Clinical Research in Cardiology (2019) 108:974–989
https://doi.org/10.1007/s00392-019-01470-6

REVIEW

Cardiac surgery 2018 reviewed

Torsten Doenst[1] · Steffen Bargenda[1] · Hristo Kirov[1] · Alexandros Moschovas[1] · Sophie Tkebuchava[1] · Rauf Safarov[1] · Mahmoud Diab[1] · Gloria Faerber[1]

Received: 8 February 2019 / Accepted: 22 March 2019 / Published online: 30 March 2019

Abstract
For the year 2018, more than 22,000 published references can be found in PubMed when entering the search term "cardiac surgery". As in the last 4 years, this review focusses on conventional cardiac surgery publications which provide important and interesting information especially relevant for non-surgical colleagues. Interventional techniques have been considered if they were published in the context of classic surgical techniques. We have again reviewed the fields of coronary revascularization and valve surgery and briefly touched on aortic surgery and surgery for terminal heart failure. For revascularization of complex coronary artery disease, bypass grafting was reconfirmed as gold standard and computer-tomographic angiography established equipoise for decision-making with classic angiography. For aortic valve treatment, some new longer-term outcomes from TAVI vs. SAVR trials confirmed equipoise of both treatments for high and medium risk. New information was provided for INR-management of mechanical aortic valves as well as long-term experiences for alternatives to mechanical valves (i.e., Ross and the relatively new Ozaki procedure). In the mitral and tricuspid field, prevalence data illustrate a significant amount of under-treatment for mitral and tricuspid valve regurgitation and evidence for life prolonging-effects of surgery. Finally, elongation of the ascending aorta was identified as new risk factor for aortic dissection and 2 years outcome of the newest generation of left ventricular assist devices demonstrate impressive improvements in outcome. While this article attempts to summarize the most pertinent publications, it does not expect to be complete and cannot be free of individual interpretation. As in recent years, it provides a condensed summary that is intended to give the reader "solid ground" for up-to-date decision-making in cardiac surgery and a stimulus for in-depth reading.

Keywords Coronary revascularization · Aortic valve surgery · Mitral valve surgery · Tricuspid valve surgery · Aortic surgery · Left ventricular assist devices · Heart transplantation

Coronary revascularization

In 2018, the field of coronary revascularization was characterized by important publications addressing (1) indications for revascularization (new guidelines appeared); (2) new tools for the diagnosis of coronary artery disease (CAD); (3) the role of medical therapy in CABG patients and (4) technical aspects of CABG conduct.

CABG versus PCI

Head et al. combined patient data from 11 prospective randomized trials comparing CABG with PCI in stable multivessel disease with or without left main stenosis. They identified a significant survival advantage of CABG at 5 years [1] (Fig. 1a). They also found more strokes in this large dataset in the CABG population at 5 years and showed through a landmark analysis that the difference was solely due to more periprocedural strokes with CABG compared to PCI and no difference after the first 30 days [2] (Fig. 1b). It is important to realize at this point that the majority of CABG procedures were performed using cardiopulmonary bypass and that avoiding manipulation of the aorta (through off-pump strategies) may significantly reduce stroke risk [3]. These technical aspects are now also part of the guideline recommendations [4] (Fig. 1c). The survival effect of CABG

✉ Torsten Doenst
doenst@med.uni-jena.de

[1] Department of Cardiothoracic Surgery, Friedrich-Schiller-University of Jena, Am Klinikum 1, 07747 Jena, Germany

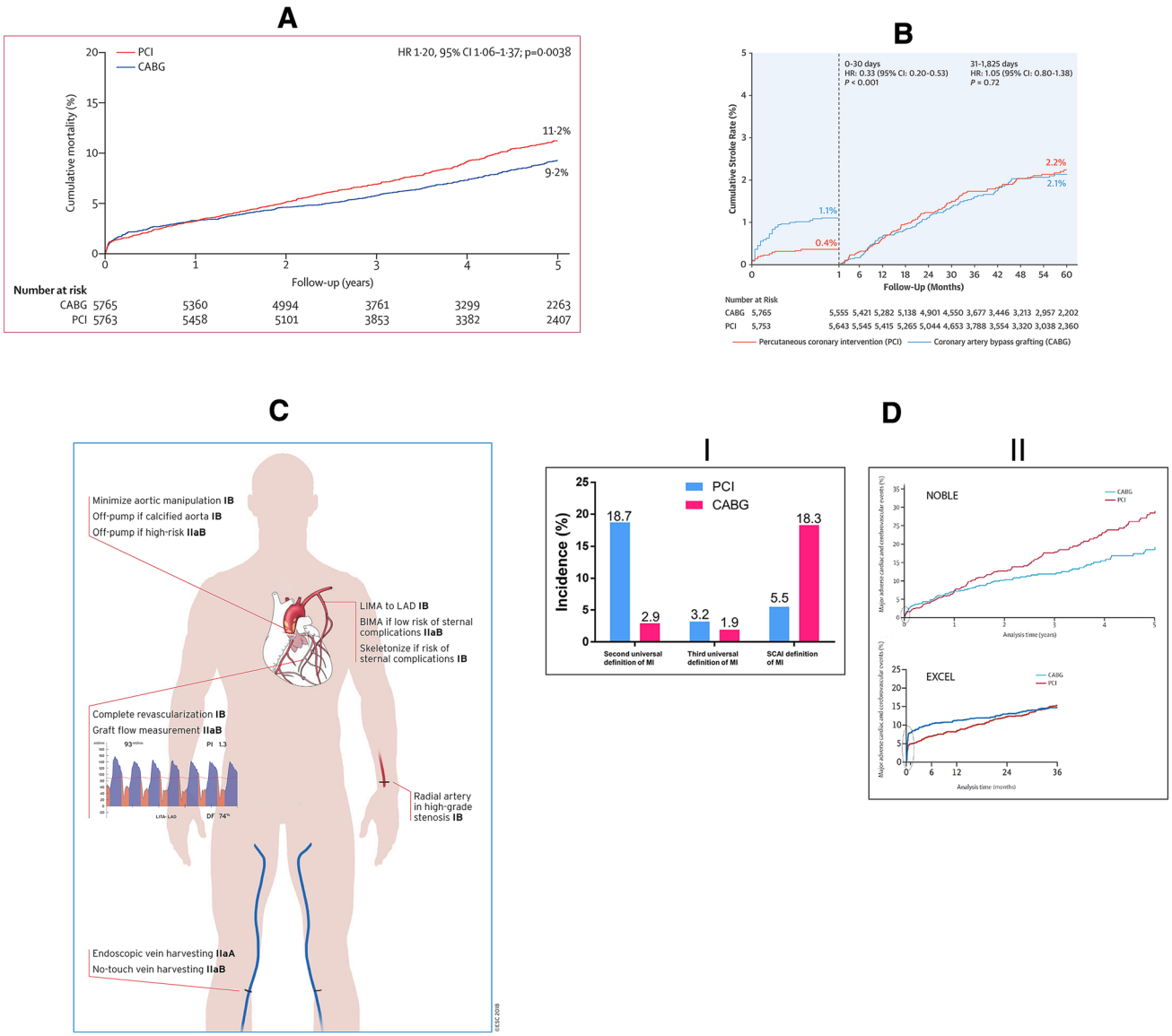


Fig. 1 Main findings of coronary bypass surgery publications 2018. **a** Pooled analysis of more than 11,000 patients from 11 randomized trials comparing coronary bypass surgery (CABG) and percutaneous coronary intervention (PCI) in patients with triple vessel disease with or without left main stem stenosis [1]. **b** Landmark analysis of the same patient population for the incidence of perioperative and long-term stroke [2]. **c** Schematic illustration of current guideline recommendations for the performance of coronary bypass surgery [4]. **d** Illustration of the impact of changing definitions of myocardial infarction on the incidence of this outcome in the same patient population (I) and the influence of using different definitions on primary endpoints of current trials (II) [8]

in the multi-trial analysis [1] was primarily visible in diabetic patients, which was further supported by Farkouh et al. [5], who published the long-term follow-up (8 years) of the FREEDOM trial (comparing PCI with CABG in diabetic patients) again with significantly better survival with CABG.

From the EXCEL trial (comparing PCI with CABG in patients with left main stenosis and SYNTAX score below 32), a sub-analysis addressing the role of main stem lesion site was published. The authors demonstrated worse outcome for patients with distal main stem versus shaft lesions, but found no difference in their primary combined endpoint of death, stroke and myocardial infarction at 3 years [6], consistent with their primary endpoint report from 2016 [7].

The EXCEL trial was heavily criticized for its consistent proclamation of non-inferiority of PCI to CABG at 3 years, despite the fact that a survival advantage was allegedly statistically significant only 12 months later [8]. Longer-term outcomes appear to be known, but have not yet been published [8].

Ruel et al. [8] criticized the current practice of design and reporting of outcomes in trials comparing PCI and CABG, including the EXCEL trial. The authors state that most trials

confer a significant selection bias towards "PCI-friendly" patients. They argue that the majority of trial patients only represent a very small fraction of every-day patients and that most excluded patients were excluded for poor suitability for PCI but not for CABG (as evident from several available trial registries). Most striking, however, is the illustration how changes in the definition of myocardial infarctions may result in completely opposite interpretations of this outcome in the same patient population (Fig. 1d). The authors conclude that from a patient perspective, publically funded trials with peer-reviewed designs and long-term follow-ups with and beyond 10 years would be desirable [8]. From a practical standpoint, such concerns regarding trial design and results presentation may not be helpful in decision-making for the every-day patient.

Based on the above criticism, the following registry studies appear to be of interest. Ram et al. published a real-life analysis of 1063 patients with triple vessel disease (27% of them had left main stenosis) from an Israeli registry demonstrating a significant survival advantage for CABG. Although this survival effect remained with risk adjustment by propensity matching [9], the limitations of more renal dysfunction, older age and more ischemia in the PCI population require mentioning.

Most studies have excluded patients with impaired left ventricular function. We demonstrated in 2016 a survival advantage of CABG over medical therapy in patients with impaired systolic function (i.e., EF < 35%) [10]. This year, Iribarne et al. [11] published outcomes from 955 CABG patients and 718 PCI patients with double and triple vessel disease (out of 74,000 patients from seven centers) that fulfilled the STICH criteria. Bypass surgery reduced mortality risk by 41% (Fig. 2a). Another analysis identified 67 propensity-matched pairs out of two British registries with 717 patients who received either PCI or CABG at an EF below 30% [12]. The authors demonstrated a significant survival advantage with CABG, quoting a more than threefold increased risk in mortality with PCI (hazard ratio 2.603, CI 1.500–4.515). Finally, Cui et al. published a meta-analysis from 8 trials comparing PCI and CABG in the presence of impaired left ventricular function [13]. Again, this analysis demonstrated a statistically significant survival advantage for bypass surgery compared to PCI, especially if the ejection fraction was below 35% (hazard ratio 1.43 CI 1.07–1.90).

New tools for the diagnosis of coronary artery disease

In order to perform CABG, adequate imaging of the coronary anatomy is mandatory and has been classically obtained by invasive coronary angiography. Progress in computer-tomographic imaging of coronary arteries has now raised the question of non-inferiority to invasive coronary angiography. We demonstrated in the SYNTAX III REVOLUTION trial on 223 patients, who presented with multi-vessel coronary artery disease, that there is equipoise between CT- and classic angiography for treatment recommendations given for CABG or PCI [14]. In this trial, not the patients, but the heart teams were randomized. All patients had received classic invasive as well as CT-coronary angiography. Treatment recommendations were given by two independent heart teams either on the basis of CT or classic angiography. There was no statistical difference in treatment recommendations by the heart teams with 26 and 28% of patients receiving treatment recommendation for CABG based on CT or invasive angiography, respectively (Fig. 2b). Cohen's kappa was 0.82 (CI 0.74–0.91), which indicates non-inferiority of CT compared to invasive angiography.

Fractional flow reserve (FFR) is another diagnostic tool, which has already significantly influenced decision-making for PCI. It is now repeatedly being tested for its potential to improve outcomes in coronary surgery. Fournier et al. suggested based on a retrospective analysis, that applying FFR to bypass surgery may reduce the number of grafts and improve survival free of myocardial infarcts [15]. In contrast, a Danish prospective randomized trial on 100 CABG patients demonstrated that adding FFR to CABG planning reduced the number of bypass targets, but did not demonstrate any difference in graft patency or failure and also no difference in clinical outcome. However, the 33 lesions that were not grafted based on an FFR-value above 0.8 at the time of surgery showed significant progress in coronary artery disease over the next 6 months [16].

There are trials currently ongoing assessing the impact of FFR measurements on graft patency after CABG surgery (e.g., IMPAG trial, NCT02527044) or use it for selecting bypass targets (ROMA trial, NCT03217006). While attempts to achieve perfect graft patency are certainly worthwhile pursuing, it remains questionable whether limiting the number of grafts is the optimal way to do it. A plausible mechanism for the difference between CABG and PCI is the protection against infarction from non-flow limiting stenosis, which is also bypassed with surgical grafts placed for a flow-limiting stenosis [17]. Reducing the number of grafts during surgery would then also reduce the amount of protection against new infarcts. Although the fraction of graft occlusion may increase in the absence of flow-limiting stenosis, occlusion rates are low and occlusions appear to be clinically silent in most cases [16, 17] 100%. If a graft occludes silently due to competitive flow, it may be still wise to place it during the primary bypass surgery [17].

The role of medical therapy in CABG patients

This reasoning above is further supported by publications pointing towards the role of medical therapy also in bypass

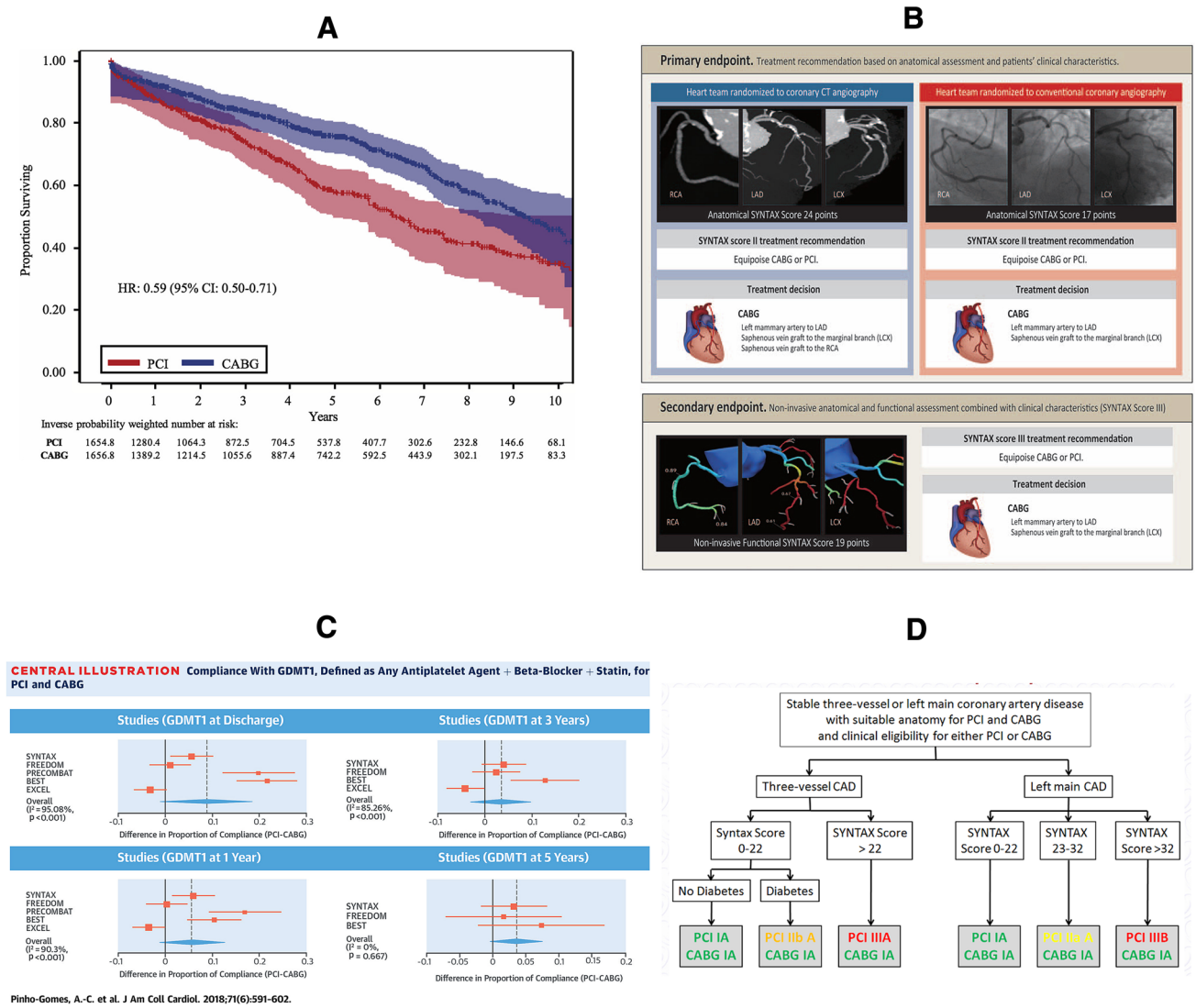


Fig. 2 Main findings of 2018 publications addressing the field of coronary bypass surgery. **a** Large retrospective analysis comparing CABG and PCI in patients with reduced systolic ventricular function [11]. **b** Central illustration of the SYNTAX III Revolution trial illustrating equipoise for CT-coronary angiography with classic invasive angiography for arriving at treatment recommendations for revascularization [14]. **c** Meta-analysis comparing the compliance with optimal medical therapy of patients having received either PCI or CABG in prospective randomized trials [19]. **d** Newly released decision tree for treatment recommendations in patients with stable three vessel coronary artery disease [32]

patients. The magnitude of primary prevention measures has recently been impressively demonstrated by the SCOT HEART trial, where the pure knowledge of the presence of CAD from a CT-coronary angiogram was able to reduce the incidence of new myocardial infarctions by 40% within 5 years [18]. Pinho-Gomes et al. performed a meta-analysis on five prospective randomized trials assessing the impact of medical therapy in patients after PCI or CABG. They demonstrated a survival impact by medical therapy and significantly greater compliance with medical therapy after PCI [19] (Fig. 2c). This finding is fully consistent with the new guideline recommendations for full medical therapy both after PCI and CABG [4]. The potential for medical therapy to improve outcomes after CABG surgery was 2018 further supported by publications from the STICH trial demonstrating worse outcome with increased blood pressures and by two trials assessing the impact of dual antiplatelet therapy after bypass grafting [20–22]. Both studies demonstrated increased graft patency with dual platelet inhibition and a tendency towards improved survival. However, the effect came at the cost of increased rates of major bleeding.

Technical aspects of CABG conduct

Graft patency, as already addressed above, is not only influenced by competitive flow or the degree of target vessel stenosis, but is also a function of graft material and surgical skill. The new ESC-guidelines on coronary revascularization for the first time give specific recommendations on technical aspects of the conduct of CABG (Fig. 1c) [4]. In addition, there were further publications in 2018, the majority of them in support of the guideline recommendations.

In general, full arterial revascularization is recommended before using venous grafts. If venous grafts are used, no touch or endoscopic harvesting techniques are suggested [23]. The quality of revascularization is supposed to be controlled by transit time flow and epicardial scanning techniques and in high-risk patients manipulation of the aorta is to be minimized [4]. These recommendations are further supported by a meta-analysis from Ueki et al. who analyzed more than 38,000 patients having undergone coronary bypass surgery with chronic renal failure. The authors demonstrated that an off-pump strategy in these patients has the potential to significantly reduce perioperative mortality [24]. In contrast to this study and the recommendations, Chikwe et al. presented a large analysis on more than 42,000 patients from the New Jersey health department registry. They selected and matched 7000 off-pump with 15,000 on-pump cases (one selection criterion was an off-pump experience above 100 cases per year and surgeon) and demonstrated a significant survival advantage with on-pump surgery after 10 years [25]. While this analysis may reflect a setback for off-pump techniques, it suffers from a potentially large selection bias which cannot be eliminated by propensity matching. It is not clear what led to the decision to perform off-pump and on-pump in these various cases. As we referred to in recent years, the differences between on- and off-pump techniques in prospective randomized trials are minimal in the vast majority of studies [26, 27].

This limitation may become even more evident if the recently presented 10-year outcomes of the ART trial are considered [28]. The trial compared a strategy of bilateral internal thoracic artery grafting versus single artery bypass grafting plus radial artery or vein in patients with multivessel disease. While the primary outcome was neutral in the intention to treat analysis, there was a significant survival advantage for bilateral internal thoracic arteries if crossovers were excluded and the surgeon's experience was high. As a consequence of these findings, coronary surgery is requested to be developed as specialty operation [29].

Thus, for patients facing coronary bypass surgery it may still be wise to select an experienced surgeon capable of performing complete arterial revascularization with minimal manipulation of the aorta. For patients fearing sternotomy, minimally invasive strategies may be an alternative. Giambruno et al. demonstrated in a set of 700 patients that a hybrid strategy using robotic LAD grafting through a left anterolateral minithoracotomy plus stenting of a second significant stenosis may achieve the same results as double bypass surgery through sternotomy [30]. Finally, we demonstrated that even bilateral mammary harvesting and grafting can be performed through a left anterolateral minithoracotomy [31].

The main findings of 2018 publications on surgical treatment for coronary artery disease are:

- New ESC guideline recommendations further define heart-team decision-making for complex CAD with or without diabetes mellitus (Fig. 2d [32]) which is fully supported by the latest studies. They specifically recommend fully arterial revascularization for coronary bypass surgery with the least possible amount of aortic manipulation (Fig. 1c).
- CT-coronary angiography may suffice for treatment decision-making in patients with multi-vessel CAD (Fig. 2b).
- Patients after CABG show worse compliance with optimal medical therapy, although medical therapy may reduce long-term death and myocardial infarction (Fig. 2c).
- Surgical precision and skill appear to be major factors for optimal long-term outcome after CABG.

Aortic valve surgery

Current recommendations for patients with aortic stenosis and intermediate or high risk for surgery contain equipoise for the primary treatment recommendation. A heart team is supposed to individualize decision-making for either transcatheter aortic valve implantation (TAVI) or surgical aortic valve replacement (SAVR) based on a set of patient-specific criteria [33]. For low-risk patients, a primary recommendation for only SAVR is given, but trials evaluating possible non-inferiority of TAVI are underway (DEDICATE, SURTAVI II, PARTNER 3, NOTION 2). Although this review does not address the field of transcatheter aortic valve replacement in detail, topics such as pacemaker requirements, valve thrombosis, paravalvular leaks and durability still remain. The following text addresses TAVI in the context of direct comparisons to SAVR as well as classic surgical topics such as mechanical valves, Ross and Ozaki procedures, rapid deployment valves and minimally invasive surgical access to the aortic valve.

TAVI versus SAVR

Armoiry et al. conducted a nationwide longitudinal observational study using the French hospital information system

between 2009 and 2015. The authors used propensity matching to select 799 TAVI/SAVR pairs of patients with high surgical risk (EuroSCORE > 20%). This comparison was characterized by similar periprocedural outcomes, but significantly higher survival with classic surgery after 5 years. The TAVI group was characterized by higher mortality, higher pacemaker rate, more strokes and more cost at 5 years (Fig. 3a) [34]. Since this analysis was a retrospective database analysis in a patient population, where a heart team has made decisions, the matching process may not fully reflect the patients' risk profiles.

Gleason et al. [35] presented the 5-year results from the prospective randomized US CoreValve trial, which in previous publications always presented superiority of TAVI

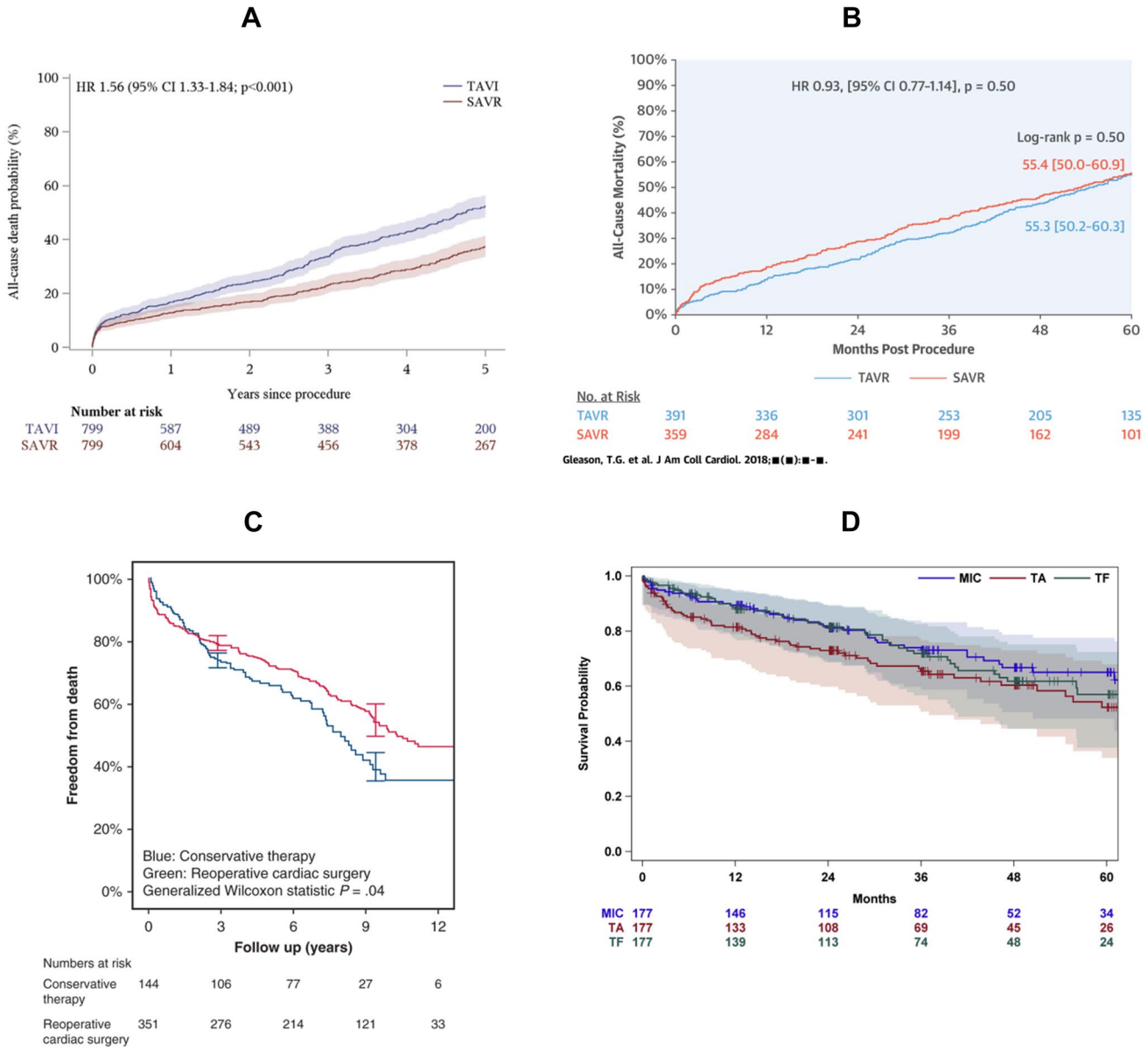


Fig. 3 Main findings of 2018 publications in the field of aortic valve replacement with surgical or transcatheter aortic valves. **a** Propensity-matched comparison of all-cause death in patients with aortic valve stenosis and high surgical risk from the French hospital information system. Patients either received transcatheter valves (TAVI) or classic surgical valve replacement (SAVR) [34]. **b** All-cause mortality at 5 years of the US Corevalve trial having compared surgical (SAVR) with transcatheter aortic valve replacement (TAVR) in patients with aortic stenosis and intermediate to high risk of surgery [35]. **c** Survival curves from a conservatively (red line) or surgically treated (blue line) of patients having presented at the Mayo Clinic with any kind of paravalvular leak in conventional valve prostheses. The decision to treat surgically was made by the same team based on the severity of clinical presentation [37]. **d** Survival curves of risk-adjusted triplets from a large database of patients having received aortic valve replacement either surgically using partial sternotomy (MIC) or with a catheter through a transapical (TA) or transfemoral (TF) access [39]

versus SAVR [36]. Figure 3b illustrates that at 5 years (mean patient age at inclusion 83), there is no longer a survival advantage for TAVI, with roughly 60% of patients having died. This equal survival was accompanied by an almost doubled need for pacemaker implantation in the TAVI group and increased rates of paravalvular leaks. Of note, the presence of already mild paravalvular leak at 1 month in this patient population was identified as an independent risk factor for mortality at 5 years (HR 1.45, CI 1.07–1.98).

The relevance of paravalvular leaks in a purely surgical patient population was published by Shah et al. who demonstrated superior 10 years survival in patients with surgical management of moderate-to-severe paravalvular leaks compared to medically managed patients with only mild paravalvular leaks. The periprocedural mortality in the operated patients caused inferior outcomes compared to the medically managed group in the first 2 years (Fig. 3c). Then, survival curves crossed and long-term survival was even better in this initially sicker patient population [37]. We commented on this finding with the requests to include long-term follow-ups in all trials assessing new technologies [38].

Another comparison of TAVI and SAVR was published by Furukawa et al., who selected 177 risk-adjusted triplets out of almost 4000 patients having received SAVR with partial sternotomy or TAVI with transfemoral or transapical access at one single center (Fig. 3d). The authors found similar outcomes at 5 years with a specific set of complications for each treatment approach used. They confirm current guideline recommendations with their findings supporting patient-specific decision-making by a heart team [39].

Another TAVI option having received significant attention immediately (despite the absence of controlled evidence), is the placement of a transcatheter valve into a previously implanted bioprosthesis (valve-in-valve TAVI). Gozdek et al. reviewed the literature and performed a meta-analysis on studies having compared valve-in-valve TAVI to classic redo-surgery. The authors found 342 patients and five retrospective analyses. Although the problem of optimal risk matching is again apparent, the valve-in-valve TAVI patients were characterized by higher gradients and increased cumulative mortality. Although the TAVI group showed lower pacemaker need and shorter ICU and hospital stays, the inferior hemodynamic and survival outcomes led the authors to conclude that valve-in-valve TAVI should be reserved for patients with high perioperative risk [40]. This conclusion was also supported by another analysis from the valve-in-valve international database that also raised concerns due to high transvalvular gradients after valve-in-valve TAVI [41].

Mechanical valves, Ross and Ozaki

Despite the fact that mechanical valves have fallen out of favor over recent years [42], their hemodynamic and durability properties may represent favorable characteristics for a large fraction of patients [43]. The PROACT trial recently demonstrated the ability to reduce the INR level to a range of 1.5–1.9 for the On-X valve, a relatively new bileaflet prosthesis made from 100% carbon [44]. In 2018, they now demonstrated that substituting anticoagulation with dual antiplatelet therapy in a patient population with low risk of thrombembolic complications is associated with increased thromboembolic events. In a second arm of this trial, they demonstrated that a reduction of the anticoagulation level to the same low range of 1.5–1.9 is also possible in high-risk patients that require combination of anticoagulation with antiplatelet therapy [45].

If anticoagulation is not an option (specifically in young patients), the Ross-operation is known as an alternative. Here, the diseased aortic valve is replaced by the patient's own pulmonary valve, which again is replaced by a homograft (fixed human pulmonary valve taken from tissue donor). Buratto et al. report a series of 392 Ross-operations between 1992 and 2016 from Australia and New Zealand. They compared them to a propensity-matched cohort of patients taken from almost 2000 patients having received a mechanical valve replacement at the same time (Fig. 4a). The authors showed a significant survival advantage in the Ross group at 20 years [46]. However, it is remarkable that the Ross group demonstrated a 30-day mortality of only 0.3% while the average cross-clamp time was almost 3 h, an ischemia time that is usually associated with increased mortality [47]. Thus, a significant selection bias may have influenced this comparison, but even if the difference were smaller or absent, the data confirm the Ross procedure as a valid alternative to mechanical valves in patients requiring aortic valve replacement at low risk.

Another alternative to mechanical valves or the Ross procedure is the relatively new Ozaki procedure. Here, the resected aortic valve is replaced by three intra-operatively generated valve cusps cut from the patient's own pericardium fixed in glutaraldehyde (Fig. 4b). This year, Ozaki et al. [48] presented their own 10 year results on 850 patients, demonstrating favorable hemodynamics and excellent durability—results comparable to conventional bioprostheses at this time point [27]. The downside of this procedure may be an elevated risk of paravalvular leakage (due to rupture of the hand sewn cusps) and the increased surgical complexity (as with the Ross procedure) limiting the ability to perform the surgery using minimally invasive access.

Rapid deployment valves and minimally invasive access to the aortic valve

Minimally invasive access to the aortic valve has gained increasing interest over the last 10 years [42]. Partial sternotomy or mini-thoracotomy approaches have been developed

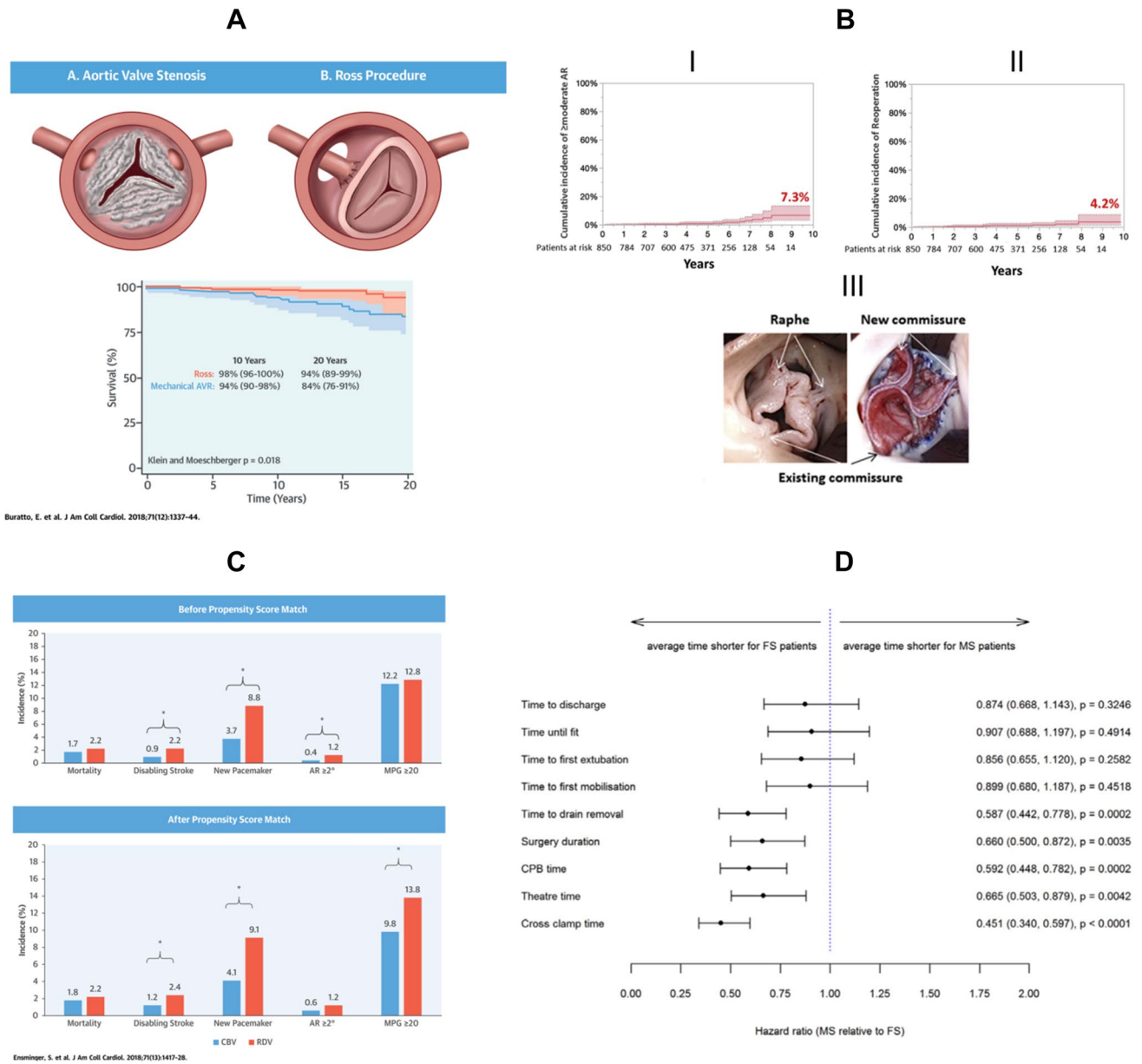


Fig. 4 Main findings of 2018 publications addressing conventional aortic valve surgery. **a** Central illustration of a publication comparing long-term survival in a group of patients having received a Ross procedure in New Zealand or Australia compared to a group of patients having received a mechanical valve [46]. **b** Incidence of aortic regurgitation (I) and reoperation (II) of the Ozaki procedure (III) [48]. **c** Central illustration of a comparison of conventionally placed bioprostheses (CBV) with rapid deployment valves (RDV) from the GARY registry [51]. **d** Forest plot of the Mini-Stern trial having compared partial to full sternotomy for classic aortic valve replacement [52]

and have usually been associated with increased cardiopulmonary bypass and clamp times [49]. In partial analogy to transcatheter valves, rapid deployment or sutureless valves have been developed which are placed with catheter delivery systems intraoperatively after the diseased aortic valve has been resected. As presented previously [26, 27], these valves allow reducing clamp- and bypass-times and have been modified specifically for the use with minimally invasive procedures.

In 2018, Sohn et al. performed a meta-analysis on 21 studies having compared conventional to rapid deployment bioprostheses (RDV) in almost 3000 patients. The authors confirmed RDV's ability to reduce clamp and bypass times but were unable to detect a survival advantage. In contrast, RDV showed higher rates of perioperative pacemaker requirements and there was a trend towards more paravalvular leaks [50].

Ensminger et al. then published an analysis from the German GARY-registry, based on 20,937 patients having received classic biological aortic valve replacement and 1125 patients having received RDV. Again, RDV reduced bypass and clamp times but were associated with inferior clinical outcomes (Fig. 4c). Patients with RDV experienced a greater need for new pacemakers, had more strokes, more paravalvular leaks and even showed increased postoperative mean pressure gradients [51].

Taking these data together with the above results from the Ross/mechanical valves comparison [46], one may conclude that the use of cardiopulmonary bypass per se is not that dangerous anymore. Such a conclusion would also be supported by equal 30-day outcomes of studies comparing On-pump to Off-Pump CABG or TAVI to SAVR [26, 27].

Minimally invasive strategies have been developed in order to reduce surgical trauma and are perceived by many as less traumatizing and the "smaller" operation, although prospective randomized trials have never demonstrated a survival advantage [49]. Nair et al. now published the results of the Mini-Stern trial [52], a prospective randomized comparison of partial sternotomy to full sternotomy on 222 patients undergoing conventional aortic valve replacement. Contrary to expectations, patients could not be discharged earlier (primary endpoint) did not show increased speed of recovery but required more time for drain removal and longer operating times including clamp and bypass times (Fig. 4d). Thus, the partial sternotomy approach was also not cost-effective. Taking these results together with retrospective database analyses that suggest a survival improvement with the partial sternotomy approach [53], we may arrive again at the conclusion that surgical skill and experience may influence outcome in retrospective database analyses more than can be corrected by classic risk adjustments.

The main findings of 2018 publications on surgical treatment of aortic valve disease are:

- At 5 years, TAVI and SAVR appear equal in intermediate- to high-risk patients (Fig. 4).
- Valve-in-valve TAVI is not associated with reduced periprocedural risk and shows elevated post-procedural gradients.
- New mechanical valves can be managed with INR levels between 1.5 and 1.9.
- Ross- and Ozaki procedures may be valid alternatives to mechanical valves in patients with the need or desire to avoid anticoagulation (Fig. 4a, b)
- Rapid deployment valves may be inferior to classic aortic bioprostheses (Fig. 4c).
- Partial sternotomy for aortic valve replacement may not be superior to full sternotomy (Fig. 4d).

Mitral and tricuspid valve surgery

In recent years, publications on mitral valve surgery stressed the importance of an early and durable repair for structural mitral regurgitation [26, 27]. For functional MR, comparisons of medical, surgical and transcatheter therapies were initiated. This year, the literature provided important information on the prevalence of mitral and tricuspid regurgitation and its impact on prognosis as well as outcomes of two trials having compared the MitraClip to medical therapy.

Dziadzko et al. published a cohort echocardiography study addressing the prevalence of mitral regurgitation in Olmsted County in Minnesota, USA. Between 2000 and 2010, 29,390 inhabitants received an echocardiographic investigation. The authors found 1294 persons with isolated moderate-to-severe mitral regurgitation. They showed that prevalence increased with age being 1% at 65 and 45% above 75 years of age. The authors confirm the relationship between the presence of MR and increased mortality and identified surgical correction as protective (Fig. 5a). Despite this finding, only 22% of patients with preserved and only 5% with impaired ventricular function received a mitral surgical procedure (mainly repairs) [54]. In parallel, a European study, consisting of more than 63,000 consecutive echocardiographic investigations from 19 European centers, was published [55]. The authors found moderate-to-severe mitral regurgitation in 5% of patients, 55% of which being of primary (i.e., structural) origin. They showed that, based on the current guidelines, 70% of patients with structural and 13% of patients with functional MR would have had an indication for surgery. Thus, combining the last two studies illustrates a massive lack of appropriate treatment for patients with mitral regurgitation. Specifically in patients with structural MR, the numbers indicate that almost 50% of patients do not receive surgical treatment despite an indication. This finding is startling, not only because of the ability of mitral repair to treat symptoms but most importantly for its ability to prolong life.

The latter statement is nicely supported by Grigioni et al., who analyzed more than 2000 patients with P2 prolapse out of the mitral regurgitation international database. The authors were able to develop a score predicting 1- and 5-year survival for medical and operative therapy. The authors included age, the presence of symptoms, atrial fibrillation, left atrial dilatation, increased pulmonary pressures and the presence of left ventricular dilatation or dysfunction as risk factors. They could show that 10-year mortality increased with increasing risk score (Fig. 5b). However, at a given risk score prognosis was always better after surgery [56].

Olmsted County was also investigated for its prevalence of tricuspid regurgitation (TR). Topilsky et al. analyzed all

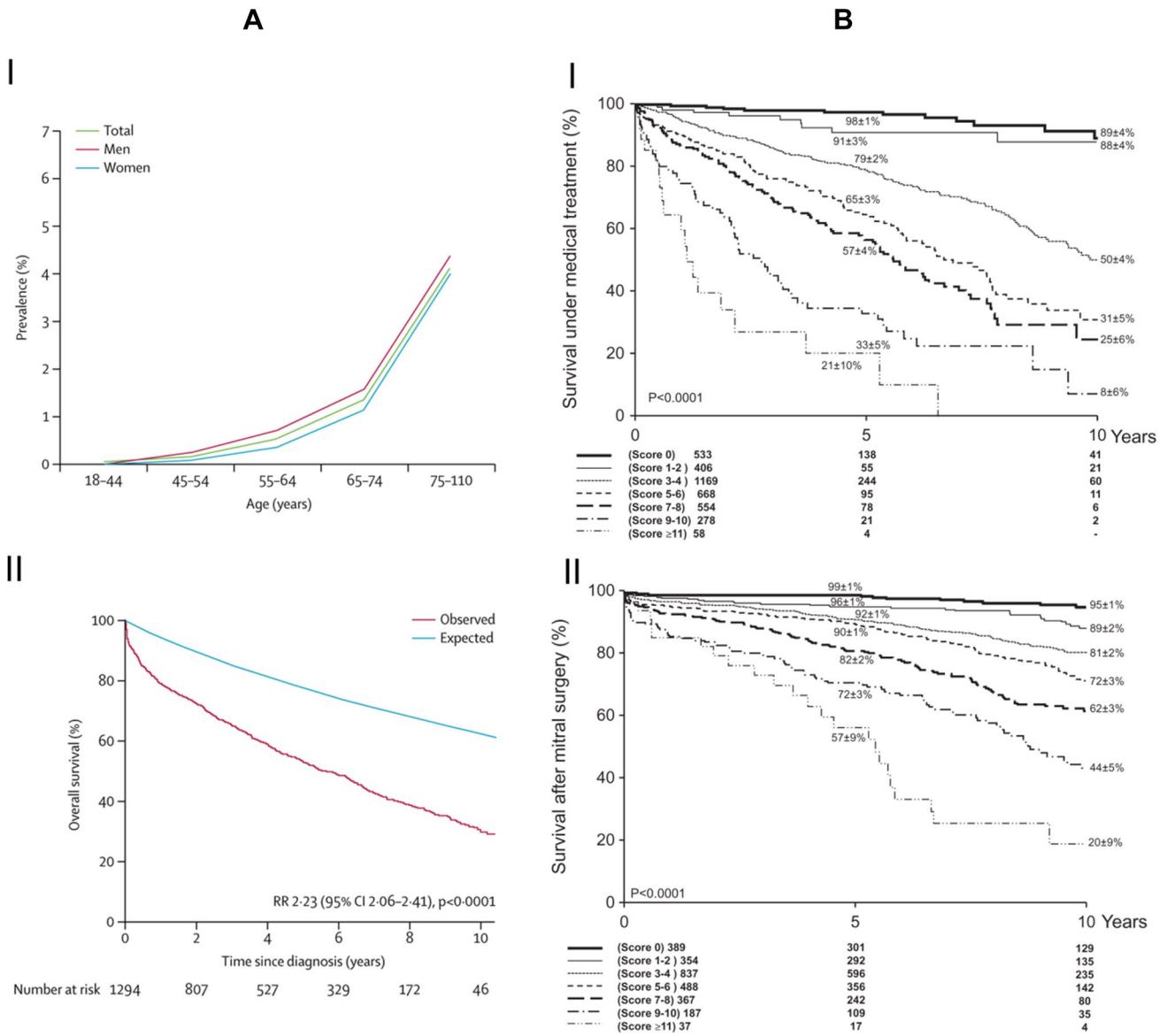


Fig. 5 Main findings of 2018 publications in the field of mitral valve surgery. **a** Prevalence of moderate-to-severe mitral regurgitation according to age (I) in Olmsted County, MN, USA, and the impact of its presence on survival compared to an expected survival for the general population (II) [54]. **b** Survival under medical (I) or surgical treatment (II) of a group of patients with structural mitral regurgitation separated by the MIDA Score [56]

echocardiographic investigations between 1990 and 2000. They identified almost 500 inhabitants with moderate-to-severe tricuspid regurgitation. Again, there was increasing incidence with age and the presence of severe TR was associated with reduced life expectancy. In more than half (60%) of the cases, a left-sided pathology was identified as cause. One quarter was due to pulmonary hypertension and 8% were idiopathic without obvious explanation. They found a prevalence of 1–4% above 65 years of age [57]. Kelly et al. analyzed intraoperative transesophageal echo-investigations from Boston's Brigham and Women's Hospital between 1990 and 2014 and assessed the prevalence of TR [58]. Similar to the Olmsted County findings, the presence of TR was a risk factor for poor long-term survival (in this case postoperatively). However, these authors demonstrated a protective survival impact for tricuspid repair, suggesting that treatment of severe TR may be able to prolong life.

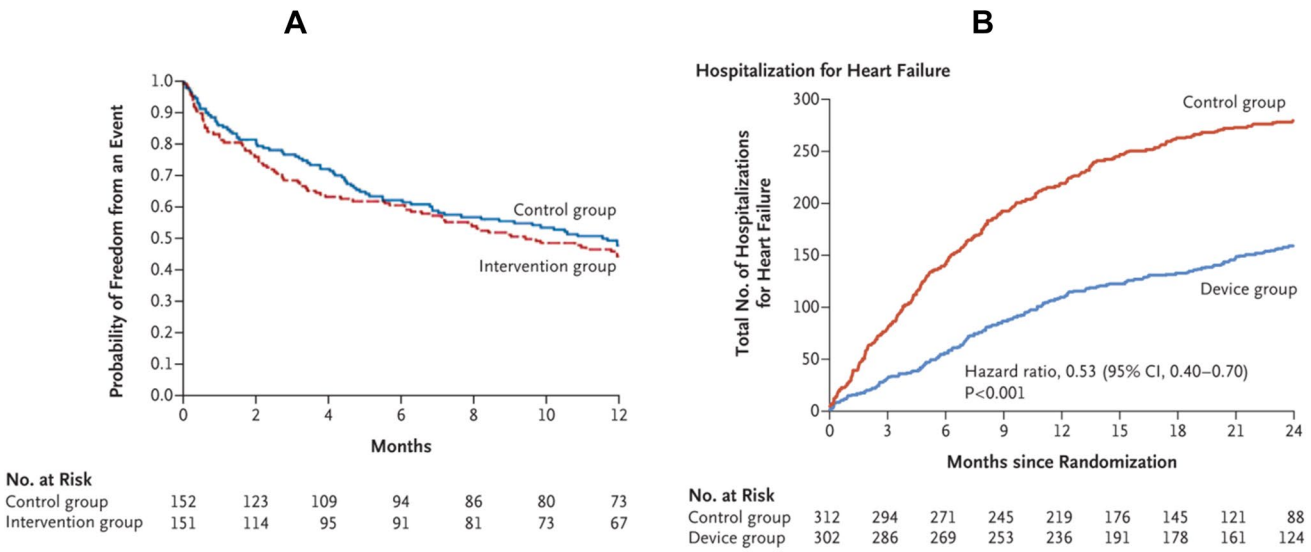
Since patients with isolated TR are often considered high risk and often have had previous cardiac surgery, we published our experience with the treatment of isolated tricuspid reoperations comparing redo-sternotomy with a minimally invasive redo-technique. We were able to identify redo-sternotomy as risk factor for short (OR 9.757,

CI 1.877–63.261) and long-term outcome (HR 2.667, CI 1.180–6.028) [59].

Mitraclip

In 2018, the MITRA FR and the COAPT trials were published, both comparing the MitraClip procedure to a conservatively treated control group in patients with functional MR and reduced ventricular function that were deemed inoperable by a heart team [60, 61]. The two trials showed drastically opposing results (Fig. 6). While the MITRA FR trial failed to demonstrate any effect of the intervention (Fig. 6a), COAPT showed impressive reductions in cardiovascular hospitalization and all-cause mortality using MitraClip (Fig. 6b). However, assessing the echocardiographic core lab reports from both trials brings up an unexpected finding in COAPT which is also illustrated in Fig. 6c.

Stone et al. report an end-diastolic volume of (device group/control) 196/194 ml, with an ejection fraction of 31/30%, resulting in an end-systolic volume of 135/134 ml and a stroke volume of around 60 ml in both groups. Surprisingly, the effective regurgitant orifice (ERO) of 0.41/0.40 cm^2 usually corresponds to a regurgitant volume over the mitral valve of also 60 ml [62]. Although



C

	MITRA FR	COAPT
EDV	270ml	195ml
EF	33%	31%
ERO	0,31	0,41
Regurg. Vol.	45ml	Nicht angegeben

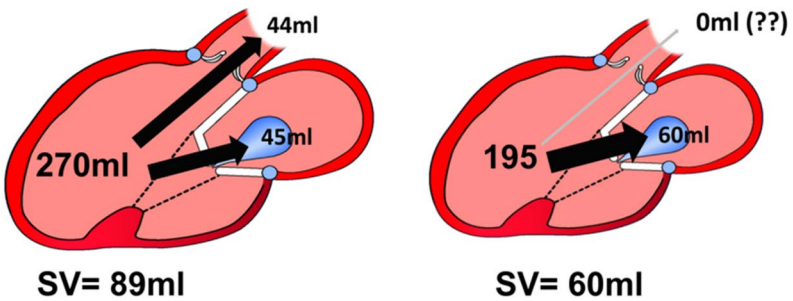


Fig. 6 Primary outcomes of the MITRA FR [60] (**a**) and the COAPT [61] (**b**) trials comparing Mitraclip to medical therapy in patients with functional mitral regurgitation and a schematic illustration of a volumetric consideration of reported echocardiographic outcomes (**c**)

confounding factors may affect this relationship [63], the variability cannot be too high, otherwise the regurgitant volume would not be relevant any more. Thus, according to these numbers, COAPT patients would have either no forward stroke volume and therefore no formal cardiac output (which cannot be possible) or have irrelevant regurgitant volume (which make the trial results difficult to explain). In MITRA FR, the numbers add up. Regurgitant volume is quantified with 45 ml (ERO 0.3 cm^2) and stroke volume can be calculated to roughly 90 ml. This inconsistency suggests that we are missing something in COAPT. The Editorial Viewpoint published by Grayburn et al. [64] attempts to address this issue, however, it still falls short in explaining how a patient can live with only minimal forward stroke volume.

The main findings 2018 for mitral and tricuspid valve surgery are:

- The prevalence of mitral and/or tricuspid regurgitation is increasing with age (MR: 1–5% above 65 years, TR: 1–4% above 65 years, Fig. 5a).
- Moderate-to-severe mitral and/or tricuspid regurgitation impairs life expectancy. Repair can improve or restore life expectancy (Fig. 5a II, most evident for structural MR)
- MitraClip for functional MR may be helpful in a selected patient population. However, based on implausible echocardiographic trial results, patient selection appears currently very difficult (Fig. 6).

Surgery of the aorta

In 2018, Krüger et al. published an important series of thoracic computer-tomographic investigations in patients with or without aortic pathologies with the aim to assess the risk for aortic dissection [65]. Thus far, recommendations for replacement of the aorta to prevent dissection are based solely on aortic diameter (i.e., 50 or 55 mm). The authors assessed more than 500 thoracic CT scans and demonstrated that elongation of the ascending aorta above 12 mm carries just as much risk for dissection as dilatation of the aorta above 5 cm.

With respect to treatment of an acute Stanford type A dissection, Merkle et al. [66] demonstrated the entire experience of Cologne University between 2006 and 2015. They added to previous findings [26, 27], that a primary approach using total arch replacement shows higher in-hospital mortality (OR 2.2 CI 1.34–7.63) and more strokes (OR 2.67 CI 1.14–6.24) if compared to an open anastomosis or partial arch replacement.

Surgery for terminal heart failure

In 2018, the focus in terminal heart failure has been again on outcomes after ventricular assist device implantation. Two publications appear to be of general interest. Mehra et al. published the 2-year outcomes of the MOMENTUM 3 trial, in which the centrifugal pump HeartMate 3 was compared with the axial-flow pump HeartMate II. The authors demonstrated superior event-free survival of the HeartMate 3 with 80% at 2 years (compared to 60% with HeartMate II). Impressively, there was no confirmed pump thrombosis with HeartMate 3 which translated into a significantly lower stroke rate at 2 years [67]. The other study addressed a subanalysis of the ROADMAP trial [68], in which about 100 patients with terminal heart failure received an assist device implantation while about 100 comparable patients were treated conservatively. There was no randomization but all patients were suffering from terminal heart failure without the need for inotropic support. The authors had previously demonstrated a survival advantage in the assist group at the cost of more complications [69]. They now analyzed the patient population with respect to the INTERMACS category. Their data suggest that patients in INTERMACS 4 (just before the need of inotropes) derive the greatest benefit from an assist device implantation. This information is very helpful for patient management, because it supports the concept of optimal timing for device implantation. The German EARLY VAD trial (NCT02387112) is assessing exactly that question in prospective randomized form and will deliver more definitive information for decision-making.

Finally, Daniel et al. published a long-term follow-up after heart transplantation in patients above 60 years of age depending on the age of the donor hearts. The authors used the UNOS database and demonstrated a significant increase in risk if donor age exceeded 50 years. Thus, at times of older recipients and older donors, organ allocation has become even more complex [70].

Acknowledgements We would like to thank Benjamin Gloy for expert technical assistance in the preparation of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Head SJ, Milojevic M, Daemen J, Ahn JM, Boersma E, Christiansen EH, Domanski MJ, Farkouh ME, Flather M, Fuster V, Hlatky MA, Holm NR, Hueb WA, Kamalesh M, Kim YH, Makikallio T, Mohr FW, Papageorgiou G, Park SJ, Rodriguez

AE, Sabik JF 3rd, Stables RH, Stone GW, Serruys PW, Kappetein AP (2018) Mortality after coronary artery bypass grafting versus percutaneous coronary intervention with stenting for coronary artery disease: a pooled analysis of individual patient data. Lancet 391(10124):939–948. https://doi.org/10.1016/s0140-6736(18)30423-9

2. Head SJ, Milojevic M, Daemen J, Ahn JM, Boersma E, Christiansen EH, Domanski MJ, Farkouh ME, Flather M, Fuster V, Hlatky MA, Holm NR, Hueb WA, Kamalesh M, Kim YH, Makikallio T, Mohr FW, Papageorgiou G, Park SJ, Rodriguez AE, Sabik JF 3rd, Stables RH, Stone GW, Serruys PW, Kappetein AP (2018) Stroke rates following surgical versus percutaneous coronary revascularization. J Am Coll Cardiol 72(4):386–398. https://doi.org/10.1016/j.jacc.2018.04.071
3. Zhao DF, Edelman JJ, Seco M, Bannon PG, Wilson MK, Byrom MJ, Thourani V, Lamy A, Taggart DP, Puskas JD, Vallely MP (2017) Coronary artery bypass grafting with and without manipulation of the ascending aorta: a network meta-analysis. J Am Coll Cardiol 69(8):924–936. https://doi.org/10.1016/j.jacc.2016.11.071
4. Neumann FJ, Sousa-Uva M, Ahlsson A, Alfonso F, Banning AP, Benedetto U, Byrne RA, Collet JP, Falk V, Head SJ, Juni P, Kastrati A, Koller A, Kristensen SD, Niebauer J, Richter DJ, Seferovic PM, Sibbing D, Stefanini GG, Windecker S, Yadav R, Zembala MO (2018) 2018 ESC/EACTS guidelines on myocardial revascularization. Eur Heart J. https://doi.org/10.1093/eurheartj/ehy394
5. Farkouh ME, Domanski M, Dangas GD, Godoy LC, Mack MJ, Siami FS, Hamza TH, Shah B, Stefanini GG, Sidhu MS, Tanguay JF, Ramanathan K, Sharma SK, French J, Hueb W, Cohen DJ, Fuster V (2018) Long-term survival following multivessel revascularization in patients with diabetes (FREEDOM Follow-On Study). J Am Coll Cardiol. https://doi.org/10.1016/j.jacc.2018.11.001
6. Gershlick AH, Kandzari DE, Banning A, Taggart DP, Morice MC, Lembo NJ, Brown WM 3rd, Banning AP, Merkely B, Horkay F, van Boven AJ, Boonstra PW, Dressler O, Sabik JF 3rd, Serruys PW, Kappetein AP, Stone GW (2018) Outcomes after left main percutaneous coronary intervention versus coronary artery bypass grafting according to lesion site: results from the EXCEL trial. JACC Cardiovasc Interv 11(13):1224–1233. https://doi.org/10.1016/j.jcin.2018.03.040
7. Stone GW, Sabik JF, Serruys PW, Simonton CA, Genereux P, Puskas J, Kandzari DE, Morice MC, Lembo N, Brown WM 3rd, Taggart DP, Banning A, Merkely B, Horkay F, Boonstra PW, van Boven AJ, Ungi I, Bogats G, Mansour S, Noiseux N, Sabate M, Pomar J, Hickey M, Gershlick A, Buszman P, Bochenek A, Schampaert E, Page P, Dressler O, Kosmidou I, Mehran R, Pocock SJ, Kappetein AP (2016) Everolimus-eluting stents or bypass surgery for left main coronary artery disease. N Engl J Med 375(23):2223–2235. https://doi.org/10.1056/NEJMoa1610227
8. Ruel M, Falk V, Farkouh ME, Freemantle N, Gaudino MF, Glineur D, Cameron DE, Taggart DP (2018) Myocardial revascularization trials. Circulation 138(25):2943–2951. https://doi.org/10.1161/circulationaha.118.035970
9. Ram E, Goldenberg I, Kassif Y, Segev A, Lavee J, Einhorn-Cohen M, Raanani E (2018) Real-life characteristics and outcomes of patients who undergo percutaneous coronary intervention versus coronary artery bypass grafting for left main coronary artery disease: data from the prospective Multi-vessel Coronary Artery Disease (MULTICAD) Israeli Registry. Eur J Cardiothorac Surg 54(4):717–723. https://doi.org/10.1093/ejcts/ezy115
10. Velazquez EJ, Lee KL, Jones RH, Al-Khalidi HR, Hill JA, Panza JA, Michler RE, Bonow RO, Doenst T, Petrie MC, Oh JK, She L, Moore VL, Desvigne-Nickens P, Sopko G, Rouleau JL (2016) Coronary-artery bypass surgery in patients with ischemic cardiomyopathy. N Engl J Med 374(16):1511–1520. https://doi.org/10.1056/NEJMoa1602001
11. Iribarne A, DiScipio AW, Leavitt BJ, Baribeau YR, McCullough JN, Weldner PW, Huang YL, Robich MP, Clough RA, Sardella GL, Olmstead EM, Malenka DJ (2018) Comparative effectiveness of coronary artery bypass grafting versus percutaneous coronary intervention in a real-world surgical treatment for ischemic heart failure trial population. J Thorac Cardiovasc Surg 156(4):1410–1421. https://doi.org/10.1016/j.jtcvs.2018.04.121
12. Shah S, Benedetto U, Caputo M, Angelini GD, Vohra HA (2018) Comparison of the survival between coronary artery bypass graft surgery versus percutaneous coronary intervention in patients with poor left ventricular function (ejection fraction < 30%): a propensity-matched analysis. Eur J Cardiothorac Surg. https://doi.org/10.1093/ejcts/ezy236
13. Cui K, Zhang D, Lyu S, Song X, Yuan F, Xu F, Zhang M (2018) Meta-analysis comparing percutaneous coronary revascularization using drug-eluting stent versus coronary artery bypass grafting in patients with left ventricular systolic dysfunction. Am J Cardiol. https://doi.org/10.1016/j.amjcard.2018.08.002
14. Collet C, Onuma Y, Andreini D, Sonck J, Pompilio G, Mushtaq S, La Meir M, Miyazaki Y, de Mey J, Gaemperli O, Ouda A, Maureira JP, Mandry D, Camenzind E, Macron L, Doenst T, Teichgraber U, Sigusch H, Asano T, Katagiri Y, Morel MA, Lindeboom W, Pontone G, Luscher TF, Bartorelli AL, Serruys PW (2018) Coronary computed tomography angiography for heart team decision-making in multivessel coronary artery disease. Eur Heart J 39(41):3689–3698. https://doi.org/10.1093/eurheartj/ehy581
15. Fournier S, Toth GG, De Bruyne B, Johnson NP, Ciccarelli G, Xaplanteris P, Milkas A, Strisciuglio T, Bartunek J, Vanderheyden M, Wyffels E, Casselman F, Van Praet F, Stockman B, Degrieck I, Barbato E (2018) Six-year follow-up of fractional flow reserve-guided versus angiography-guided coronary artery bypass graft surgery. Circ Cardiovasc Interv 11(6):e006368. https://doi.org/10.1161/circinterventions.117.006368
16. Thuesen AL, Riber LP, Veien KT, Christiansen EH, Jensen SE, Modrau I, Andreasen JJ, Junker A, Mortensen PE, Jensen LO (2018) Fractional flow reserve versus angiographically-guided coronary artery bypass grafting. J Am Coll Cardiol 72(22):2732–2743. https://doi.org/10.1016/j.jacc.2018.09.043
17. Doenst T, Haverich A, Serruys P, Bonow RO, Kappetein AP, Falk V, Velazquez EJ, Diegeler A, Sigusch H (2019) PCI and CABG for treating stable coronary artery disease: JACC review topic of the week. J Am Coll Cardiol 73(8):964–976. https://doi.org/10.1016/j.jacc.2018.11.053
18. Newby DE, Adamson PD, Berry C, Boon NA, Dweck MR, Flather M, Forbes J, Hunter A, Lewis S, MacLean S, Mills NL, Norrie J, Roditi G, Shah ASV, Timmis AD, van Beek EJR, Williams MC (2018) Coronary CT angiography and 5-year risk of myocardial infarction. N Engl J Med 379(10):924–933. https://doi.org/10.1056/NEJMoa1805971
19. Pinho-Gomes AC, Azevedo L, Ahn JM, Park SJ, Hamza TH, Farkouh ME, Serruys PW, Milojevic M, Kappetein AP, Stone GW, Lamy A, Fuster V, Taggart DP (2018) Compliance with guideline-directed medical therapy in contemporary coronary revascularization trials. J Am Coll Cardiol 71(6):591–602. https://doi.org/10.1016/j.jacc.2017.11.068
20. Andersson B, She L, Tan RS, Jeemon P, Mokrzycki K, Siepe M, Romanov A, Favaloro LE, Djokovic LT, Raju PK, Betlejewski P, Racine N, Ostrzycki A, Nawarawong W, Das S, Rouleau JL, Sopko G, Lee KL, Velazquez EJ, Panza JA (2018) The association between blood pressure and long-term outcomes of patients with ischaemic cardiomyopathy with and without surgical revascularization: an analysis of the STICH trial. Eur Heart J 39(37):3464–3471. https://doi.org/10.1093/eurheartj/ehy438

21. Cardoso R, Knijnik L, Whelton SP, Rivera M, Gluckman TJ, Metkus TS, Blumenthal RS, McEvoy JW (2018) Dual versus single antiplatelet therapy after coronary artery bypass graft surgery: an updated meta-analysis. Int J Cardiol 269:80–88. https://doi.org/10.1016/j.ijcard.2018.07.083
22. Zhao Q, Zhu Y, Xu Z, Cheng Z, Mei J, Chen X, Wang X (2018) Effect of ticagrelor plus aspirin, ticagrelor alone, or aspirin alone on saphenous vein graft patency 1 year after coronary artery bypass grafting: a randomized clinical trial. JAMA 319(16):1677–1686. https://doi.org/10.1001/jama.2018.3197
23. Zenati MA, Bhatt DL, Bakaeen FG, Stock EM, Biswas K, Gaziano JM, Kelly RF, Tseng EE, Bitondo J, Quin JA, Almassi GH, Haime M, Hattler B, DeMatt E, Scrymgeour A, Huang GD (2018) Randomized trial of endoscopic or open vein-graft harvesting for coronary-artery bypass. N Engl J Med. https://doi.org/10.1056/nejmoa1812390
24. Ueki C, Miyata H, Motomura N, Sakata R, Sakaguchi G, Akimoto T, Takamoto S (2018) Off-pump technique reduces surgical mortality after elective coronary artery bypass grafting in patients with preoperative renal failure. J Thorac Cardiovasc Surg 156(3):976–983. https://doi.org/10.1016/j.jtcvs.2018.03.145
25. Chikwe J, Lee T, Itagaki S, Adams DH, Egorova NN (2018) Long-term outcomes after off-pump versus on-pump coronary artery bypass grafting by experienced surgeons. J Am Coll Cardiol 72(13):1478–1486. https://doi.org/10.1016/j.jacc.2018.07.029
26. Doenst T, Essa Y, Jacoub K, Moschovas A, Gonzalez-Lopez D, Kirov H, Diab M, Bargenda S, Faerber G (2017) Cardiac surgery 2016 reviewed. Clin Res Cardiol 106(11):851–867. https://doi.org/10.1007/s00392-017-1113-2
27. Doenst T, Kirov H, Moschovas A, Gonzalez-Lopez D, Safarov R, Diab M, Bargenda S, Faerber G (2018) Cardiac surgery 2017 reviewed. Clin Res Cardiol 107(12):1087–1102. https://doi.org/10.1007/s00392-018-1280-9
28. Taggart D (2018) Randomized comparison of single versus bilateral internal thoracic artery grafts in 3102 CABG patients: major cardiovascular outcomes at 10 years of follow-up. In: Paper presented at the ESC, Munich
29. Mack M, Taggart D (2018) Coronary revascularization should be a subspecialty focus in cardiac surgery. J Thorac Cardiovasc Surg. https://doi.org/10.1016/j.jtcvs.2018.08.078
30. Giambruno V, Jones P, Khaliel F, Chu MW, Teefy P, Sridhar K, Cucchietti C, Barnfield R, Kiaii B (2018) Hybrid coronary revascularization versus on-pump coronary artery bypass grafting. Ann Thorac Surg 105(5):1330–1335. https://doi.org/10.1016/j.athoracsur.2017.11.019
31. Diab M, Farber G, Sponholz C, Tasar R, Lehmann T, Tkebuchava S, Franz M, Doenst T (2018) Coronary artery bypass grafting using bilateral internal thoracic arteries through a left-sided minithoracotomy: a single-center starting experience. Thorac Cardiovasc Surg. https://doi.org/10.1055/s-0038-1670632
32. Windecker S, Neumann FJ, Juni P, Sousa-Uva M, Falk V (2019) Considerations for the choice between coronary artery bypass grafting and percutaneous coronary intervention as revascularization strategies in major categories of patients with stable multivessel coronary artery disease: an accompanying article of the task force of the 2018 ESC/EACTS guidelines on myocardial revascularization. Eur Heart J 40(2):204–212. https://doi.org/10.1093/eurheartj/ehy532
33. Baumgartner H, Falk V, Bax JJ, De Bonis M, Hamm C, Holm PJ, Iung B, Lancellotti P, Lansac E, Rodriguez Munoz D, Rosenhek R, Sjogren J, Tornos Mas P, Vahanian A, Walther T, Wendler O, Windecker S, Zamorano JL (2017) 2017 ESC/EACTS guidelines for the management of valvular heart disease. Eur Heart J 38(36):2739–2791. https://doi.org/10.1093/eurheartj/ehx391
34. Armoiry X, Obadia JF, Pascal L, Polazzi S, Duclos A (2018) Comparison of transcatheter versus surgical aortic valve implantation in high-risk patients: a nationwide study in France. J Thorac Cardiovasc Surg 156(3):1017–1025. https://doi.org/10.1016/j.jtcvs.2018.02.092
35. Gleason TG, Reardon MJ, Popma JJ, Deeb GM, Yakubov SJ, Lee JS, Kleiman NS, Chetcuti S, Hermiller JB, Heiser J, Merhi W, Zorn GL 3rd, Tadros P, Robinson N, Petrossian G, Hughes GC, Harrison JK, Conte JV, Mumtaz M, Oh JK, Huang J, Adams DH (2018) Self-expanding transcatheter aortic valve replacement or surgical valve replacement in high-risk patients: 5-year outcomes. J Am Coll Cardiol. https://doi.org/10.1016/j.jacc.2018.08.2146
36. Reardon MJ, Adams DH, Kleiman NS, Yakubov SJ, Coselli JS, Deeb GM, Gleason TG, Lee JS, Hermiller JB Jr, Chetcuti S, Heiser J, Merhi W, Zorn GL 3rd, Tadros P, Robinson N, Petrossian G, Hughes GC, Harrison JK, Maini B, Mumtaz M, Conte JV, Resar JR, Aharonian V, Pfeffer T, Oh JK, Qiao H, Popma JJ (2015) 2-year outcomes in patients undergoing surgical or self-expanding transcatheter aortic valve replacement. J Am Coll Cardiol 66(2):113–121. https://doi.org/10.1016/j.jacc.2015.05.017
37. Shah S, Alashi A, Pettersson GB, Rodriguez LL, Gillinov AM, Grimm RA, Navia J, Kapadia SR, Svensson LG, Griffin BP, Desai MY (2018) Characteristics and longer-term outcomes of paravalvular leak after aortic and mitral valve surgery. J Thorac Cardiovasc Surg. https://doi.org/10.1016/j.jtcvs.2018.08.096
38. Doenst T, Richter M (2018) Paravalvular leaks in valve replacement: do we need to blow the whistle? J Thorac Cardiovasc Surg. https://doi.org/10.1016/j.jtcvs.2018.08.052
39. Furukawa N, Kuss O, Emmel E, Scholtz S, Scholtz W, Fujita B, Ensminger S, Gummert JF, Borgermann J (2018) Minimally invasive versus transapical versus transfemoral aortic valve implantation: a one-to-one-to-one propensity score-matched analysis. J Thorac Cardiovasc Surg 156(5):1825–1834. https://doi.org/10.1016/j.jtcvs.2018.04.104
40. Gozdek M, Raffa GM, Suwalski P, Kolodziejczak M, Anisimowicz L, Kubica J, Navarese EP, Kowalewski M (2018) Comparative performance of transcatheter aortic valve-in-valve implantation versus conventional surgical redo aortic valve replacement in patients with degenerated aortic valve bioprostheses: systematic review and meta-analysis. Eur J Cardiothorac Surg 53(3):495–504. https://doi.org/10.1093/ejcts/ezx347
41. Seiffert M, Treede H, Schofer J, Linke A, Woehrle J, Baumbach H, Mehilli J, Bapat V, Simonato M, Walther T, Kullmer M, Boekstegers P, Ensminger S, Kurz T, Eltchaninoff H, Rastan A, Werner N, de Weger A, Frerker C, Lauer B, Muller O, Whisenant B, Thukkani A, Weisz G, Dvir D (2018) Matched comparison of next- and early-generation balloon-expandable transcatheter heart valve implantations in failed surgical aortic bioprostheses. EuroIntervention 14(4):e397–e404. https://doi.org/10.4244/eij-d-17-00546
42. Beckmann A, Meyer R, Lewandowski J, Frie M, Markewitz A, Harringer W (2018) German heart surgery report 2017: the annual updated registry of the German Society for Thoracic and Cardiovascular Surgery. Thorac Cardiovasc Surg 66(8):608–621. https://doi.org/10.1055/s-0038-1676131
43. Hammermeister K, Sethi GK, Henderson WG, Grover FL, Oprian C, Rahimtoola SH (2000) Outcomes 15 years after valve replacement with a mechanical versus a bioprosthetic valve: final report of the Veterans Affairs randomized trial. J Am Coll Cardiol 36(4):1152–1158
44. Puskas J, Gerdisch M, Nichols D, Quinn R, Anderson C, Rhenman B, Fermin L, McGrath M, Kong B, Hughes C, Sethi G, Wait M, Martin T, Graeve A (2014) Reduced anticoagulation after mechanical aortic valve replacement: interim results from the prospective randomized on-X valve anticoagulation clinical trial randomized Food and Drug Administration investigational device exemption trial. J Thorac Cardiovasc Surg 147(4):1202–1210. https://doi.org/10.1016/j.jtcvs.2014.01.004 **(discussion 1210–1201)**

45. Puskas JD, Gerdisch M, Nichols D, Fermin L, Rhenman B, Kapoor D, Copeland J, Quinn R, Hughes GC, Azar H, McGrath M, Wait M, Kong B, Martin T, Douville EC, Meyer S, Ye J, Jamieson WRE, Landvater L, Hagberg R, Trotter T, Armitage J, Askew J, Accola K, Levy P, Duncan D, Yanagawa B, Ely J, Graeve A (2018) Anticoagulation and antiplatelet strategies after On-X mechanical aortic valve replacement. J Am Coll Cardiol 71(24):2717–2726. https://doi.org/10.1016/j.jacc.2018.03.535
46. Buratto E, Shi WY, Wynne R, Poh CL, Larobina M, O'Keefe M, Goldblatt J, Tatoulis J, Skillington PD (2018) Improved survival after the Ross procedure compared with mechanical aortic valve replacement. J Am Coll Cardiol 71(12):1337–1344. https://doi.org/10.1016/j.jacc.2018.01.048
47. Doenst T, Borger MA, Weisel RD, Yau TM, Maganti M, Rao V (2008) Relation between aortic cross-clamp time and mortality—not as straightforward as expected. Eur J Cardiothorac Surg 33(4):660–665. https://doi.org/10.1016/j.ejcts.2008.01.001
48. Ozaki S, Kawase I, Yamashita H, Uchida S, Takatoh M, Kiyohara N (2018) Midterm outcomes after aortic valve neocuspidization with glutaraldehyde-treated autologous pericardium. J Thorac Cardiovasc Surg 155(6):2379–2387. https://doi.org/10.1016/j.jtcvs.2018.01.087
49. Doenst T, Diab M, Sponholz C, Bauer M, Farber G (2017) The opportunities and limitations of minimally invasive cardiac surgery. Dtsch Arztebl Int 114(46):777–784. https://doi.org/10.3238/arztebl.2017.0777
50. Sohn SH, Jang MJ, Hwang HY, Kim KH (2018) Rapid deployment or sutureless versus conventional bioprosthetic aortic valve replacement: a meta-analysis. J Thorac Cardiovasc Surg 155(6):2402–2412.e2405. https://doi.org/10.1016/j.jtcvs.2018.01.084
51. Ensminger S, Fujita B, Bauer T, Mollmann H, Beckmann A, Bekeredjian R, Bleiziffer S, Landwehr S, Hamm CW, Mohr FW, Katus HA, Harringer W, Walther T, Frerker C (2018) Rapid deployment versus conventional bioprosthetic valve replacement for aortic stenosis. J Am Coll Cardiol 71(13):1417–1428. https://doi.org/10.1016/j.jacc.2018.01.065
52. Nair SK, Sudarshan CD, Thorpe BS, Singh J, Pillay T, Catarino P, Valchanov K, Codispoti M, Dunning J, Abu-Omar Y, Moorjani N, Matthews C, Freeman CJ, Fox-Rushby JA, Sharples LD (2018) Mini-Stern Trial: a randomized trial comparing mini-sternotomy to full median sternotomy for aortic valve replacement. J Thorac Cardiovasc Surg. https://doi.org/10.1016/j.jtcvs.2018.05.057
53. Merk DR, Lehmann S, Holzhey DM, Dohmen P, Candolfi P, Misfeld M, Mohr FW, Borger MA (2015) Minimal invasive aortic valve replacement surgery is associated with improved survival: a propensity-matched comparison. Eur J Cardiothorac Surg 47(1):11–17. https://doi.org/10.1093/ejcts/ezu068 **(discussion 17)**
54. Dziadzko V, Clavel MA, Dziadzko M, Medina-Inojosa JR, Michelena H, Maalouf J, Nkomo V, Thapa P, Enriquez-Sarano M (2018) Outcome and undertreatment of mitral regurgitation: a community cohort study. Lancet 391(10124):960–969. https://doi.org/10.1016/s0140-6736(18)30473-2
55. Monteagudo Ruiz JM, Galderisi M, Buonauro A, Badano L, Aruta P, Swaans MJ, Sanchis L, Saraste A, Monaghan M, Theodoropoulos KC, Papitsas M, Liel-Cohen N, Kobal S, Bervar M, Berlot B, Filippatos G, Ikonomidis I, Katsanos S, Tanner FC, Cassani D, Faletra FF, Leo LA, Martinez A, Matabuena J, Grande-Trillo A, Alonso-Rodriguez D, Mesa D, Gonzalez-Alujas T, Sitges M, Carrasco-Chinchilla F, Li CH, Fernandez-Golfin C, Zamorano JL (2018) Overview of mitral regurgitation in Europe: results from the European Registry of mitral regurgitation (EuMiClip). Eur Heart J Cardiovasc Imaging 19(5):503–507. https://doi.org/10.1093/ehjci/jey011
56. Grigioni F, Clavel MA, Vanoverschelde JL, Tribouilloy C, Pizarro R, Huebner M, Avierinos JF, Barbieri A, Suri R, Pasquet A, Rusinaru D, Gargiulo GD, Oberti P, Theron A, Bursi F, Michelena H, Lazam S, Szymanski C, Nkomo VT, Schumacher M, Bacchi-Reggiani L, Enriquez-Sarano M (2018) The MIDA Mortality Risk Score: development and external validation of a prognostic model for early and late death in degenerative mitral regurgitation. Eur Heart J 39(15):1281–1291. https://doi.org/10.1093/eurheartj/ehx465
57. Topilsky Y, Maltais S, Medina Inojosa J, Oguz D, Michelena H, Maalouf J, Mahoney DW, Enriquez-Sarano M (2018) Burden of tricuspid regurgitation in patients diagnosed in the community setting. JACC Cardiovasc Imaging. https://doi.org/10.1016/j.jcmg.2018.06.014
58. Kelly BJ, Ho Luxford JM, Butler CG, Huang CC, Wilusz K, Ejiofor JI, Rawn JD, Fox JA, Shernan SK, Muehlschlegel JD (2018) Severity of tricuspid regurgitation is associated with long-term mortality. J Thorac Cardiovasc Surg 155(3):1032–1038. https://doi.org/10.1016/j.jtcvs.2017.09.141
59. Farber G, Tkebuchava S, Dawson RS, Kirov H, Diab M, Schlattmann P, Doenst T (2018) Minimally invasive, isolated tricuspid valve redo surgery: a safety and outcome analysis. Thorac Cardiovasc Surg 66(7):564–571. https://doi.org/10.1055/s-0038-1627452
60. Obadia JF, Messika-Zeitoun D, Leurent G, Iung B, Bonnet G, Piriou N, Lefevre T, Piot C, Rouleau F, Carrie D, Nejjari M, Ohlmann P, Leclercq F, Saint Etienne C, Teiger E, Leroux L, Karam N, Michel N, Gilard M, Donal E, Trochu JN, Cormier B, Armoiry X, Boutitie F, Maucort-Boulch D, Barnel C, Samson G, Guerin P, Vahanian A, Mewton N (2018) Percutaneous repair or medical treatment for secondary mitral regurgitation. N Engl J Med. https://doi.org/10.1056/nejmoa1805374
61. Stone GW, Lindenfeld J, Abraham WT, Kar S, Lim DS, Mishell JM, Whisenant B, Grayburn PA, Rinaldi M, Kapadia SR, Rajagopal V, Sarembock IJ, Brieke A, Marx SO, Cohen DJ, Weissman NJ, Mack MJ (2018) Transcatheter mitral-valve repair in patients with heart failure. N Engl J Med. https://doi.org/10.1056/nejmoa1806640
62. Zoghbi WA, Adams D, Bonow RO, Enriquez-Sarano M, Foster E, Grayburn PA, Hahn RT, Han Y, Hung J, Lang RM, Little SH, Shah DJ, Shernan S, Thavendiranathan P, Thomas JD, Weissman NJ (2017) Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr 30(4):303–371. https://doi.org/10.1016/j.echo.2017.01.007
63. Grayburn PA, Carabello B, Hung J, Gillam LD, Liang D, Mack MJ, McCarthy PM, Miller DC, Trento A, Siegel RJ (2014) Defining "severe" secondary mitral regurgitation: emphasizing an integrated approach. J Am Coll Cardiol 64(25):2792–2801. https://doi.org/10.1016/j.jacc.2014.10.016
64. Grayburn PA, Sannino A, Packer M (2019) Proportionate and disproportionate functional mitral regurgitation: a new conceptual framework that reconciles the results of the MITRA-FR and COAPT Trials. JACC Cardiovasc Imaging 12(2):353–362. https://doi.org/10.1016/j.jcmg.2018.11.006
65. Kruger T, Sandoval Boburg R, Lescan M, Oikonomou A, Schneider W, Vohringer L, Lausberg H, Bamberg F, Blumenstock G, Schlensak C (2018) Aortic elongation in aortic aneurysm and dissection: the Tubingen Aortic Pathoanatomy (TAIPAN) project. Eur J Cardiothorac Surg 54(1):26–33. https://doi.org/10.1093/ejcts/ezx503
66. Merkle J, Sabashnikov A, Deppe AC, Zeriouh M, Maier J, Weber C, Eghbalzadeh K, Schlachtenberger G, Shostak O, Djordjevic I, Kuhn E, Rahmanian PB, Madershahian N, Rustenbach C, Liakopoulos O, Choi YH, Kuhn-Regnier F, Wahlers T (2018) Impact of ascending aortic, hemiarch and arch repair on early and long-term outcomes in patients with Stanford A acute aortic

dissection. Ther Adv Cardiovasc Dis 12(12):327–340. https://doi.org/10.1177/1753944718801568

67. Mehra MR, Goldstein DJ, Uriel N, Cleveland JC Jr, Yuzefpolskaya M, Salerno C, Walsh MN, Milano CA, Patel CB, Ewald GA, Itoh A, Dean D, Krishnamoorthy A, Cotts WG, Tatooles AJ, Jorde UP, Bruckner BA, Estep JD, Jeevanandam V, Sayer G, Horstmanshof D, Long JW, Gulati S, Skipper ER, O'Connell JB, Heatley G, Sood P, Naka Y (2018) Two-year outcomes with a magnetically levitated cardiac pump in heart failure. N Engl J Med 378(15):1386–1395. https://doi.org/10.1056/NEJMoa1800866
68. Shah KB, Starling RC, Rogers JG, Horstmanshof DA, Long JW, Kasirajan V, Stehlik J, Chuang J, Farrar DJ, Estep JD (2018) Left ventricular assist devices versus medical management in ambulatory heart failure patients: an analysis of INTERMACS Profiles 4 and 5 to 7 from the ROADMAP study. J Heart Lung Transplant 37(6):706–714. https://doi.org/10.1016/j.healun.2017.12.003
69. Estep JD, Starling RC, Horstmanshof DA, Milano CA, Selzman CH, Shah KB, Loebe M, Moazami N, Long JW, Stehlik J, Kasirajan V, Haas DC, O'Connell JB, Boyle AJ, Farrar DJ, Rogers JG (2015) Risk assessment and comparative effectiveness of left ventricular assist device and medical management in ambulatory heart failure patients: results from the ROADMAP Study. J Am Coll Cardiol 66(16):1747–1761. https://doi.org/10.1016/j.jacc.2015.07.075
70. Daniel M, Chen C, Chung J, Goldberg L, Acker MA, Atluri P (2018) Interaction of donor and recipient age: do older heart transplant recipients require younger hearts? Ann Thorac Surg. https://doi.org/10.1016/j.athoracsur.2018.06.085