

German Heart Surgery Report 2021: The Annual Updated Registry of the German Society for Thoracic and Cardiovascular Surgery

Andreas Beckmann¹ Renate Meyer² Jana Lewandowski¹ Andreas Markewitz¹ Daniela Bläßfeld¹
Andreas Böning³

¹German Society for Thoracic and Cardiovascular Surgery,
Langenbeck-Virchow-Haus, Berlin, Germany

²BQS Institute for Quality and Patient Safety, Hamburg, Germany

³Department for Adult, Pediatric Cardiac and Vascular Surgery,
University Clinic Gießen, Gießen, Germany

Address for correspondence: Andreas Beckmann, MD, Deutsche
Gesellschaft für Thorax-, Herz- und Gefäßchirurgie [DGTHG],
Langenbeck-Virchow-Haus, Luisenstr. 58-59, 10117 Berlin, Germany
(e-mail: gf@dgthg.de).

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Abstract

Based on a longtime voluntary registry, founded by the German Society for Thoracic and Cardiovascular Surgery (GSTCVS) in 1980, well-defined data of all cardiac, thoracic and vascular surgery procedures performed in 78 German heart surgery departments during the year 2021 are analyzed. Under more than extraordinary conditions of the further ongoing worldwide coronavirus disease 2019 (COVID-19) pandemic, a total of 161,261 procedures were submitted to the registry. In total, 92,838 of these operations are summarized as heart surgery procedures in a classical sense. The unadjusted in-hospital survival rate for the 27,947 isolated coronary artery bypass grafting procedures (relationship on-/off-pump 3.2:1) was 97.3%. For the 36,714 isolated heart valve procedures (19,242 transcatheter interventions included) it was 96.7 and 99.0% for the registered pacemaker and International Classification of Diseases (ICD) procedures (19,490), respectively. Concerning short- and long-term circulatory support, a total of 3,404 ECLS/ECMO implantations and 750 assist device implantations (L-/ R-/ BVAD, TAH), respectively were registered. In 2021 329 isolated heart transplantations, 254 isolated lung transplantations, and one combined heart-lung transplantations were performed.

Keywords

- ▶ heart valve surgery
- ▶ congenital heart disease
- ▶ coronary artery bypass grafting
- ▶ aortic surgery
- ▶ heart-lung-transplantation
- ▶ COVID 19

This annually updated registry of the GSTCVS represents voluntary public reporting by accumulating actual information for nearly all heart surgical procedures in Germany, constitutes advancements in heart medicine and represents a basis for quality management for all participating institutions. In addition, the registry demonstrates that the provision of cardiac surgery in Germany is up to date, appropriate, and nationwide patient treatment is guaranteed all the time.

Introduction

Legitimate demands for a sophisticated quality management in medicine – by authorities, scientific organizations, health care companies and patients all over the world – have stimulated a quality awareness. This resulted in the development of

versatile quality assurance activities such as benchmark projects, public reporting, registries, and others to answer those needs. More than 30 years ago the board of directors of the German Society for Thoracic and Cardiovascular Surgery (GSTCVS, www.dgthg.de) decided to set up a periodic data collection of all cardiac surgical procedures in terms of a

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voluntary, unaudited registry.^{1,2} Since 1989, the data are updated annually, summarized in the sense of a scientific registry, and published in the society journal each year.^{3–7} The prevalent aims are: to detect developments and upcoming trends in cardiac surgery in Germany; to compile various results for nearly all cardiac surgical procedures; to provide each participant with a benchmark of the institutional results in comparison to the nationwide achievements; and to facilitate an evaluation on an international level for the GSTCVS.

For monitoring actual conditions as well as developments in cardiac medicine, the registry covers all relevant techniques and also innovative technologies incl. minimally invasive cardiac surgery as well as all kinds of heart valve procedures, incl. transcatheter heart valve interventions (e.g. TAVI). Thereby, important findings for current patient safety and the future of patient care are collected for evaluation under different aspects.

Data presented in this report comprehend the survey of the year 2021 whereby more than special circumstances, caused by the further ongoing COVID-19 pandemic, must necessarily be taken into account when interpreting the results.

Material and Methods

Since 2004 a standardized questionnaire gathers specific information for well-defined procedures, exactly described by an annually updated German adaption of the International Classification of Procedures in Medicine called “operation code” (OPS: Operationen- und Prozedurenschlüssel).

All participating institutions were requested to complete the structured questionnaire by January 25, 2022, entering all performed procedures and associated in-hospital mortality. The recommended path for data export is an electronic transmission of an encrypted file to the society office in Berlin. After transaction, the data were decrypted, evaluated for completeness and compiled for further analysis, thus ensuring anonymity for each participating institution. This compilation algorithm enables a high compliance for submission of complete datasets.

Inclusion criteria for the registry data 2021 were all cardiac surgical procedures performed on patients from January 1 to December 31, 2021, unrelated to the date of patients' admission or discharge as compared to other registries. Like in the earlier years, the number of procedures was counted rather than individual patients. For example, if a patient initially required isolated coronary artery bypass grafting (CABG), later followed by a mitral valve reconstruction due to an undesirable event, one count in the category “coronary surgery” and a second one in the category “mitral valve reconstruction” are enumerated. Thus, the registry contains more procedures than the real number of patients operated on.

Death of patients was defined as in-hospital mortality. Per definition, the observed mortality is always attributed to the first cardiac procedure, e.g. the death of a patient requiring a replacement of ascending aorta due to complication after CABG would only be attributed to coronary procedure.

The main reason for this structural set-up of the registry – established over four decades – is to keep in accordance with the

German data privacy act with its specific regulations for patients. Furthermore, it seemed to be relevant to get detailed information about all performed procedures and not only the number of treated patients. Finally the process of data acquisition had to be standardized and feasible for all participating departments in Germany, thus enabling the submission of a complete data set, regardless of the hardware and software used locally.

In 2021, a total of 78 institutions performed heart surgery. As in the years before, all departments answered the questionnaire and delivered a complete data set for the surgical details, including unadjusted in-hospital mortality rates. In addition, comparisons between the registry data and the external quality assurance in accordance with §§ 135a/136/137 SGB V, obligatory for licensed German hospitals (§ 108 SGB V), are possible. Due to unexpected technical problems very little data concerning some patients' origins were not available for the year 2021.

For descriptive statistical analyses categorized tables and a summary registry data file consolidate the transmitted information of all departments, providing the basis for this and further publications. Longitudinal data from earlier registry specifications are also included in the presentation. The period considered where developments are shown is restricted to the past 10 years.

Categorical data are displayed as absolute and/or relative frequencies. Due to lack of complete data for patients' risk adjustment, all mortality rates are unadjusted. Quantitative data are presented as absolute frequencies and arithmetic mean values. Where appropriate, the value range is presented additionally. Patient age, though originally a quantitative variable, is only available in age groups and therefore treated as a categorical variable. German population-based measures are calculated as frequencies per 100,000 inhabitants and are based on the latest published data of the Federal Office for Statistics (Destatis) dated September 30, 2021.

The questionnaires were compiled using Microsoft Visual Basic for Applications. Analyses were performed with IBM SPSS Statistics v22 and Microsoft Excel 2010, charts and tables were created with Microsoft Excel 2010.

Registry Data 2021

► **Table 1** shows the distribution of cardiac surgical procedures between the 16 German states, based on the population count of the Federal Office for Statistics as of September 30, 2021. Concerning patients' origin it has to be considered that a very small amount of missing data (0.9%) influences the distribution of heart procedures per federal state. Taking this into account, the range of heart operations per 100,000 inhabitants shows a minimum of 96.3 (Baden-Württemberg, population: 11,123,393) and a maximum of 156.1 (Sachsen-Anhalt, population: 2,172,221), while the nationwide mean-value at the end of 2021 was 109.9 (► **Table 1**). In addition, ► **Table 1** shows a state-by-state representation of confirmed COVID-19 cases/100,000 population with a median of 5,483.9 (range: 9,594), a minimum of 3,174 in Schleswig-Holstein and a maximum of 12,768 in Sachsen. Thus, the mean of confirmed COVID-19 cases was threefold higher than last year's and a much broader

range among the federal states (range 2020: 2,504) could be observed.

Analyzing quantified categories of heart operations by department dimension, categorizes more than 66.7% of institutions into two clusters with 500 up to 1,499 procedures (2021: 52/78) and 21.8% into those with a minimum of 1,500 up to a maximum of 4,040 performed procedures, respectively (►Table 2). Before the pandemic started in January 2020 the caseload of the heart surgery departments was considerably higher.

Summarizing the departments by various heart surgical procedures, it can be asserted that heart operations in patients suffering from congenital heart disease or CHD (<1 year, with extracorporeal circulation [ECC]) are conducted in 21, isolated heart transplantations in 19 and combined heart–lung transplantations in one institution (►Table 3).

Overall, as shown in ►Table 4, 161,261 procedures were reported to the registry for the year 2021, a difference of 0.3% compared to 2020 (161,817 procedures) but a remarkable decline to 2019 (175,705 procedures). In 2021 the total amount of 92,838 heart surgical procedures in the narrower sense remained almost unchanged to the previous year (92,809 procedures) while from 2020 to 2019 a COVID-19 influenced decrease of 7.6% (100,446 procedures) was seen. Regarding CABG procedures an ongoing decrease must be recorded while heart valve and thoracic aorta procedures increased. The remarkable increase of assist device procedures by 12.5% is caused by a rise of non-permanent systems, almost certainly an effect of the COVID-19 pandemic (►Table 4).

The number of procedures using ECC in Germany from 2012 to 2021 are illustrated in ►Table 5. Since 2012, a gradual reduction can be observed with the strongest decline in 2020. Presumably this reflects on one hand achievements of established innovations with minimally invasive heart surgical procedures, and on the other hand a relevant effect of the COVID-19 pandemic since 2020. In addition, the comparison of 2020 and 2021 shows a further decrease of 2,448 cardiac procedures using ECC during the ongoing pandemic situation.

Concerning gender distribution, the registry shows an overall male/female ratio of almost 2:1 with the greatest difference (4:1) in the patient group with coronary procedures (►Table 6). 10,560 (11.4%) operations were conducted as emergency procedures, and 6,783 (7.3%) were reoperations (►Table 7). These proportions appear quite consistent over the past years.

As shown in ►Table V1 14,279 (38.9%) isolated heart valve procedures were performed as single, 2,792 as double (7.6%), and 323 (0.9%) as triple valve procedures. Further 2,834 (36.8%, $n = 7,698$) aortic valve and 3,369 (55.7%, $n = 6,052$) mitral valve operations were performed via a minimally invasive access (►Table V2). The number of single heart valve procedures via transcatheter approach increased over the last 2 years concerning aortic, mitral and tricuspid valve. The unadjusted mortality of the surgical aortic valve procedures amounts to 2.9%, nearly consistent over the last 3 years. Concerning the transcatheter aortic valve implantations (TAVI), transferred by all heart surgery departments in Germany, the unadjusted mortality rate was 1.9% in 2021, a

decrease of 0.5 percentage points compared to the two previous years (2020/2019: 2.4%).

In 6,754 (87.7%) isolated aortic valve operations under ECC conditions, xenograft prostheses were implanted, a consistent distribution over the last 5 years (►Table V3, ►Fig. 5). Concerning the treatment of mitral valve disease, in 63.3% (3,828) of the isolated mitral valve operations a reconstruction with preservation of the native valve could be achieved (►Fig. 7). In a total of 2,500 combined mitral valve repair procedures, 1,094 (43.8%) simultaneous CABG procedures, 765 tricuspid valve repairs (30.6%), 464 (18.6%) aortic valve procedures and 177 (7.1%) concomitant CABG and AVR were performed (►Table V4).

The subgroup of 3,115 multiple heart valve procedures amounted to 2,546 (81.7%) double heart valve operations as a combination of mitral + tricuspid ($n = 1,296$) or mitral + aortic ($n = 1,250$) valve procedures (►Table V5). Regarding the 16,903 transcatheter aortic valve implantations (TAVIs), an increase to 15,992 (94.6%) procedures performed by transvascular access and a lasting decrease to 911 (5.4%) by transapical access could be observed. In TAVI procedures without ECC the unadjusted mortality for those by transvascular access improved to 1.6% (255/15,917), respectively 4.9% (44/901) for the transapical approach. On the other hand, TAVI under use of ECC shows a remarkably high unadjusted mortality rate of 26.7% (20/75), respectively 30.0% (3/10) (►Table V6), probably related to complications during the initial procedure.

Concerning the transmitted 36,122 CABG procedures, 77.4% were performed as isolated operations ($n = 27,947$), 11.8% ($n = 4,267$) combined with surgical aortic valve replacement (sAVR) and 5.2% ($n = 1,896$) with simultaneous mitral valve operations (►Table C1). These numbers depict a minimal decline compared to the previous year. ►Table C2 provides an overview of the isolated CABG operations focused on the number of bypass grafts and indicates the corresponding unadjusted mortality rates for on/off pump surgery. While the total number of isolated CABG procedures showed a small decrease, the subgroup of isolated CABG without ECC increased to 6,667 (2020: 6,440). In addition, the unadjusted mortality rate of this subgroup decreased to 1.6% (2020: 2.0%), independent of the number of bypasses. In this context it has to be taken into account that conversions from off- to on-pump CABG are not captured. ►Tables Con1 and 2 show data concerning congenital heart surgery procedures. In this subcategory the total number ($n = 5,589$) shows a small decline, meanwhile the unadjusted overall mortality rate changed to 2.1% (►Table Con1) compared to 2020 ($n = 5,637$; 2.6%;) and 2019 ($n = 5,834$; 2.7%), respectively. ►Tables Mis1–5 demonstrate further compiled registry data under different aspects and for various categories like the Ross procedure, heart and lung transplantations, aortic surgery and heart rhythm procedures. With a total of 18,576 specified pacemaker and ICD procedures, the number declined by almost 3.2% (2020: 19,187) (►Fig. 11), while the unadjusted mortality rate increased for pacemaker procedures to 0.9% (2020: 0.7%) and for ICD procedures to 1.2% (2020: 0.9%) (►Table Mis4). As expected, the highest mortality rates for both CIED procedures were detected in the revision categories.

Compared to the data of previous years, some significant changes can be seen on one hand, while several developments remained almost unchanged in 2021 on the other hand. The number of CABG procedures, isolated or combined, shows a further decrease of 4.9% in 2021, considerably less than the decline of the previous year (13.9%). The number of isolated heart valve procedures rose to the level of 2019 (increase of 3.5%) (►Fig. 1). However, unadjusted mortality rates for CABG, AVR vary just slightly over the last decade (►Fig. 2). The age distribution of patients continues to evolve toward a higher percentage of elderly patients (≥ 80 years) as well as a continuous increase of adults ≤ 69 years (49.5%) (►Fig. 3). Presently, 29.8% of the cardiac procedures are performed in patients from 70 to 79 years of age, and 20.7% in octo-/nonagenarians. The relative amount of isolated off-pump CABG increases steadily, reaching 23.9% in 2021 (2020: 21.9%) (►Fig. 4).

With regard to heart valve prostheses distribution, in 90.0% ($n = 6,754$) sAVR was performed using a xenograft (►Fig. 5), whereas in 10.0% ($n = 748$) a mechanical prosthesis was implanted: a consistent proportion over the past 5 years. The unchanged development of transcatheter heart valve procedures in Germany led to a total of 19,285 transferred procedures in 2021 (►Table V6). Focused on the distribution of aortic valve procedures for 2021, 16,903 (69.2%) TAVI and 7,523 (30.8%) sAVR were reported to the registry (►Fig. 6). It must be emphasized that exclusively the German departments for cardiac surgery contribute to these data. Therefore, the registry cannot reach completeness of TAVI data due to the fact that procedures documented by cardiology departments are incompletely included. On the basis of and in addition to the recommendations of international scientific guidelines and expert consensus on the management of valvular heart disease, respectively,^{8–10} the German Federal Joint Committee (G-BA) implemented a quality assurance directive¹¹ for “minimally invasive heart valve interventions (TAVI, transcatheter mitral clip reconstruction)” in 2015, which is still under evaluation. Further surveys for selected procedures, such as the legally compulsory quality assurance (§135a SGB V) or the voluntary nationwide German Aortic Valve Registry (GARY),^{12–25} provide various important findings and thus also contribute to an exceptional patient benefit.

In 2021, the rate of isolated mitral valve reconstructions remains almost unchanged on a remarkable level of 63.3% (2020: 64.1%) (►Fig. 7). Based on the fact that all isolated mitral valve procedure are included, regardless of the underlying mitral valve disease concerning morphology or urgency of operation, it can be assumed that the relative rate of mitral valve reconstruction would certainly be even higher if patients without a possibility or indication for reconstruction would have been excluded (e.g., mitral valve stenosis, calcifications, or endocarditis) like in other publications, e.g., Gammie et al.²⁶ Therefore, other published rates of mitral valve repair have to be interpreted with caution if compared to this registry.

In 2021 almost half (48.5%; $n = 2,685$) of cardiac operations for CHD were performed in neonates/infants < 1 year, 34.6% in children between 1 and 17 years and 16.9% in patients at least 18 years of age (►Fig. 8). These numbers show a quite steady level over the past decade.

Concerning ventricular assist device (L-/ R-/ BVAD, TAH) implantations ($n = 750$) a further significant decrease of 11.0% compared to 2020 ($n = 843$) (►Fig. 9) could be observed, while the total number of heart transplantations decreased to 329, a decline of 3.2% compared to the previous year (►Fig. 10). Nevertheless, the mechanical circulatory support therapy, in particular LVAD, is still of outstanding importance for patients with end-stage heart failure.

Discussion

Even under the exceptional conditions of the further ongoing COVID-19 pandemic, the registry of the GSTCVS enables a comprehensive overview of all heart surgical procedures performed in German cardiac surgery departments in 2021. The accuracy of this registry remains high due to the implemented compilation algorithm using standardized operation coding as a relevant criterion for reimbursement purposes. This is supported by other authors who could demonstrate a high accuracy for major outcome parameters in unaudited registries.²⁷ As observed in recent years, heart surgery in Germany is performed on a high level with superior in-hospital patient survival compared to international surveys. In addition, the registry demonstrates that the provision of cardiac surgery in Germany could be always enabled (24/7/365) nationwide, even under COVID-19 conditions. These aspects are especially important in the context of various developments in the German health care policy and considering the background of demographic trends of the German population, leading to more patients at increased age combined with a higher proportion of related comorbidities and an accordingly complex perioperative risk profile.

Compared to 2020, the number of cardiac surgery procedures showed a smaller decrease for isolated/combined CABG and sAVR than in 2019 to 2020, an ongoing trend in the view of the German population characteristics and in the context of application of scientific guidelines.^{10,28,29} Despite this, for the years 2020 und 2021 it must be taken into account that the care of patients with heart disease was affected by the consequences of SARS-CoV-2 pandemic with shutdowns and restrictions, respectively. Due to limited intensive care resources in all German cardiac centers, provision of elective/urgent heart surgical procedures was affected substantially. Otherwise, the low level in heart transplantations needs more efforts for a positive development in the future, even when the COVID pandemic will have been overcome.

Further improvements of the registry are recommended to enable more specified assessments and particularly risk-adjusted data analyses. However, if significant fundamental changes related to the modality of data collection were to be implemented, a modified structure would have to ensure further longitudinal data analysis.

Completeness, validity, and further progress depend on continued efforts and a close collaboration of the German Society for Thoracic and Cardiovascular Surgery and all German cardiac surgical departments. This will be of outstanding importance as a contribution for patient safety and to obtain evidence for the high quality of heart surgery in Germany.

Conflict of Interest

None declared.

Acknowledgement

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Abbreviations

ASD atrial septal defect
 AVC atrioventricular canal
 CABG coronary artery bypass grafting
 CHD congenital heart disease
 CIED cardiac implantable electronic devices
 DLTx double lung transplantation

DORV double outlet right ventricle
 ECC extracorporeal circulation
 ECLS extracorporeal life support
 ECMO extracorporeal membrane oxygenation
 HLTx heart-lung transplantation
 HTx heart transplantation
 ICD implantable cardioverter defibrillator
 LTx lung transplantation
 PDA patent ductus arteriosus
 PTS patients
 SAVR surgical aortic valve replacement
 SLTx single lung transplantation
 TAH total artificial heart
 TAVI transcatheter aortic valve implantation
 TGA transposition of great arteries
 Tx transplantation
 VAD ventricular assist device
 VSD ventricular septal defect

Tables and Figures**Table 1** German states/Heart operations/confirmed COVID-19 cases

Federal state	Population ^a	Quantity ^b	Heart procedures/ 100,000 inhabitants	Total number of COVID-19 cases ^c	COVID-19 cases/ 100,000 population ^c
Baden-Württemberg	11,123,393	10,716	96.3	774,223	6,960
Bayern	13,176,644	13,051	99.0	998,071	7,575
Berlin	3,669,811	3,704	100.9	230,966	6,294
Brandenburg	2,537,202	3,152	124.2	200,301	7,895
Bremen	675,171	685	101.5	33,606	4,977
Hamburg	1,853,049	2,186	118.0	101,845	5,496
Hessen	6,290,030	7,036	111.9	340,702	5,417
Mecklenburg-Vorpommern	1,612,466	1,228	76.2	87,764	5,443
Niedersachsen	8,025,848	9,479	118.1	333,592	4,156
Nordrhein-Westfalen	17,918,037	19,939	111.3	979,527	5,467
Rheinland-Pfalz	4,105,944	4,636	112.9	205,203	4,998
Saarland	983,070	1,034	105.2	53,790	5,472
Sachsen	4,046,699	4,860	120.1	516,664	12,768
Sachsen-Anhalt	2,172,221	3,391	156.1	194,547	8,956
Schleswig-Holstein	2,920,850	3,875	132.7	92,704	3,174
Thüringen	2,112,007	2,509	118.8	245,940	11,645
<i>Deutschland</i>	<i>83,222,442</i>	<i>91,481</i>	<i>109.9</i>	<i>5,389,445</i>	<i>6,476</i>

^aFederal Office for Statistics of German Population; due date September 30st 2021.^b*n* = 529, foreign residences excluded.^cRobert Koch Institute: laboratory confirmed COVID-19 cases; due date December 30st, 2021.**Table 2** Departments assorted by quantified categories (Σ^a [*n* = 92,838])

Procedures (quantity)	<500	500–999	1,000–1,499	1,500–1,999	2,000–5,000
Departments	9	32	20	6	11
Average	373	795	1,241	1,708	2,635
Range	157–491	551–975	1,036–1,493	1,565–1,982	2,057–4040

^aCIED and extracardiac surgery without ECC are excluded.

Table 3 Departments summarized by heart surgery procedures 2021

Category	n
Coronary artery bypass grafting	77
Heart valve surgery	77
Pacemaker/ICD procedures	75/74
Surgery for CHD (pat, <1 y with ECC)	21 ^a
Heart transplantation	19 ^b
Heart-lung transplantation	1

^aN = 2,061: thereof: 19–40 op. in three units, 50–85 op. in nine units, 109–207 op. in nine units.

^bN = 329: thereof: 1–4 transpl. in five units, 5–9 transpl. in four units, 10–19 transpl. in five units, 33–63 transpl. in five units.

Table 5 Cardiac procedures using extracorporeal circulation (2012–2021)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Departments	79	79	78	78	78	78	78	78	78	78
Operations	84,388	84,040	83,787	81,527	79,082	76,696	72,331	71,759	63,720	61,272
Average	1,068	1,064	1,074	1,045	1,014	983	927	920	817	786

Table 4 Frequency of cardiac procedures 2021

Category	With ECC	Without ECC	Total	Diff, 2020 (%)
CABG isolated	21,280 ^a	6,667 ^a	27,947	−5.1%
CABG combined	7,961 ^a	214 ^a	8,175	−4.3%
Heart valve procedures	17,665 ^a	19,049 ^a	36,714	+ 3.5%
Surgery of thoracic aorta	7,499 ^a	704 ^a	8,203	+ 4.7%
Surgery for CHD	4,645 ^a	890 ^a	5,535	−0.6%
Cardiac surgery, other	1,322 ^a	1,210 ^a	2,532	+ 0.1%
Assist device procedures	578 ^a	2,832 ^a	3,410	+12.5%
Extracardiac surgery	287 ^a	48,968	49,255	+0.2%
Pacemaker and ICD procedures	35 ^a	19,455	19,490	−3.7%
Total	61,272	99,989	161,261	−0.3%

^aSum: n = 92,838 (heart surgery procedures).

Table 6 Gender distribution

Distribution	Female		Male	
	n	%	n	%
Heart valve procedures	15,523	42	21,191	58
Coronary procedures	7,592	21	28,530	79
CHD procedures	2,491	45	3,044	55
Surgery of thoracic aorta	2,746	33	5,457	67
Cardiac surgery, other	1,525	60	1,007	40
Assist device	885	26	2,525	74
Pacemaker and ICD	7,073	36	12,417	64
Extracardiac surgery	17,375	35	31,880	65
Total	55,210	34	106,051	66

Table 7 Additional data 2020 vs. 2019

Procedures with ECC	2021		2020	
Emergency	10,560	11.4%	10,445	11.3%
Redo	6,783	7.3%	7,330	7.9%

Table V1 Isolated heart valve procedures

Procedure	N	†	%
Single valve	14,279	500	3.5
Double valve	2,792	259	9.3
Triple valve	323	51	15.8
Transcatheter access (single valve)	19,203	380	2.0
Transcatheter access (double valve)	39	3	7.7
Unspecified	78	5	6.4
Total	36,714	1,198	3.3

Notes: Transcatheter heart valve procedures: 16,903 aortic valve implantation; 230 mitral valve implantation; 1,542 mitral valve repair; six tricuspid valve implantation; 522 tricuspid valve repair; 39 double aortic and mitral valve procedure.

Table V3 Isolated aortic/mitral valve operations

Prosthesis/ native heart valve	Aortic			Mitral		
	n	†	%	n	†	%
Xenograft	6,754	209	3.1	1,798	168	9.3
Mechanical prosthesis	748	13	1.7	422	19	4.5
Repair	175	4	2.3	3,828	48	1.3
Homograft	21	0	0.0	4	0	0.0
Total	7,698	226	2.9	6,052	235	3.9

Note: Transcatheter procedures and apical aortic conduits procedures (n = 1) are not included.

Table V2 Single heart valve procedures

Access path	N	†	%
Aortic valve			
Sternotomy	4,864	188	3.9
Partial sternotomy	2,834	38	1.3
Transvascular	15,992	275	1.7
Transapical	911	47	5.2
Mitral valve			
Sternotomy	2,683	202	7.5
Minimal invasive	3,369	33	1.0
Transcatheter	1,772	52	2.9
Tricuspid valve			
Sternotomy	346	28	8.1
Minimal invasive	127	10	7.9
Transcatheter	528	6	1.1
Pulmonary valve			
Sternotomy	55	1	1.8
Minimal invasive	0	0	–
Transcatheter	0	0	–
Total	33,481	880	2.6

Note: Apical aortic conduits procedures (n = 1) are not included.

Table V5 Multiple heart valve procedures

Combination	N	†	%
Mitral + tricuspid	1,296	91	7.0
Aortic + mitral	1,250	147	11.8
Aortic + mitral + tricuspid	320	51	15.9
Aortic + tricuspid	133	19	14.3
Aortic + pulmonary ^a	102	2	2.0
Tricuspid + pulmonary	11	0	0.0
Aortic + mitral + pulmonary	3	0	0.0
Total	3,115	310	10.0

Notes: Transcatheter procedures are excluded.

^aIncluding Ross procedures.

Table V4 Isolated/combined mitral valve procedures—implantation/replacement vs. repair

Mitral valve procedures	Repair			Implantation/replacement			Total		
	n	†	%	N	†	%	n	†	%
Isolated	3,828	48	1.3	2,224	187	8.4	6,052	235	3.9
+ CABG	1,094	46	4.2	802	130	16.2	1,896	176	9.3
+ Tricuspid valve repair ^a	765	22	2.9	492	63	12.8	1,257	85	6.8
+ Aortic valve	464	27	5.8	786	120	15.3	1,250	147	11.8
+ CABG + Aortic valve replacement	177	19	10.7	245	53	21.6	422	72	17.1
Total	6,328	162	2.6	4,549	553	12.2	10,877	715	6.6

^a39 procedures (not specified mitral valve + tricuspid valve surgery) excluded. Mortality: 15% (6/39).

Table V6 Transcatheter heart valve procedures

	Without ECC		With ECC		Total		
	<i>n</i>	†	<i>N</i>	†	<i>n</i>	†	%
Aortic valve implantation	16,818	299	85	23	16,903	322	1.9
Transvascular	15,917	255	75	20	15,992	275	1.7
Transapical	901	44	10	3	911	47	5.2
Mitral valve	1,666	40	106	12	1,772	52	2.9
Repair	1,448	27	94	4	1,542	31	2.0
Implantation	218	13	12	8	230	21	9.1
Tricuspid valve repair	527	6	1	0	528	6	1.1
Repair	521	6	1	0	522	6	1.1
Implantation	6	0	0	0	6	0	0.0
Aortic + mitral valve implantation	38	3	1	0	39	3	7.7
Aortic valve implantation ^a + CABG	24	1	13	2	37	3	8.1
Mitral valve implantation ^b + CABG	4	1	2	0	6	1	16.7
Aortic + mitral valve + CABG	0	0	0	0	0	0	–
Total	19,077	350	208	37	19,285	387	2.0

Notes: Pulmonary valve implantation for CHD excluded; 5% of TAVI by transapical access and less than 1% of TAVI under ECC conditions.

^aFemoral, subclavian or transaortic access.

^bTransvascular and transapical access.

Table C1 Isolated CABG and combined procedures with/without ECC

	<i>n</i>	†	%
Isolated CABG	27,947	751	2.7
+ Aortic valve replacement	4,267	215	5.0
+ Other	1,468	69	4.7
+ Mitral valve repair	1,094	46	4.2
+ Mitral valve replacement	802	130	16.2
+ Aortic valve replacement + mitral valve repair	177	19	10.7
+ Aortic + mitral valve replacement	245	53	21.6
+ Aneurysmal resection	79	7	8.9
+ Transcatheter aortic valve implantation	37	3	8.1
+ Transcatheter mitral valve procedure	6	1	16.7
Total	36,122	1,294	3.6

Table C2 Isolated CABG on-/off-pump surgery

Grafts	On-Pump			Off-Pump			Total		
	<i>n</i>	†	%	<i>n</i>	†	%	<i>n</i>	†	%
Single	527	29	5.5	1,205	15	1.2	1,732	44	2.5
Double	4,194	145	3.5	1,783	35	2.0	5,977	180	3.0
Triple	9,456	267	2.8	2,515	38	1.5	11,971	305	2.5
Quadruple	5,374	140	2.6	912	17	1.9	6,286	157	2.5
Quintuple + more	1,729	60	3.5	252	5	2.0	1,981	65	3.3
Total	21,280	641	3.0	6,667	110	1.6	27,947	751	2.7

Table Con1 Congenital heart surgery with/without ECC

Age (years)	n		†		%	
	With ECC	Without ECC	With ECC	Without ECC	With ECC	Without ECC
< 1	2,030	676	65	16	3.2	2.4
1–17	1,747	196	20	0	1.1	0.0
≥ 18	922	18	19	0	2.1	0.0
Total	4,699	890	104	16	2.2	1.8

Table Con2 Procedures for congenital heart disease with and without ECC

Lesion/Procedure	Age < 1 y			Age 1 to 17 y			Age ≥ 18 y		
	n	†	%	n	†	%	n	†	%
ASD	37	0	0.0	238	0	0.0	204	1	0.5
Complete AV-canal	173	0	0.0	103	1	1.0	5	0	0.0
VSD	288	2	0.7	104	1	1.0	12	0	0.0
Fallot's tetralogy	193	0	0.0	24	0	0.0	2	0	0.0
DORV	53	0	0.0	11	1	9.1	1	0	0.0
TGA	147	1	0.7	2	0	0.0	0	–	–
TGA + VSD	70	2	2.9	3	0	0.0	0	–	–
Truncus arteriosus	33	0	0.0	10	0	0.0	0	–	–
Fontan circulation	2	0	0.0	292	5	1.7	3	0	0.0
Norwood	133	22	16.5	1	0	0.0	0	–	–
Pulmonary valve	63	2	3.2	180	1	0.6	76	3	3.9
Transcatheter pulmonary valve implantation	0	–	–	7	0	0.0	4	0	0.0
Aortic valve	53	1	1.9	176	0	0.0	338	2	0.6
Ross procedure	5	0	0.0	20	1	5.0	31	0	0.0
Mitral valve	27	0	0.0	117	3	2.6	93	8	8.6
Tricuspid valve	103	2	1.9	87	0	0.0	44	3	6.8
PDA	153	8	5.2	18	0	0.0	2	0	0.0
Coarctation	238	3	1.3	26	0	0.0	3	0	0.0
Others	929	38	4.1	479	7	1.5	122	2	1.6
HTx	6	0	0.0	39	0	0.0	0	–	–
HLTx	0	–	–	0	–	–	0	–	–
LTx	0	–	–	6	0	0.0	0	–	–
Total	2,706	81	3.0	1,943	20	1.0	940	19	2.0

Table Mis1 Ross procedures (autologous AV and PVR)

Age (years)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
<18	36	33	37	28	38	38	29	32	35	25
≥18	117	107	90	64	72	52	61	104	70	124
Total	153	140	127	92	110	90	90	136	105	149

Table Mis2 Heart and lung transplantation

Transplant	With ECC			Without ECC		
	<i>n</i>	†	%	<i>n</i>	†	%
HTx	329	26	7.9			
HLTx	1	0	0.0			
LTx	93	8	8.6	161	9	5.6

Notes: All pediatric transplantations (demonstrated in ► **Table Con2**) are included in this table.

Note: Eurotransplant (ET) report 2021: 324 HTx, 2 HTx + kidneyTx, 1 HTx + liverTx, 2 HLTx, 264 DLTx, 16 SLTx, 0 LTx + kidneyTx and 1 LTx + liverTx.

Table Mis3 Aortic surgery

Replacement ^a	With ECC			Without ECC		
	<i>N</i>	†	%	<i>n</i>	†	%
Supracoronary replacement of ascending aorta	1,173	85	7.2			
Supracoronary ascending + aortic valve replacement	1,133	45	4.0			
Infracoronary replacement of ascending aorta						
Mechanical aortic valve conduits	309	16	5.2			
Biological aortic conduits	1,023	102	10.0			
David procedure	502	7	1.4			
Yacoub procedure	108	5	4.6			
Other	292	21	7.2			
Aortic arch replacement ^b	2,815	400	14.2			
Replacement of descending aorta	65	3	4.6	6	1	16.7
Thoraco-abdominal aortic replacement	75	12	16.0	20	1	5.0
Endostent descending aorta	4	3	75.0	678	21	3.1
Total	7,499	699	9.3	704	23	3.3

Notes: All procedures involving aortic surgery are included in this table. Isolated aortic surgery as well as all possible combined procedures (e.g. additional CABG) are summarized in this category.

^aProcedures for abdominal aortic diseases excluded: 442 abdominal procedures and 34 endovascular abdominal stents.

^bAll possible combined procedures included; the only common denominator is aortic arch surgery.

Table Mis4 Pacemaker and ICD procedures

Device/Category				With ECC		Without ECC	
	<i>n</i>	†	%	<i>n</i>	†	<i>n</i>	†
Pacemaker	12,443	118	0.9	8	1	12,435	117
Implantation	8,478	75	0.9	4	0	8,474	75
Battery exchange	1,706	3	0.2	0	0	1,706	3
Revision procedures	2,259	40	1.8	4	1	2,255	39
ICD	6,133	72	1.2	18	5	6,115	67
Implantation	2,445	11	0.4	1	0	2,444	11
Battery exchange	1,499	2	0.1	1	0	1,498	2
Revision procedures	2,189	59	2.7	16	5	2,173	54
Miscellaneous	914	10	1.1	9	0	905	10
Total	19,490	200	1.0	35	6	19,455	194

Table Mis5 Surgical procedures for tachyarrhythmia

Energy source	Endocardiac	Epicardiac	Total
	<i>n</i>	<i>n</i>	
Unipolar radio frequency	55	244	299
Unipolar cooled radio frequency	57	102	159
Bipolar radiofrequency	234	1,598	1,832
Cryotherapy	1,331	324	1,655
Microwave	0	0	0
Focused ultrasound	2	98	100
Laser	0	0	0
Other	6	3	9
Total	1,685	2,369	4,054

Note: 223 procedures are unspecified with regard to endo-/epicardiac ablation.

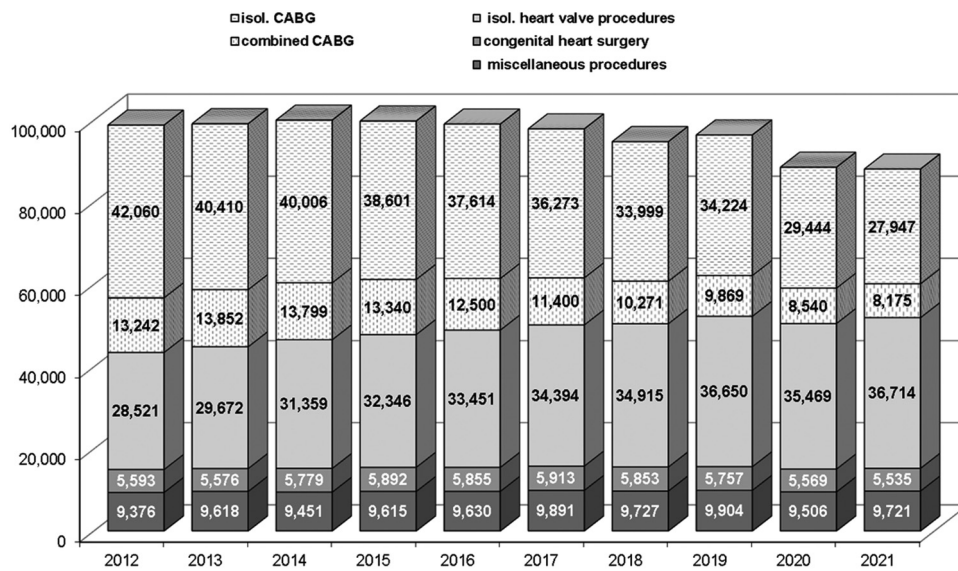


Fig. 1 Selected heart surgical categories (2012–2021). Notes: Congenital heart surgery: atrial septal defect repairs in adults or in combination with coronary artery bypass grafting (CABG) or heart valve procedures are summarized in the CABG or heart valve procedure groups; miscellaneous procedures: all other types of procedures with extracorporeal circulation.

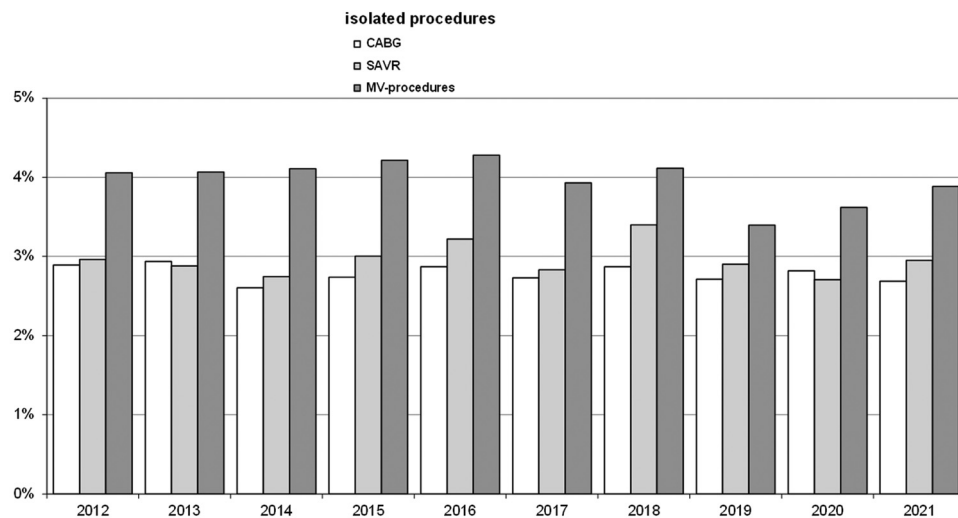


Fig. 2 Unadjusted mortality for selected procedures (2012–2021).

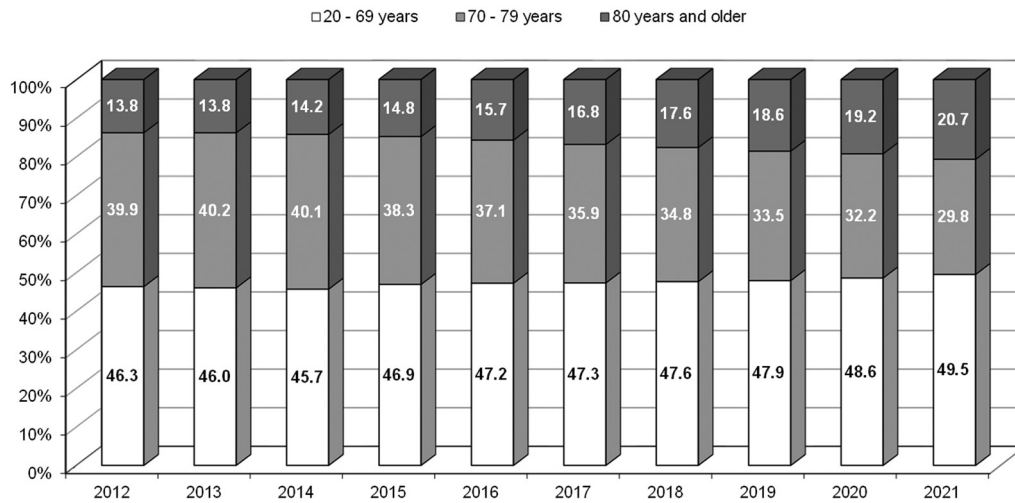


Fig. 3 Age distribution of cardiac procedures (2012–2021). Notes: Patients <20 years and CIED procedures were excluded.

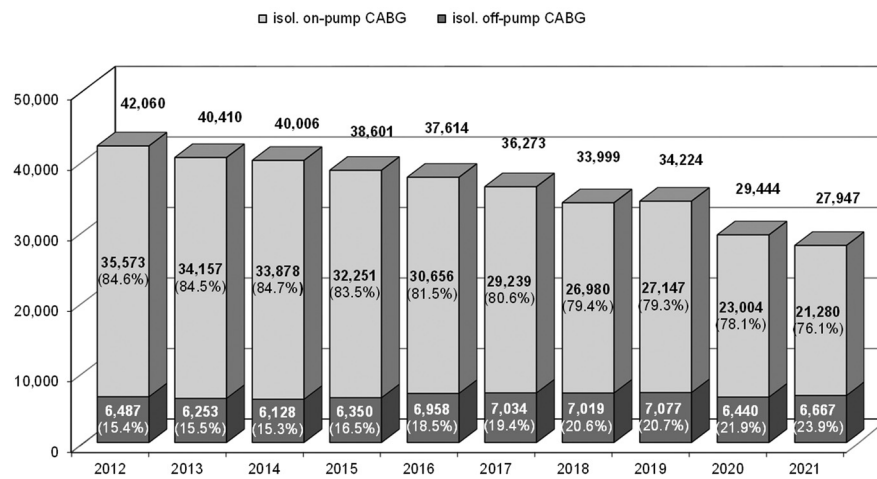


Fig. 4 Isolated coronary artery bypass grafting (CABG) (2012–2021)

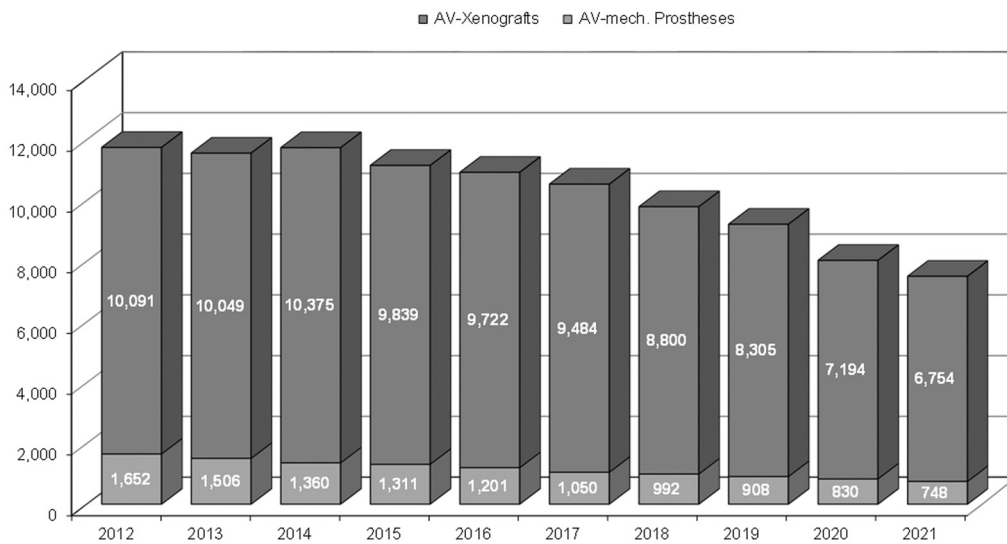


Fig. 5 Isolated aortic valve (AV) replacement (2012–2021). Notes: Ross procedures, homograft implantations, and transcatheter heart valve interventions excluded.

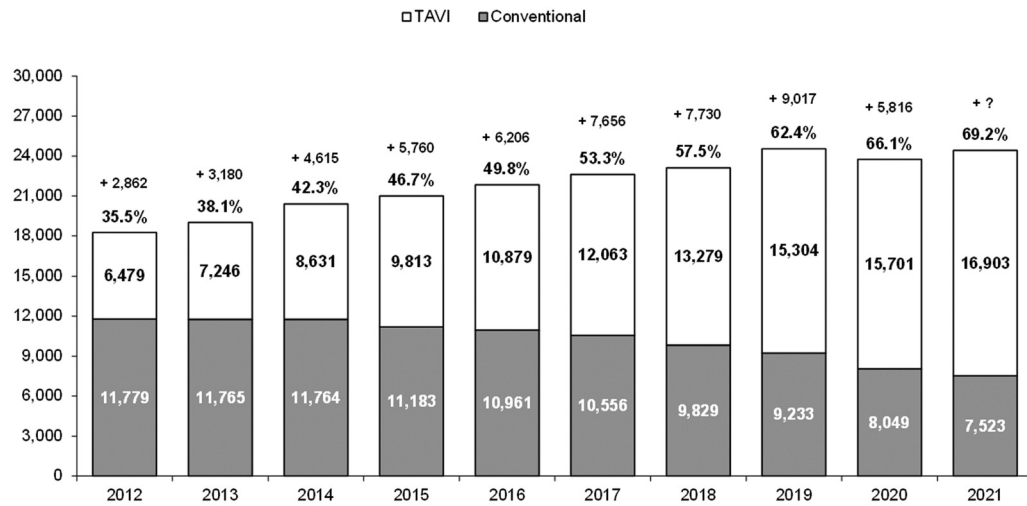


Fig. 6 Isolated aortic valve replacement and transcatheter aortic valve implantation (TAVI) (2012–2021) + additional TAVI procedures calculated from the German legal quality assurance program, §§ 135a/ 136/ 137 SGB V. TAVI, transcatheter heart valve intervention.

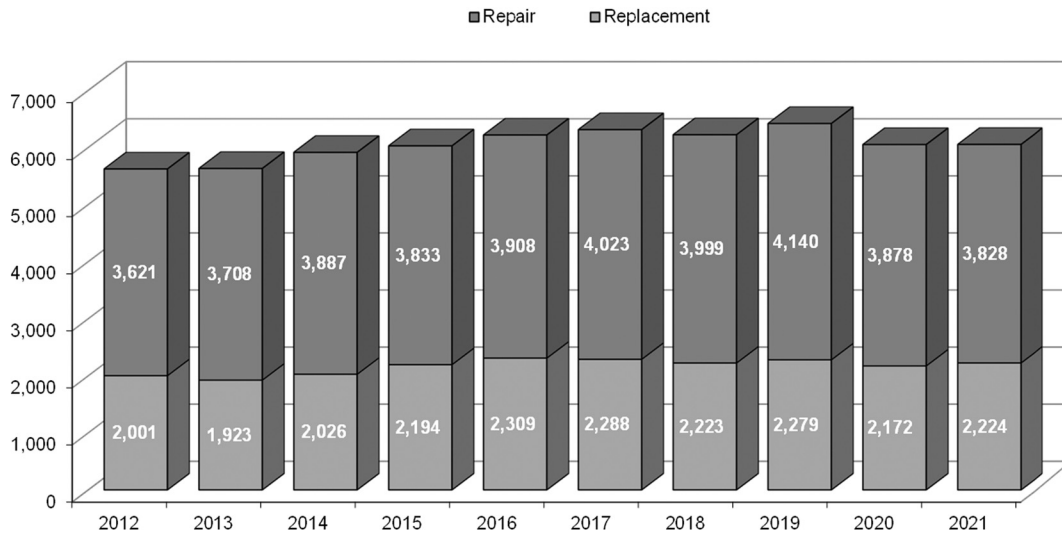


Fig. 7 Isolated mitral valve surgery (2012–2021).

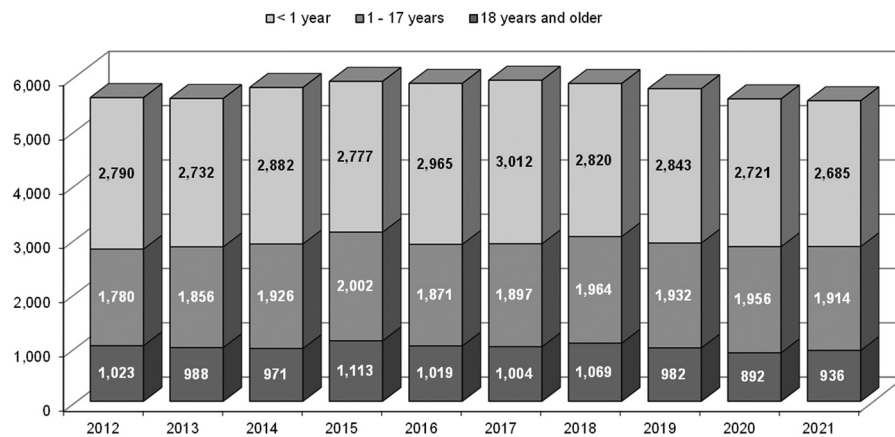


Fig. 8 Age distribution for congenital heart disease (CHD) (2012–2021). Notes: Bias possible due to the fact that not all relevant procedures can be allocated exactly to CHD category in patients >18 years (e.g. aortic valve disease).

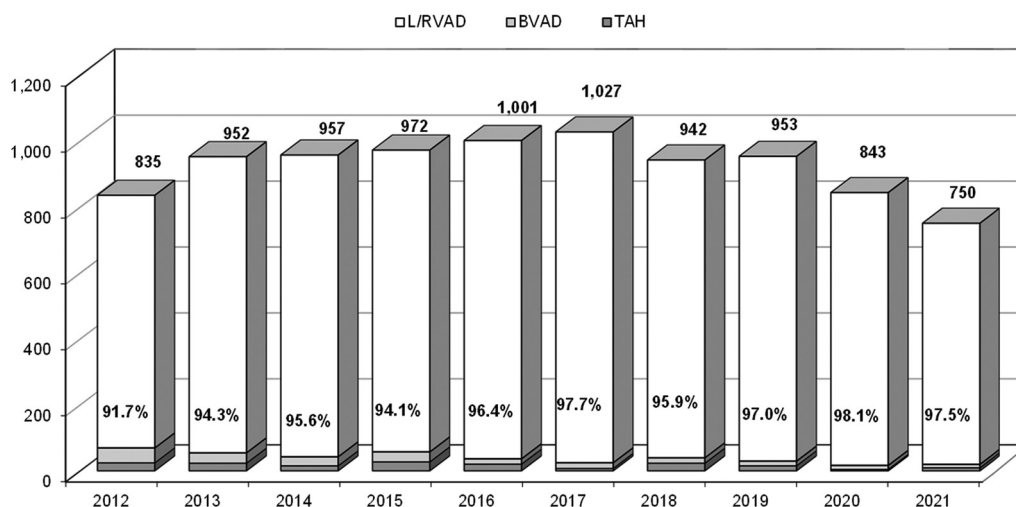


Fig. 9 Mechanical circulatory support devices (2012–2021).

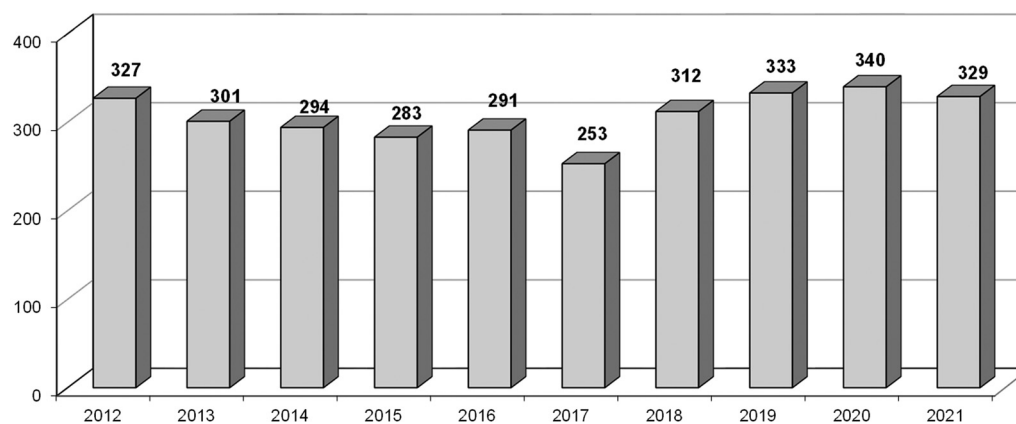


Fig. 10 Heart transplantation (2012–2021).

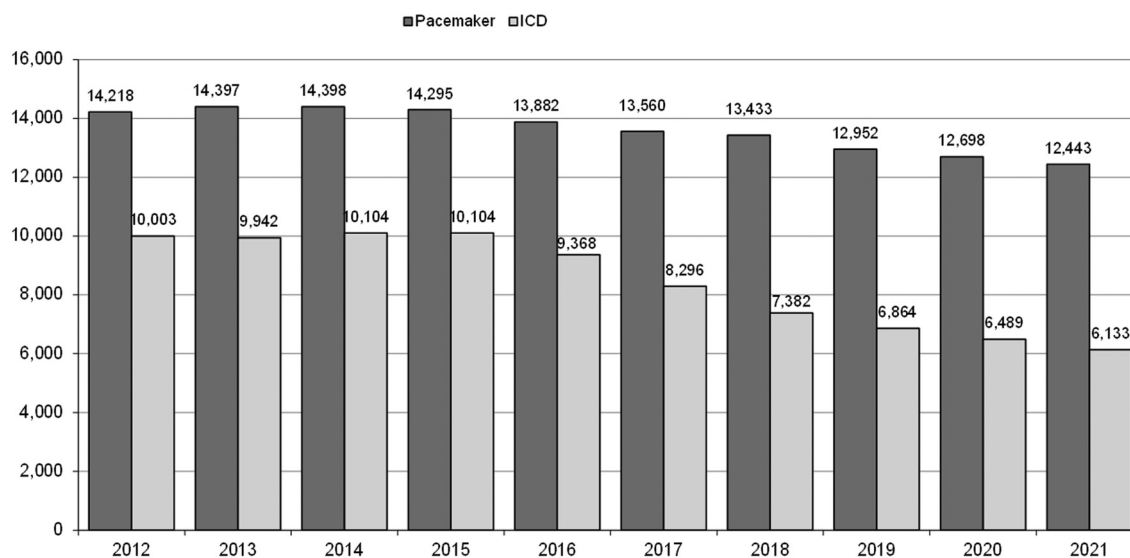


Fig. 11 Pacemaker and ICD procedures (2012–2021).

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