of Cardiovascular Surgery, University of Health Sciences, Istanbul Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital, Istanbul, Turkey

Received: April 19, 2017 ***Accepted:*** February 14, 2018 ***Published online:*** April 24, 2019

ABSTRACT

Robotic surgery has evolved worldwide after 2000s. In cardiac surgery, totally endoscopic robotic endoscopic surgery has been frequently performed in mitral/tricuspid valve pathologies, atrial septal defects, coronary revascularization, and intracardiac tumors. In this review, we discuss robotic approach to coronary revascularization and surgical technique in patients with ischemic heart disease in the light of literature data.

Keywords: Coronary revascularization, ischemic heart disease, robotic surgery.

In recent years, robotic surgical technologies and techniques have developed rapidly throughout the world and have taken their place in different branches. In the literature, robotic surgery was first described in the field of gynecology and obstetrics, followed by urology.[1-7] In the late 1990s, cardiac surgeons paid an interest and began to use the robotic systems.[1-7] Developments in endoscopic imaging technologies, the construction of small diameter instruments, and improvements in peripheral cannulation devices and applications have enabled the use of robotic surgery in cardiac surgeries. All these developments through special surgical trainings and clinical programs have made the use of robotic systems in cardiac surgery widespread. In the beginning of the 2000s, left internal thoracic artery harvesting for robotic-assisted coronary revascularization operations and total endoscopic mitral valve operations have been successfully performed in increasing numbers around the world with the widespread use of the da Vinci telemanipulation system.[8-13]

The first use of endoscopic systems dates back to the early 1980s (Table 1).[10] Since then, systems can be classified into two main groups including prototypes and improved systems. Prototypes were first used in 1983. The first orthopedic operation (arthroscopy) was performed in the history of medicine with the Arthrobot (Vancouver, BC, Canada), which is considered the first surgical robot. Then, in 1985, the first brain biopsy was performed with the Unimation Puma 200 (Unimation; manufacturer defunct) device under the guidance of computed tomography.[14] In 1992, the first fully closed robotic surgical practice (prostate surgery) in the world using the Probot (Imperial College, London, UK) was performed at St. Thomas hospital.[15] The use of these devices has revolutionized the surgical practice and a new era of robotic surgery has been introduced. With the advances in technology and increased interest in endoscopic surgical techniques, a rapid progress to current techniques has been achieved.

The first period in which prototypes were used followed the second period, in which advanced surgical systems were used. This period extended from the 1990s to the present day. Initially, two main systems were used between 1990 and 2000. The latter, Aesop Hermes-ready (Computer Motion Inc., Santa Barbara, CA, USA) system, was introduced in 1994.[15] This system can be described as a camera system which is moved or guided by vocal command. With the vocal commands of the surgeon, the camera holder could move in the desired and programmed direction, while

Corresponding author: Burak Onan, MD. SBÜ İstanbul Mehmet Akif Ersoy Göğüs ve Kalp Damar Cerrahisi Eğitim ve Araştırma Hastanesi Kalp ve Damar Cerrahisi Kliniği, 34303 Küçükçekmece, İstanbul, Turkey.
Tel: +90 553 - 622 38 78 e-mail: burakonan@hotmail.com

Citation:
Onan B. Coronary revascularization in robotic cardiac surgery. Cardiovasc Surg Int 2018;5(1):12-23.

Table 1
Chronological background of robotic endoscopic surgical systems

	The development of surgical endoscopic systems
Prototypes	
1983, the first surgical robot, 'Arthrobot'	Orthopedy operation-arthroscopy,
1985, the Unimation "Puma 200"	Computed-tomography guided first robotic cerebral biopsy
1992, "the PROBOT"	The first totally endoscopic robotic surgery in the world-prostate surgery
Advanced systems	
1994, Aesop Hermes-ready system	Computer motion
1998, Zeus system	Computer motion, * the first coronary bypass in 1998
1996, da Vinci system (intuitive surgical)	Telemanipulation system, * the first robotic case was mitral valve repair in 1996 * the first minimally invasive direct coronary artery bypass in 1999

the surgeon was performing surgery with the help of an endoscopic screen. This system was followed by the Zeus (Computer Motion Inc., Santa Barbara, CA, USA) surgical system.[15] In this system, a stereotactic screen was added to the previous system, allowing the surgeon to apply endoscopic surgery using both the camera and right and left arm using a special screen and vocal command system. However, the difficulties and limitations of the use of these systems prevented them from becoming widespread. The era of the Aesop and Zeus systems ended with the use of the da Vinci telemanipulation system, which is a more sophisticated surgical technology.

The first robot-assisted cardiac operation with the da Vinci surgical endoscopic system was performed in 1996 using the prototype of this system, and it was a mitral valve repair operation performed by Carpentier et al.[4] This operation was followed by Mohr et al.[5] and, later in the same year, Loulmet et al.[2] performed minimally invasive direct coronary artery bypass (MIDCAB) graft surgeries. Minimally invasive techniques, however, have begun to be used in hybrid surgical interventions. The first emergence of hybrid interventions was in the late 1990s. Hybrid applications in cardiac surgery were first introduced by Benetti and Ballester in 1995.[6] The first thoracoscopic left internal thoracic artery (ITA) removal and endoscopic minimally invasive single-vessel coronary artery bypass grafting (CABG) were successfully performed in two patients by Dr. Benetti.[6] Subsequently, in 1996 and 1999, robot-assisted minimally invasive myocardial revascularization procedures were performed in multivessel disease.[2,7] Since then, minimally invasive and robotic surgical techniques and cardiac catheterization procedures have been used more frequently.[8]

In Turkey, the first robotic heart surgery program was initiated at Florence Nightingale Hospital in Istanbul, Turkey under the leadership of Prof. Belhhan Akpınar, MD. This program is also the first robotic endoscopic surgery program in Turkey. Prof. Akpınar and Prof. Ertan Sagbas and Prof. Mustafa Guden from his team performed the first successful robotic coronary bypass series in our country and long-term outcomes have recently been published.[16-18] In addition, the mitral valve and atrial septal defect operations were successfully performed with the first three-arm version of the da Vinci system. This team has the largest series of robotic cases in Turkey. Successful results of this surgery team succeeded by Prof. Cem Alhan's robotic program and successful results have been reported recently.[19,20] The robotic surgery program, which was initiated by our team in May 2013 by Prof. Ihsan Bakir and currently carried out by our team, is one of the largest series in Turkey. Until now, more than 350 robotic total endoscopic heart surgeries and more than 100 robotic MIDCAB cases were successfully performed in our center.[21-26] All of these operations have allowed our country to be among the top five countries in the world and to be among one of the first in Europe, in the field of robotic cardiac surgeries (Data from Cordamed Inc., Istanbul, Turkey, 2016). This success is extremely important for the medical literature in Turkish and surgical success of Turkey.

ADVANTAGES OF ROBOTIC SURGERY

For minimally invasive cardiac surgical interventions, the main goal is to minimize trauma to the patients with lower postoperative morbidity and mortality rates for high-risk patients for surgery.[27] We can divide the advantages of the robotic surgery in two main groups: technical and clinical. Among the technical advantages, the main feature distinguishing robotic surgery from other endoscopic surgical procedures is that the maximum image area is three-dimensional which allows the surgeon to apply surgical techniques comfortably and safely on the endoscopic imaging console. In addition, the robot's instrument arms work synchronously with the right and left arm movements of the surgeon. Port diameters are small (8.12 mm) and surgical incisions are small accordingly. All of these offer the patient with the least invasive surgical procedure. The major clinical advantages of robotic surgery are as follows:

- No sternotomy or wide thoracotomy incisions
- Less systemic inflammatory response
- Avoidance or minimization of cardiopulmonary bypass (CPB), cardiac arrest, and aortic manipulation
- Absent or minimal bleeding/use of blood products
- Less postoperative pain and early mobilization
- Rapid postoperative healing period
- Shortened hospital stay
- Sooner return to daily living activities or work
- Improved cosmetic results
- Postoperative psychological advantages, such as self-confidence

DISADVANTAGES OF ROBOTIC SURGERY

Besides all these advantages, there are some disadvantages including longer operating times, the need for a specific learning curve, technical details and know-how, endoscopic surgical experience, and the absence of sensory recall on the console during surgery called the haptic feedback. More importantly, the high cost of the device and low number of centers where the devices are available cannot be neglected.

FEATURES OF ROBOTIC da VINCI SYSTEM

The only endoscopic surgical system currently in use without any alternative is the da Vinci system. Features of this system include three-dimensional (3D) and advanced resolution (1080i) imaging, advanced sensitivity, 270-degree wrist motion, spatial orientation, haptic feedback, training programs and simulation. This system mainly consists of two main units (Figure 1). First unit is the surgeon console which provides the surgeon to operate in an endoscopic 3D simulator. The surgeon sees the operation area with a high-resolution, high-performance imaging system. The second unit is the patient console which allows robotic instruments to be fixed in the thoracic cavity and to simulate appropriate movement. Robotic arms and instruments placed in the thorax are easily used via successful simulation of the hand movements of the surgeon and active wrist movement. There are different instruments in robotic surgery for harvesting the internal thoracic artery. These include micro-spatula, micro-forceps, mini-clip applicators, endoscopic heart stabilizers, porte

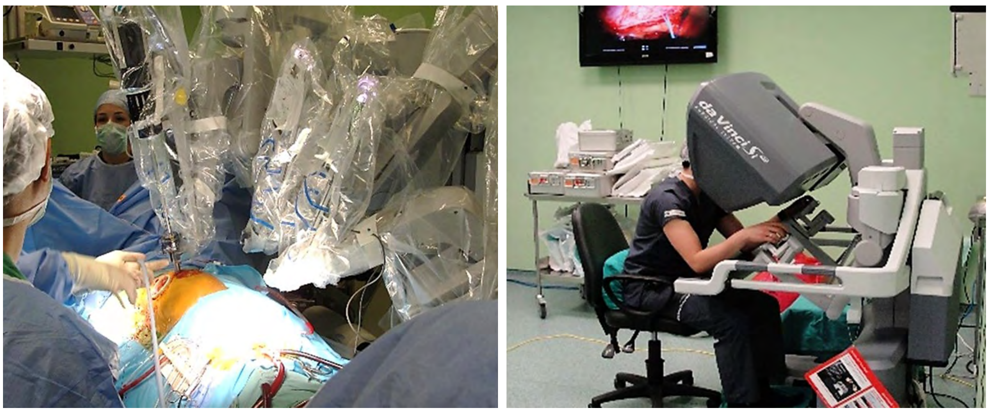

Figure 1. Surgeon console and patient bedside unit of the da Vinci system.

Table 2
Robotic cardiac surgical procedures

Procedures	Details
Coronary artery bypass grafting	Robotically-assisted minimally invasive direct coronary artery bypass Totally endoscopic coronary artery bypass
Mitral valve repair or replacement	Resection versus non-resection repair techniques Biological and mechanical valve replacement
Atrial septal defect closure	Primary closure of secundum type defects Patch closure of all types of atrial septal defects including coronary sinus type defects
Ablation for atrial fibrillation	Radiofrequency ablation or cryoablation procedures
Anomalous partial pulmonary venous return	Right upper pulmonary veins to the superior vena cava or right atrium
Left atrial appendage closure	With mitral valve surgery
Partial atrioventricular septal defects	Primum septal defect and mitral cleft closures
Intracardiac tumor resection	Right or left atrial and left ventricular myxomas Fibroelastoma of the mitral valve
Left ventricular pacemaker lead implantation	Arrhythmia surgery

aiguille (needle holder), potts scissors, and retractors. Depending on the process to be done, some of these tools can be selected. Frequently performed robotic surgical interventions include robot-assisted CABG with total endoscopic or mini-thoracotomy, mitral valve repair or replacement, closure of atrial septal defects, radiofrequency or cryoablation procedures in the treatment of atrial fibrillation, resection of some cardiac tumors, and left ventricular epicardial pacemaker implantation (Table 2).

INDICATIONS AND CONTRAINDICATIONS FOR ROBOTIC CABG

There is no absolute contraindication for minimally invasive cardiac operations.[27] All patients are candidates for a minimally invasive procedure. However, every patient should be examined in detail and the priority should be not to harm the patient during the intervention. The clinical status of the patients, associated morbidities, and anatomical features should be also evaluated well. Patient selection in robotic surgery is extremely important in terms of indications as much as the intervention itself. All interventions may not be appropriate for every patient.

Robotic CABG is commonly used in total occlusion or osteal stenosis of the left anterior descending artery (LAD).[9,11,16,17] It may be applied occasionally in proximal LAD stenosis, which is not suitable for percutaneous intervention. In addition, although less frequently, it can be used for the treatment of multivessel disease. In these patients, both ITAs and a second graft can be used individually or with sequential anastomosis techniques, although these interventions

Table 3
Patient selection criteria for robotic surgery

Ideal patient's characteristics	Relative contraindications
Body mass index less than 30 kg/m^2	Chest deformity
Age less than <70 years	Obstructive or restrictive lung disease
Left ventricular ejection fraction above 50%	Previous pericarditis or pleuritis
Isolated cardiac pathology	History of cardiothoracic operations
Forced expiratory volume in 1 second above 80%	History of chest trauma
Creatinine less than 1 mg/dL	Previous rib fracture, pneumo/hemothorax, tube thoracostomy
Femoral artery diameter above 7-8 mm	Peripheral artery disease
	Elevated diaphragm level
	History of radiotherapy to chest

are rarely applied in daily use. In addition, hybrid therapy may be an appropriate approach in some patient groups.[9,11] In hybrid procedures, stenting is usually performed with percutaneous technique in the right coronary or circumflex coronary arteries in the presence of severe stenosis or occlusion of the LAD artery. Left ITA-LAD artery anastomosis can be, then, performed by robotic methods. Of note, hybrid approaches can be used to reduce the morbidity and mortality of open heart operations.

PATIENT SELECTION

Surgical approach is decided before surgery according to the patients' history and physical examination.[27] The features which should be considered during patient selection are presented in Table 3. Possible complications can be prevented in this way. Cardiac surgical procedures are usually performed in older patients and lung, kidney, and cerebral diseases are common in this population. Avoidance of CPB or minimization of surgical incision in coronary artery disease can prevent organ dysfunction.[28,29] In addition, it has been shown that reducing inflammatory response provides protection of heart, lung, and kidney function. Minimally invasive approach and incisions are associated with less postoperative pain.[26,30,31] This provides more comfort for patients during coughing, the removal of secretions, and functional rehabilitation of the lungs.

Pleural pathologies are relative contraindications for robotic interventions. While mild and local adhesions do not cause much problems in endoscopic procedures, it is more appropriate to perform the operation with conventional techniques in the presence of severe adhesions and calcifications. Preoperative diagnosis of adhesions in the left pleura can be difficult and thoracic X-ray or computed tomography can be more helpful to predict adhesions and pleural thickening in severe lung pathologies, while mild pleural thickening and adhesions are difficult to be diagnosed preoperatively. Surgery and vision can be impaired in emphysematous pulmonary disease. Previous pericarditis can complicate the application of the surgical technique. In reoperation cases, MIDCAB and totally endoscopic coronary artery bypass grafting (TECAB) procedures are not preferred. Emphysematous changes and pleural thickening, retractions or calcifications are among the relatively contraindications in minimally invasive procedures.

In addition to associated morbidities, anatomical features are also important for a minimally invasive procedure. The height and weight of the patient and thoracic structure should be evaluated during physical examination in the preoperative period. Shorter patients with a short diameter of anteroposterior and upper-lower should be carefully examined for minimally invasive surgical techniques. Excessively obese patients (body mass index over 30 kg/m^2) should be meticulously evaluated. In female patients, the dimensions of the breast tissue may create difficulties during the port placement. In addition, the diaphragm height may impair the vision and access to the heart from the left thorax. In such cases, the left arm instruments and stabilizers cannot be placed from the fifth or sixth intercostal space for robotic surgical set-up.

Cardiopulmonary bypass may be required for MIDCAB and TECAB procedures in minimally invasive cardiac surgery. Therefore, it is of utmost importance to evaluate the aorta and iliofemoral arteries during preoperative angiography. Peripheral cannulation is often used for CPB. Patients with advanced age, diabetes, hypertension, and peripheral vascular disease should undergo preoperative physical examination and vascular imaging. Evaluation of the peripheral vascular structures for CPB prevents possible complications such as vascular laceration, rupture, or dissection.

ANESTHETIC APPROACH

Patients are operated under general anesthesia and double-lumen intubation.[32,33] In addition, single lumen intubation can be used safely, particularly during robotic-assisted CABG. The cessation of the left pulmonary ventilation during removal of the left and right ITA is particularly important during the placement of robotic instruments and postoperative bleeding control. Radial artery and central venous catheterization is usually performed in the preparation stage of the operation. External defibrillation pads are routinely used. One of the pads is placed on the lateral wall of the right thorax and the other on the posterior wall of the thorax just below the left scapula. After the procedure, heparin is neutralized with protamine. The dual lumen endotracheal tube is, then, replaced by a single lumen tube. Patients are extubated in the intensive care unit.

Transesophageal echocardiography is routinely used during surgery in all patients.[32,33] Therefore,

Table 4
Surgical steps in robotic coronary revascularization

Surgical steps
General anesthesia with single lung ventilation
Skin pads for defibrillation
Right 30 degree-supine position, left arm positioning
Port placement for robotic instruments
Docking procedure
Electrocautery for internal thoracic artery harvesting (15-20 W)
Carbon dioxide insufflation (3-6 lt/min, 8-12 mmHg pressure)
Harvesting of the left or right internal thoracic artery in a semi- or full-skeletonized fashion
Systemic heparinization
Mini-thoracotomy, coronary artery exposure, anastomosis for a MIDCAB procedure
No thoracotomy, pericardiotomy, endoscopic coronary artery exposure and anastomosis for a TECAB procedure

MIDCAB: Minimally invasive direct coronary artery bypass; TECAB: Totally endoscopic coronary artery bypass.

the knowledge and experience on echocardiography of the cardiac anesthesiologist is extremely important. Since the operation is performed with total endoscopy or mini-thoracotomy, the status of cardiac functions can be easily monitored by echocardiography. The volume and inotropic support during the procedure ensures the optimal evaluation of the heart. In addition, cerebral near-infrared spectroscopy is quite useful in robotic surgery. Using this tool, we can detect the alterations in hemodynamic parameters, intravascular volume requirement, hematocrit levels, and oxygen saturation level.

SURGICAL STEPS

After general anesthesia is delivered, the patient is placed in the supine position 30° to the right to remove the ITA (Table 4, Figure 2). The left thorax is elevated with a support placed beneath the scapula, the left arm lies sideways, and patient's dorsum is thrown back to give a slightly fowler position. The surgical field is prepared and covered with sterility. After this stage, the ports are placed for the left ITA harvesting. If the MIDCAB procedure is to be applied, left ITA is transected endoscopically after systemic heparinization, mini-bulldog clamp or mini-clips are used for hemostasis. The bleeding control of the chest wall is performed. The procedure is continued with mini-thoracotomy from the left fourth intercostal space. For total endoscopic CABG, the intervention is performed by opening the pericardium, followed by harvesting of the ITA.

Robotic CABG can be performed with off-pump or on-pump techniques. Therefore, perfusion support is important during both applications. External cardiac stabilization is important when using the off-pump technique. During anastomosis, air insufflation systems are used at low levels using room air or carbon dioxide. The main goal is to adjust the minimum effective level and it is known that excessive use of insufflation causes endothelial damage. In addition, the use of intra-coronary shunt preferably varies. In this case, the patient should be kept in normothermic degrees and the activated coagulation time should be kept between 150 and 200 sec. Using the on-pump technique, the MIDCAB or TECAB procedures can

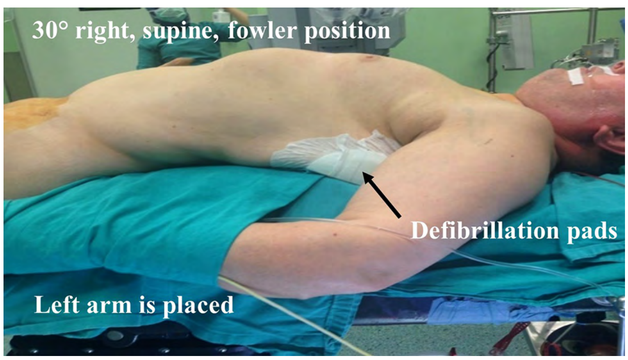

Figure 2. Position of the patient for robotic coronary revascularization.

be performed with or without cardiac arrest under peripheral CPB. The femoral tract is safely used in cases requiring peripheric cannulation and CPB.[34]

PLACEMENT OF ROBOTIC PORTS

The robotic system we use today is da Vinci Si HD (Intuitive Surgical, Inc., Sunnyvale, CA, USA) endoscopic surgery system. The ports can be placed differently (Figure 3). With the left thoracic approach, the left lung is deflated, and the thorax is monitored for possible adhesions with the camera port. This port is usually placed in the junction of the fourth intercostal space and anterior axillary line. Depending on the position of the patient, it can be shifted slightly to the medial or lateral position. The anatomy of the thorax is determinant for the position. The right arm instruments are placed through a port at the third intercostal space intersecting the anterior axillary line. In the same way, the left arm instruments are placed through a port in the fourth or fifth intercostal space intersecting the anterior axillary line. Approximately a 4- to 6-cm distance between these three ports allows the system to operate without any collision. In cases with elevated diaphragm, the surgical appearance and the operability of the system can be relieved by a traction suture, which will be placed on the diaphragm base. In total endoscopic CABG cases, the epicardial stabilizer is taken from the anteromedial of the left arm port into the thorax from the fifth intercostal space. Instruments commonly used for porting robotic arms include Debakey forceps, needle holder, mini-clip applicator, and electrocautery spatula. Surgical stages are achieved through the synchronized operation of the console and the bedside surgeon. The experience in endoscopic procedures and surgical knowledge of the bedside surgeon facilitates the operation.

After placement of the ports, the robotic patient side unit is docked. The electrocautery should be preferably used at a power of 20W. The use of higher power cautery causes more smoke in the thoracic cavity which impairs the endoscopic vision. In addition, excessive electrocautery leads to bleeding problems and hemostasis difficulties. It should not be forgotten that this robotic surgery is totally endoscopic and, in case of bleeding, gauze or serum washing cannot be taken from outside. During surgery, there are only instruments in the thorax and there is no one to assist you. This requires the surgeon to be more careful and experienced in robotic procedures.

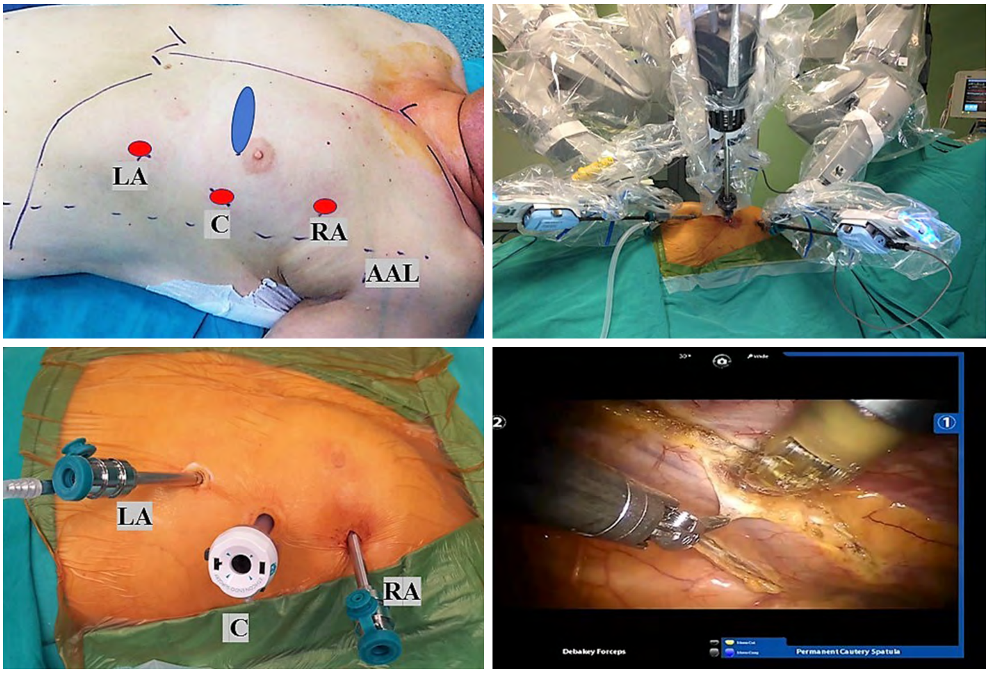

Figure 3. Port placement, docking, and harvesting of the left internal thoracic artery.
LA: Left arm; C: Camera; RA: Right arm; AAL: Anterior axillary line.

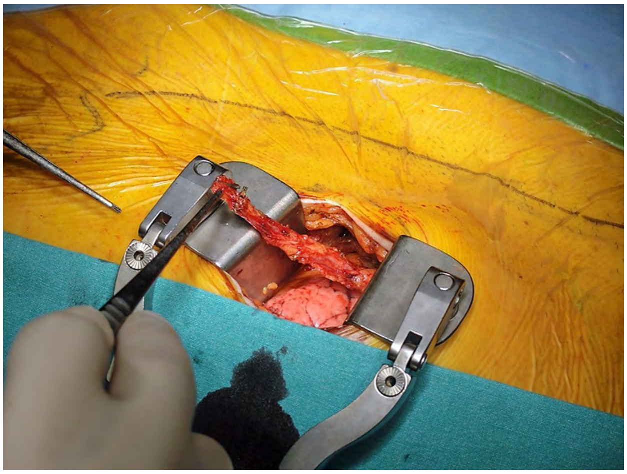

Figure 4. An intraoperative view showing the ideal length of the left internal thoracic artery and anterior mini-thoracotomy.

HARVESTING OF INTERNAL THORACIC ARTERY

In robotic surgery, ITA can technically be removed in three ways: pediculated, semi-skeletonized, or full-skeletonized (Figure 4). Cautery spatulas, mini-forceps, and mini-clamps are often used to remove the ITA robotically. Although each technique has own advantages and disadvantages, endothelial integrity can be protected with all three techniques. However, semi-skeletonizing and full-skeletonizing removal techniques highly depend on the surgeon's experience. In these techniques, the endothoracic fascia is first separated from the ITA. For full-skeletonized removal of ITA, the surgeon should avoid any traction on the vessel. There is no sensory feedback in robotic systems; therefore, traction depends on the experience and hand manipulations of the surgeon. In addition, atraumatic ITA harvesting requires the use of robotic mini-clips and angled precise Pott's scissors. When the equipment is not available, it may be advisable not to use semi- and full-skeletonized ITA removal techniques. By this way, ITA can be obtained in the ideal length and flow.

Another important issue is the technique of removing the pedicled ITA. Although adequate ITA length can be achieved in patients with a long sternum, this technique may cause ITA shortness in most patients. A short ITA anastomosis to the coronary arteries may cause traction, bleeding, myocardial ischemia, and mortality in the postoperative period. Avoiding pedicled ITA harvesting is helpful to prevent fatal complications.

If both ITAs are to be harvested, first the right ITA should be harvested and, then, the left ITA should be prepared endoscopically. During the procedure, thorax is washed by carbon dioxide insufflation (3-6 lt/min, 8-12 mmHg pressure). At the end of the procedure, a chest tube or silicone drainage tube may be placed in the chest cavity, if applicable. The skin is closed with interrupted sutures using sharp 4/0 prolene stitches.

MIDCAB PROCEDURE

Several studies in the literature have demonstrated the long-term efficacy of the MIDCAB procedure. This procedure is a safe alternative to off-pump sternotomy operations.[8] In long-term follow-up, graft patency has shown comparable results to normal operations.[8,16] Robotic instruments and ports are removed after the isolated left ITA or bilateral ITA is removed and transected. Left anterior mini-thoracotomy is performed along the fourth intercostal space starting from the lateral side of the sternum with 5 to 10 cm in length. The thoracic cavity is explored with the retractors used in minimally invasive surgery. Left ITA is assessed for free flow, size, and quality before the anastomosis. The distal side is prepared for the anastomosis. The pericardium opens anteromedially in the direction of the apex-pulmonary hilus, parallel to the LAD artery. Thus, the left ITA enters the pericardial space without any kink or torsion. Once the pericardiostomy is performed, the LAD is revealed with the help of sutures. External vacuum-assisted or pressure-assisted systems can be used for LAD stabilization (Figure 5). Coronary anastomosis is done using the off-pump technique. Air or carbon dioxide insufflation may be used during the procedure. The use of shunt during the anastomosis is based on the surgeon's preference.

An ideal left-sided ITA-LAD anastomosis can be summarized as an anastomosis in which endothelial injury-free manipulations are used, whereas ITA is not stretched and shows good filling (Figure 6 and 7). The left ITA should be left at the end of surgery between the mediastinum and the left lung, anterior to pulmonary hilus, ensuring that there is no traction. In case of suspicious vascular tension, it should be kept in mind that postoperative catastrophes may occur. In addition, in patients with a poor coronary artery vascular quality or low left ventricular function,

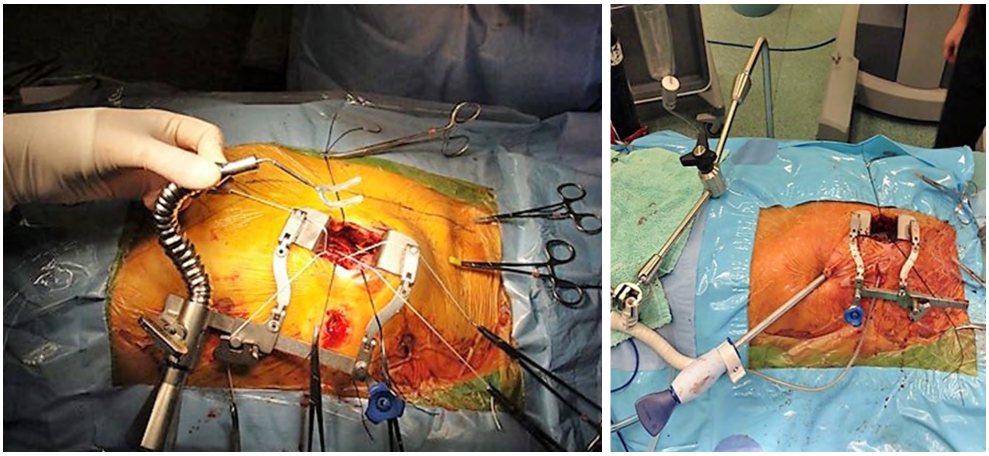

Figure 5. Surgical set-up for off-pump coronary revascularization through anterior mini-thoracotomy using mechanical (left view) and vacuum-assisted (right view) cardiac stabilizers.

MIDCAB under CPB may be preferred to warrant patient safety.

TECAB PROCEDURE

For the first time, total endoscopic off-pump CABG surgery was performed by Watanabe et al.[1] Loulmet et al.[2] reported the first robotic on-pump TECAB procedure with cardiac arrest in 1998. The first off-pump TECAB operation with endoscopic stabilizers was performed by Falk et al. in 2000.[3] Due to these difficulties, TECAB operations, which need a high degree of surgical experience and technical skills, have not become popular since then.

Robotic instruments are inserted into the thorax after placement of the ports. Bilateral or left ITA is harvested from the anterior chest wall by total endoscopic robotic surgery. Thoracotomy is not performed. Once the left ITA is prepared endoscopically and divided, the pericardium is opened and the target coronary artery is exposed. Coronary anastomosis can be performed using the on-pump or off-pump technique. After epicardial stabilization, the coronary artery can be rotated with special mini-loops, where applicable, from the proximal or distal side. Coronary artery is prepared for anastomosis by arteriotomy with robotic coronary scalpel and potts scissors. Coronary anastomosis can be made with ready-made suture materials, such as U-clips (Medtronic, Minneapolis, MN, USA) or prolene sutures. Continuous or individual suturing techniques are optional. At this stage, blood drops

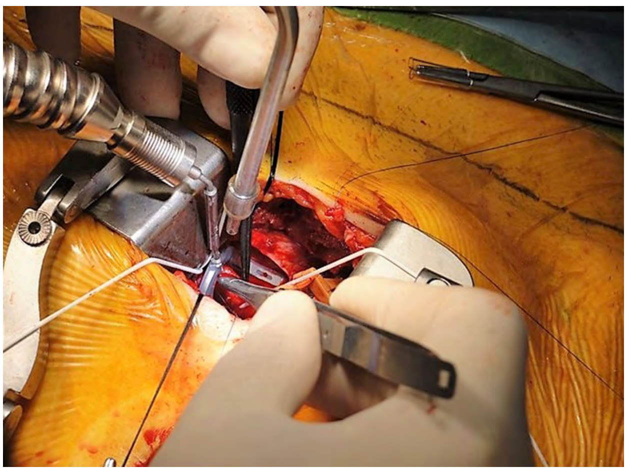

Figure 6. Off-pump coronary revascularization.

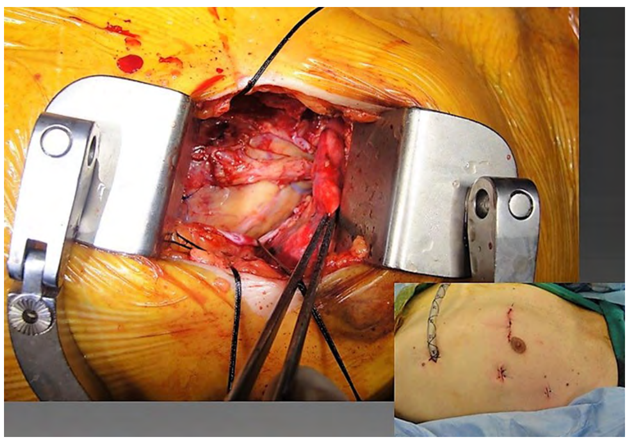

Figure 7. Final view after anastomosis of the left internal thoracic artery with the left anterior descending artery.

which accumulate in the surgical field are washed with a liquid-injection system mounted on the epicardial stabilization apparatus and a clear view is provided. Hypothermia can be maintained according to the preference of the surgeon in on-pump procedures. Endo-aortic balloon occlusion or transthoracic aortic clamps can be also used, if cardiac arrest is to be performed. A special epicardial vacuum stabilizer is used during coronary anastomoses.

MIDCAB AND TECAB IN AN ON-PUMP BEATING HEART

The on-pump technique can be used in MIDCAB and TECAB procedures. Hemodynamic stabilization can be performed by evacuating the heart on-pump during the MIDCAB operation. This is the preferred approach in multivessel disease or in cases with a poor vascular structure. A more secure anastomosis is provided for the patient safety during bypass.

MIDCAB AND TECAB WITH ON-PUMP CARDIAC ARREST

Some surgeons may prefer anastomosing on the arrested heart using this technique. This technique is preferred to perform a safe operation and to increase the anastomosis quality, particularly in patients with relatively thin and unstructured vessels. Antegrade blood cardioplegia can be used as a cardioplegia agent and Custodiol-HTK (histidine-tryptophan-ketoglutarate) cardioplegia solution can be used to provide cardiac arrest, as well. This liquid component, which is an organ preservation solution, can be safely delivered every 120 min to achieve cardiac arrest.[13,35] Endo-aortic balloon occlusion catheters are the easiest and reliable methods in TECAB procedures. However, transesophageal echocardiography and perfusionist support during operation and occlusion are extremely important.

HYBRID CORONARY REVASCULARIZATION

The main objective of hybrid treatment approaches is to reduce surgical morbidity and mortality using minimally invasive surgical techniques and catheterization interventions.[9,11] Postoperative complications in the surgical treatment of cardiovascular diseases are related to the type of operation, timing, and associated morbidities of the patient before surgery. Cardiopulmonary bypass methods used during cardiovascular surgery may also cause adverse effects after surgery.[36] Therefore, minimally invasive techniques with lesser systemic traumas and the simultaneous application of percutaneous catheterization methods have become more popular in recent years. Hybrid interventions used in cardiovascular diseases include hybrid CABG (minimally invasive) and percutaneous coronary interventions (PCI).

Hybrid CABG/PCI treatment is a combination of traditional surgical methods and PCI in a broad sense. Using this approach, early or elective interventions can be planned in patients with indications for coronary artery revascularization. Hybrid CABG/PCI can be used in high-risk patients for conventional surgical treatment.[9,11,37] The LAD revascularization with the left ITA is performed surgically in these patients. Complementary non-LAD coronary artery revascularization is performed with PCI. Indications for hybrid CABG/PCI include proximal LAD stenosis and presence of a non-LAD lesion (right coronary or circumflex artery) suitable for PCI. Non-LAD non-surgical coronary lesions (such as the proximal circumflex artery lesion in the atrioventricular groove) which are unsuitable for surgery, but suitable for PCI, can be preferred in hybrid methods. Hybrid coronary interventions can be performed by MIDCAB or TECAB techniques.[9,11]

In conclusion, robotic CABG operations are currently among the minimally invasive cardiac surgical interventions. These interventions offer important advantages, such as appropriate early rehabilitation of the disease, less blood product use, less pain, favorable cosmetic outcomes, and early return to daily life. Nevertheless, robotic surgical systems have significant disadvantages, such as high cost and limited availability. In the future, we believe that alternative robotic systems would be invented and become widespread, and the beneficial advantages would get ahead of the current disadvantages.

Declaration of conflicting interests

The author declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The author received no financial support for the research and/or authorship of this article.

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Cardiovasc Surg Int 2018;5(1):24-25
http://dx.doi.org/DOI: 10.5606/e-cvsi.2018.682
www.e-cvsi.org

Cardiovascular Surgery and Interventions

Letter to the Editor | Open Access

Pulmonary sinus of Valsalva aneurysm: A rare and important entity

İhsan Alur, Melih Us

Department of Cardiac and Vascular Surgery, Private Hisar Hospital Intercontinental, Istanbul, Turkey

Received: January 24, 2018 ***Accepted:*** February 14, 2018 ***Published online:*** April 24, 2019

We read the case report by Gajjar et al.[1] with a great interest. We, firstly, congratulate the authors and thank them for sharing their rare case and experiences with us. Nonetheless, we would like to make some contributions to this issue.

Pulmonary artery aneurysms (PAAs) or pulmonary sinus of Valsalva aneurysms (PSVAs) may be associated with connective tissue diseases, such as Ehlers-Danlos syndromes type VI, Marfan syndrome, Rubinstein-Taybi syndrome, Loeys-Dietz syndrome, and arterial tortuosity syndrome, Noonan syndrome, pulmonary valve stenosis or absent pulmonary valve syndrome, or the three most frequent congenital heart defects with a left-to-right shunt such as ventricular septal defects, atrial septal defects, and patent ductus arteriosus.[2-4] The aortic valve pathologies such as hypoplastic and bicuspid aortic valve disease may present concomitantly, as well.[4] In addition, PAAs or PSVAs can be associated with coronary artery anomalies and congenital keratoglobus.[2] On the other hand, acquired factors include chronic obstructive pulmonary disease, chronic pulmonary embolism, valvular heart diseases resulting in pulmonary arterial hypertension (PAH), vasculitis such as Behçet's disease, Hughes-Stovin syndrome or giant-cell arteritis, infections such as mycosis, tuberculosis, syphilis, septic pulmonary embolism, rheumatic disease such as sarcoidosis, or congenital pulmonary arteriovenous fistula or aneurysm, extravascular or intravascular post-trauma, and degenerative diseases including atherosclerosis and cystic medial degeneration.[2,4,5] Beyond this, several PAA cases without any underlying cause have been also reported in the literature. They are usually seen in the younger age group and affects both sexes equally.[4] The most common symptoms in patients with a PAA are shortness of breath, fatigue, palpitations, chest pain, syncopal episodes, cough, hemoptysis, and hoarseness. Pulmonary artery dissection or rupture, which is a fatal complication, develops in approximately one-third of cases with a PAA. Other severe complications include right cardiac failure due to pulmonary valve regurgitation, coronary ischemia secondary to left main coronary artery pressure, airway obstruction due to tracheal bronchial pressure, hoarseness due to recurring laryngeal nerve pressure, and formation of a thrombus inside the aneurysm, leading to pulmonary thromboembolism.[2] Hemoptysis is associated with a possible symptom and may be a warning sign for the presence of a ruptured aneurysm.

Dissection of a PAA is a rare, but life-threatening complication which occurs in approximately 20% of all PAA patients without PAH.[4] A structural collagen tissue disorder or infection, thinning/weakening of the pulmonary artery wall due to chronic inflammation, wall tension caused by degeneration, and chronic pressure/volume overload have been blamed for the basis of the pathophysiological mechanism of PAAs.[2] Medical treatment is recommended to improve clinical signs and symptoms of PAAs. If PAH accompanies a PAA, calcium channel blockers, anticoagulant treatment, diuretics, vasoactive substances such as endothelin receptor antagonists, phosphodiesterase type 5 inhibitors, and prostacyclin derivatives can be used.[2,4] However, it should be kept in mind that the majority of patients with normalized pressure still have a risk of increase in the PAA diameter.[4] Shunt

Corresponding author: İhsan Alur, MD. Hisar Hastanesi Intercontinental Kalp ve Damar Cerrahisi Bölümü, 34768 Ümraniye, İstanbul, Turkey.
Tel: +90 216 - 524 13 00 e-mail: alur_i@hotmail.com

Citation:
Alur İ, Us M. Pulmonary sinus of Valsalva aneurysm: A rare and important entity. Cardiovasc Surg Int 2018;5(1):24-25.

flow (left-to-right) or valvular pathologies (aortic or pulmonary valve) cause persistent hemodynamic stress, leading to PAA formation and dilatation and must, therefore, be a contraindication for conservative medical treatment. Nonetheless, there is no clear consensus on the surgical treatment for a PAA. Some authors have advocated surgical repair and recommended surgical intervention, when the pulmonary artery is dissected or the pulmonary artery diameter increases progressively.[2] However, surgical treatment is required in cases of right ventricular dysfunction, severe valvular insufficiency, thrombus formation in the aneurysm sack, confirmed PAH, compression of adjacent structures, and symptomatic patients with chest pain, shortness of breath, coughing, and hemoptysis, an absolute PAA diameter of ≥5.5 cm, an increase in the diameter of the aneurysm of ≥0.5 cm within six month, and signs of rupture or dissection.[2,4] Possible alternatives for surgical treatment of a PAA include interposition with a Dacron or homograft, repair with a pericardial patch, aneurysmorrhaphy, and arterioplasty.[2] In general, patients with PAH should be seriously considered for the surgical treatment. It is considered that an aggressive surgical approach has the risk of dissection and rupture in these patients. Nevertheless, surgical therapy seems to be the only treatment with the possibility of effective long-term survival.[4] In patients with vasculitis, immunosuppressive therapy seems to be reasonable. Interventional therapy is a relatively new treatment method for PAAs, and coil embolization seems to be a good treatment option for iatrogenic causes and small branches of the pulmonary artery. Moreover, there is even a report of complete occlusion of a dissected PAA by a covered stent.[4]

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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