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REVIEW ARTICLE

Hybrid Cardiovascular Surgery

Hibrid Kardiyovasküler Cerrahi

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ABSTRACT

Today, cardiologists and cardiovascular surgeons are more likely to encounter patients with multiple comorbidities and cardiovascular diseases. Percutaneous and surgical techniques alone cannot be successful or are high risks in these patients. By using the strengths of the two methods in a hybrid manner, low-risk procedures can be performed in these patients. With the developing technology, new hybrid procedures can be created for myocardial revascularization, heart valve diseases, aortic and peripheral vascular diseases.

Keywords: Hybrid Surgery, Cardiovasculsr Surgery, cardiovascular disease

ÖZ

Gümünüzde kardiyologlar ve kardiyovasküler cerrahlar birden çok komorbiditeye ve kardiyovasküler hastalığa sahip hasta grubuyla daha sık karşılaşmakta. Perkutan ve cerrahi teknikler bu hastalarda tek başına başarı sağlayamamakta veya yüksek riskli olmakta. İki yöntemin güçlü yönlerini hibrid bir şekilde kullanarak bu hastalarda düşük riskli prosedürler gerçekleştirilebilmektedir. Gelişen teknoloji ile birlikte miyokardiyal revaskülarizasyon, kalp kapak hastalıkları, aort ve periferik damar hastalıkları için yeni hibrid prosedürler oluşturulabilmektedir.

Anahtar Kelimeler: hibrid cerrahi, kalp ve damar cerrahisi, kardiyovasküler hastalıklar

Hybrid Cardiovascular Surgery

In cardiac surgery, the frequency of encountering patients with complications with high mortality and morbidity is increasing in parallel with the aging population. In these patients, treatment with interventional procedures is often insufficient, and total open surgery involves high risks. While investigating the ideal treatment approach in such patients, hybrid treatment options have become an alternative. In this method, simultaneous or staggered treatment is performed by making use of open surgery and interventions to a certain extent (1-3). Thus, it is aimed to have the least complications and high survival rate. Hybrid therapy in cardiac surgery in the world gained momentum after 1996 with the introduction of drug-eluting stents and minimally invasive surgical applications (3).

The application area of hybrid interventions in the treatment of cardiac events is quite wide. These include percutaneous coronary intervention (PCI) with coronary bypass surgery (CABG), valve replacement combined with PCI, aortic debranching with endovascular grafting, combined epicardial and endocardial ablation (3-20). To achieve good results in hybrid surgery, good collaboration between cardiologist and surgeon is required. In these approaches, studies on patient selection are still ongoing. In this review, we planned to evaluate the combined hybrid procedures that can be applied in the main problems in cardiac surgery.

Basic recommendations before hybrid cardiovascular interventions

Today, with the increase in the volume of hybrid cardiovascular (HCV) procedures, it has become a necessity to provide harmony and cooperation between departments such as interventional cardiology, cardiovascular surgery, radiology and anesthesia, as well as the design and efficient administration of a HCV system.

Planning for a successful HCV procedure should begin well before the procedure. In institutions with a HCV program, a multidisciplinary team with members from interventional cardiology, cardiovascular surgery, radiology and anesthesia departments should be established. Patients scheduled for this should ideally be evaluated by all members of the multidisciplinary team prior to the planned procedure. This team should meet regularly to discuss and plan cases, evaluate the operation and its follow-up, evaluate the short, medium and long term results of the approach and take improvement measures. In addition, nurses, caregivers and auxiliary staff who will work in the hybrid cardiovascular intervention (HCVI) unit and in the post-operative follow-up stages should be selected and educated among individuals with sufficient knowledge and skills.

For a successful HCVI, a sufficiently wide, ergonomic hybrid room (suite) is needed, which includes surgical, anesthetic and interventional equipments, allowing procedures in the operating room and catheterization laboratory. The room should have a laminar flow and the utmost attention should be paid to surgical sterility. A high quality fixed fluoroscopy unit is required in the hybrid room, ideally biplane, floor or ceiling mounted. Some centers use portable fluoroscopy units, which are less costly. However, these devices are not very suitable for complex hybrid cases, and their image quality is low. Fluoroscopy unit should be able to perform Digital Subtraction Angiography. Some fluoroscopy units have 360° rotational computed tomography angiography feature. In this way, it can be a good assistant for difficult and complex operations by obtaining 3D angiographic images. With the image-fusion technique developed in recent years, the tomography taken in the preoperative period is loaded into the fluoroscopy unit, assisting to provide navigation during the procedure, thus reducing the exposure to radiopaque materials and radiation in complex and difficult procedures. Echocardiography and intravascular ultrasound imaging methods should also be available in the hybrid room if needed. In addition, the hybrid room should be in a location where imaging devices such as tomography and magnetic resonance imaging can be easily reached.

The full-time use of the hybrid room may not be possible given the current volume of cardiovascular interventions alone. In cases where the room is not used for hybrid procedures, it should also be used as a catheter laboratory or cardiovascular operating room in line with the needs of the institution and its physical location should be determined accordingly.

Hybrid coronary revascularization

Although the treatment with PCI in coronary artery disease (CAD) has increased gradually in recent years, surgical treatment is still the gold standard in multivessel lesions, especially in three-vessel disease and left main CAD. The superiority of surgical treatment with PCI has been proven in patients especially with poor left ventricular functions and diabetic patients. In this superiority, the use of internal mammary artery (IMA) graft to the left anterior descending coronary branch (LAD) has a large share. The patency rate of this graft in the 10- and 20-year follow-ups is up to 90-95% (21,22). However, the use of grafts other than IMA does not seem to be as beneficial as PCI. Saphenous vein graft, which is the most commonly used secondary graft, has a stenosis rate of 30% in 1 year and 50% in 10 years (23). Restenosis rates of drug-eluting stents (DES) following PCI are approximately 8% per year (24). This demonstrates the potential benefit of the hybrid coronary revascularization (HCR) procedure. PCI to the left circumflex coronary artery and/or right coronary artery following a minimally invasive or off-pump IMA-LAD procedure may be a superior alternative to conventional CABG or multi-vessel PCI in selected patients.

HCR procedures began in the world in 1996. First, the patient underwent CABG operation a few days after the interventional cardiologists performed PCI on the lesion responsible for myocardial infarction (MI).In this way, cooperation between interventional cardiologists and cardiovascular surgeons began to increase. Over time, patients' cosmetic concerns, developing technology, and studies to shorten their recovery and hospital stay have increased the tendency for minimally invasive CABG.As a result, these cases became feasible with a single combined procedure.

Since then, it has been shown in clinical evaluation studies on this subject that the results are at least not worse than classical CABG applications. Despite all the positive results, the clinical use of HCR is still limited. The most important limiting factor here is that the hybrid operating rooms required for the procedure are expensive and cannot be set up everywhere. The second factor is the lack of accepted common practices on HCR. However, the method is increasingly entering clinical uses over time.

Indications and contraindications:

Hybrid coronary revascularization is particularly indicated in high-risk patients with non-LAD lesions suitable for PCI and multivessel patients with proximal LAD lesions suitable for surgery. HCR is more beneficial in patients with additional lesions that increase morbidity and mortality, such as diabetes, advanced obesity, kidney failure, lung disease, and advanced age. HCVI has advantages in patients with concomitant organ dysfunctions, a history of recent MI, previous sternotomy, an ejection fraction of less than 40%, and a diffuse atherosclerotic plaque in the aorta. In addition, this procedure should be considered in patients with porcelain aorta, inadequate arterial and venous grafts, and patients with at least two vessels coronary arteries disease who are not suitable for grafting (2).

On the other hand, HCR is contraindicated in patients with intramyocardial course of LAD, ungraftable LAD, stenosis in the subclavian artery or IMA, and a body mass index above 40 kg/m$^{2.}$ Diffuse CAD, coronary arteries smaller than 1.5 mm, curved and extensive calcifications of coronary arteries, previously stented coronary arteries, presence of fresh thrombus, chronic total occlusions, bifurcation lesions and peripheral arterial diseases causing problems for catheterization also limit and complicate the application of HCR. In addition, both PCI and HCR are not possible in patients with radiocontrast allergy and dual antiplatelet therapy contraindications.

The following indications are included in the American Guidelines for HCR:

1. Presence of one or more of the following (Class IIa, level of evidence B):

a. Patients who are unsuitable for classical CABG due

to the presence of advanced calcified aorta or poor graft condition, but having coronaries suitable for PCI.

b. Not having enough grafts for CABG,

c. Failure to perform PCI on the LAD for reasons such as excessively curved anatomy or chronic total occlusion

2. in patients who will undergo multi-vessel PCI or CABG, if it is thought that better results will be obtained by considering the risk-benefit balance of the procedure, HCR can be considered as an alternative (Class IIb, level of evidence C).

According to the European guidelines, hybrid intervention is defined as "the sequential or combined application of surgical and interventional revascularization procedures in specific patients in experienced centers" (Class IIb, level of evidence B).

For this purpose, simultaneous or stepwise hybrid approaches may be preferred. In the combined approach, it is possible to achieve complete revascularization in a single step with minimal effect on patient comfort. In addition, the IMA-LAD anastomosis patency can also be checked. Up to 12% of early graft failures can be detected and corrected angiographically. With this approach, the hospital stay may also be shorter. However, there is a risk of bleeding complications due to dual antiplatelet therapy and incomplete neutralization of heparin. Stent thrombosis may be another risk factor.

Hybrid coronary interventions can be as PCI before CABG, concomitant CABG and PGK, or PCI after CABG. In the stepwise method, incomplete revascularization between two procedures may pose a risk for a cardiac event. In addition, the risk of bleeding after CABG is high due to dual antiplatelet therapy in patients who have undergone PCI before. Stent thrombosis may occur due to heparin neutralization. However, in cases where IMA-LAD anastomosis was performed first, anastomosis control is also possible during stenting. There is no risk of bleeding due to antiaggregants. For these reasons, unless otherwise needed, IMA-LAD anastomosis is performed first, than PCI performed. One of the most important problems in simultaneous procedures is the loading dose of clopidogrel. In a study, it was shown that a loading dose of 300 mg of clopidogrel provided sufficient platelet inhibition without an increase in adverse events after the procedure (25).

Studies have shown that HCR has better results after DES, shortens hospital and intensive care unit stays, and accelerates recovery. It is emphasized that there is no difference between off-pump and on-pump CABG in terms of complications and survival. In a study by Hage et al. in 2019, 216 off-pump CABG and 147 HCR (robotic minimally invasive IMA-LAD and PCI to other vessels) were compared (4). It was observed that patients who underwent hybrid coronary revascularization recovered in a shorter time, and there was no difference between the groups in terms of short and long-term outcomes. In a study by Giambruno et al. (6), 682 on-pumps and 147 HCR (robotic minimally invasive IMA-LAD and PCI to other vessels) were compared. The hybrid approach has been shown to have lower hospital mortality (1.3% CABG, 0% HCR) and shorter hospital stay. In the follow-ups, fewer anginal symptoms were observed in HCR patients, and no difference was found between survival and revascularization rates.

Percutaneous coronary intervention and minimally invasive valve surgery.

Today, heart valve repairs or replacements can be performed with low morbidity and mortality. However, minimally invasive surgical procedures have been used for the last 15 years in order to avoid complications in comorbid conditions such as advanced age, frailty, previous heart surgeries, severe lung disease, chronic kidney failure, multiple procedures, and obesity (10-12). In 1996, Cosgrove's (26) minimally invasive aortic valve replacement surgeries have been the pioneer of minimally invasive surgery in valve diseases. In this way, procedures in high-risk patients can be performed through small incisions.

The traditional approach for combined valve disease and CAD usually includes combined valve surgery and standard CABG. Combined valve surgery and CABG mortality is higher than in patients who have these operations alone. Mortality and morbidity rate increases even more in patients with reoperations and multiple comorbidities. The mortality of PCI in elective cases is below 1%. The mortality of minimally invasive valve surgery is also between 0.7-2% (27). In this situation, significantly better results can be expected in minimally invasive valve surgery combined with PCI. since this method simplifies a high-risk surgery Although hybrid approaches that combine traditional valve operations and PCI are applied occasionally, they are still not common. In this condition, alternatively, minimally invasive valve replacement or repair or catheter-based transapical aortic valve implantation (TAVI) procedures simultaneously with PCI are available. PCI and right thoracotomy facilitate the surgeon's work in patients with CAD and mitral valve disease who have had previous aortic valve replacement. In the same scenario, in the presence of a history of CABG and a patent graft, the operation can also be performed on the beating heart. Two high-risk procedures can be performed as two low-risk procedures.

In this procedure, the timing of PCI is important because of increase bleeding from the use of clopidogrel. PCI can be performed 5-7 days or 24 hours before surgery. However, an increased need for transfusion and revision may be observed in these patients. In addition, it should be kept in mind that there may be a risk of stent thrombosis during heparin neutralization in surgery. It is most appropriate to perform PCI after clopidogrel loading in the hybrid room, and then to complete the surgery within 6 hours of the onset of the drug's effect.

Byrne et al. (28). performed aortic and mitral valve surgery after PCI on 26 high-risk patients. In the case of simultaneous CABG and valve surgery in this patient group, the mortality rate was 22% according to the Society of Thoracic Surgens score. As a result of the hybrid approach, mortality was 3.8%. Brinster et al. (29) observed the positive effects of hybrid intervention on mortality in the coexistence of high-risk CAD and severe valve disease. The authors performed preoperative PCI on 18 patients with advanced age (mean: 76), severe aortic stenosis, and one or two severe CAD. Of these, six patients were treated with DES before surgery and 12 patients on the morning of surgery. Before the intervention, 325 mg of acetylsalicylic acid were administered to the patients. And 300 mg of clopidogrel were administered after the PCI. Subsequently, the patients underwent minimally invasive aortic valve surgery. Although operative mortality due to gastrointestinal perforation was observed in one patient: No mortality was observed in 17 patients in 19-month follow-up. Seven patients required one unit of erythrocyte suspension. Acute and subacute stent thrombosis was not observed. In a study George et al. (10), PCI was performed on 26 patients after mitral valve surgery in the hybrid room. 300 mg of clopidogrel was given after induction of anesthesia in standard cases. 300 mg of clopidogrel was given after X-clamping in reoperations. There was no mortality, stent thrombosis or indication for reintervention. In high-risk patients, minimally invasive valve surgery with PCI can reduce adverse events. However, it is unknown whether this strategy provides long-term benefit over conventional surgical valve replacement and CABG, especially in cases with PCI to the proximal LAD. Therefore, randomized controlled studies are needed. PCI and minimally invasive valve surgery may be preferred in selected patients to reduce the cumulative risk.

Coexistence of Carotid and Coronary Artery Disease

Carotid artery disease and CAD is a relatively common finding. CAD occurs in almost 50% of carotid endarterectomy (CAA) patients. Also, significant carotid artery disease is seen in approximately 14% of patients underwent CABG(30). MI may be seen in up to 17% of patients underwent carotid endarterectomy and stroke may be observed in up to 20% of patients underwent CABG (31). In combined CEA and CABG surgeries, adverse events can increase up to 27% (31).

With the advent of distal embolism protection devices, carotid artery stenting (CAS) has become safer. In this way, interest in combined CAS and CABG procedures has started to increase in order to reduce the risks in combined procedures. The risks have been tried to be minimized, especially with the beating heart bypass by not touching the aorta technique. In the combined CAS-CABG hybrid procedure: CABG followed by CAS and CAS followed by immediate CABG procedures may be preferred. It is important to evaluate aortic and carotid artery calcifications with preoperative thorax and neck tomographic angiography in terms of preventing aortic emboli in patients who will undergo CAS.

In the literature, there are many studies related to such combined processes. Of these, Ziada et al. (32) found that the risk of MI or stroke in 167 (56 CAS+CABG, 111 CEA+CABG) patients was significantly lower in patients who underwent CABG followed by CAS (%5,4) compared to patients who underwent combined CEA-CABG (%18,9).

Carotid artery stenting and CABG hybrid procedure reduces mortality and morbidity in selected patients. During the timing of stenting, it should be considered that clopidogrel use will increase the risk of bleeding in CABG, and planning should be done accordingly.

Carotid Artery and Aortic Valve Stenosis

The coexistence of carotid artery stenosis and aortic valve stenosis (AS) usually occurs in the presence of advanced age and risk factors such as hypertension and hyperlipidemia. It is estimated that up to 13% of patients with degenerative calcific AS also have carotid stenosis (33). To reduce the risk of surgery, aortic valve surgery followed by CAS treatment has been recommended. Patients with severe AS may experience reduced preload and hypotension with carotid bulb stimulation during carotid stenting. It should be kept in mind that it is generally not tolerated in AS patients and may complicate the procedure.

Hybrid Vascular Procedures

In recent years, with the developing technology, it is possible to intervene endovascularly in the lesions of the arch, descending and abdominal aorta, which have high surgical morbidity and mortality, in patients with advanced age and many comorbid factors. In some cases, endovascular treatment alone is not sufficient and limited surgical procedures are involved.

Open surgical repair of aortic arch aneurysm requires cardiopulmonary bypass, aortic cross-clamp, and deep hypothermic circulatory arrest and is associated with significant morbidity and mortality (13-19). In the case of normal disease-free aortic regions in the ascending and descending aorta, hybrid application is possible. First, the aortic arch branches are revascularized with the help of a branched dacron graft from the supraconary ascending aorta. The endovascular stent graft is then extended from the ascending aorta to the descending aorta. Koullias et al. (34) reported a 30-day mortality rate of 8.3%, a stroke rate of 4.2%, and a leak rate of 9.2% in 463 patients underwent hybrid aortic arch intervention in a study. The results of hybrid surgical endovascular aortic arch procedures are generally promising.

In Stanford type A dissections, the frozen elephant trunk hybrid procedure can be performed in the form of reimplantation of the ascending and aortic arch and branches of the arcus aorta with the help of a

branched graft and placement of an endovascular stent graft extending from the distal of the branched graft to the descending aorta (16). In this way, it is aimed to stabilize the descending aorta, to progress the dissection and to prevent a secondary intervention or to create an easy site for a second endovascular repair or surgery. Chu et al. (17) reported in a study that, the 30-day, 1-year and 2-year survival rates of 40 patients underwent frozen elephant trunk technique between 2014-17 were 95%, 95%, and 90% respectively.

Thoracoabdominal aortic aneurysm surgeries are challenging surgeries with serious complications such as spinal cord damage up to 20%, mesenteric and renal ischemia, and death due to X-clamp and CPB (16,19). Patients are mostly elderly and with multiple comorbidities. Endovascular approaches have therefore received great interest. Endovascular procedures such as fenestrated and branched grafts, chimney technique cannot meet the need to preserve major visceral and renal branches in this area and cannot fully resolve complications such as leakage. Hybrid procedures have been developed involving endovascular stent graft placement for aneurysm exclusion followed by laparoscopic or open surgical bypass of visceral and renal vessels can be perform in one or two stages .

Bakoyiannis et al. (36) reported in a study with 108 patients, that the 30-day mortality was 10% and the graft patency was 97% in an average follow-up period of 10.6 months, and the results were quite promising.

Hybrid Methods in Lower Extremity Artery Disease

The use of the hybrid technique in lower extremity arterial disease is to achieve complete revascularization (37-40). Patients with multifocal disease involving the ilio-femoral and femoro-popliteal systems can be treated in a hybrid fashion with endovascular stenting of the iliac artery followed by surgical bypass or endarterectomy to the femoro-popliteal lesion. In this condition, the incoming blood flow to the graft can be increased to increase the graft patency. In addition, in the case of lesions involving the femoro-popliteal and distal arteries, the femoro-popliteal lesion can be treated in a hybrid manner with surgical bypass or endarterectomy and drug-coated balloon dilation to the distal vessels. In this condition, the distal run-off of the graft can be increased to increase the graft patency.

Other Cardiovascular Hybrid Procedures

Today, percutaneous treatment methods are used with high success rates to cope with challenging conditions such as post-infarction ventricular septal rupture and paravalvular leak (PVL) (41). Sometimes it is not possible to access the lesions by the percutaneous route, and it appears as a situation that hinders the success of the procedures. For example, percutaneous access and closure of mitral PVLs directly adjacent to the medial, posteromedial, interatrial septum and aortic valve is difficult. In this case, left lateral thoracotomy can be performed to allow the device to reach the mitral PVL easily.

In order to avoid ventriculotomy in patients with PIVSR, reptured septum can be closed, especially in the anterior region, with a puncture made from the anterior aspect of the right ventricle. The device can be placed by direct access from the right atrium to the right ventricle. In this way, the device can be manipulated and checked whether it is placed in the right place.

In the future

It is certain that the appetite of interventional cardiologists and cardiovascular surgeons towards minimally invasive and hybrid procedures with the advancing technology and materials science will lead to increased hybridization and continued growth of HCV techniques. Discovery of new techniques, elucidation of optimal timing strategies between phases of hybrid procedures, continuous improvements and integration of multimodality imaging technologies used for HCVI, including computed tomography, echocardiography, and angiography, are horizons we hope to see in the near future.

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