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REPORT

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The European Registry for Patients with Mechanical Circulatory Support (EUROMACS): third Paediatric (Paedi-EUROMACS) report

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Abstract

OBJECTIVES: A third paediatric report has been generated from the European Registry for Patients with Mechanical Circulatory Support (EUROMACS). The purpose of EUROMACS, which is operated by the European Association for Cardio-Thoracic Surgery, is to gather data related to durable mechanical circulatory support for scientific purposes and to publish reports with respect to the course of mechanical circulatory support therapy. Since the first report issued, efforts to increase compliance and participation have been extended. Additionally, the data provided the opportunity to analyse patients of younger age and lower weight.

METHODS: Participating hospitals contributed pre-, peri- and long-term postoperative data on mechanical circulatory support implants to the registry. Data for all implants in paediatric patients (<19 years of age) performed from 1 January 2000 to 31 December 2020 were analysed. This report includes updates of patient characteristics, implant frequency, outcome (including mortality rates, transplants and recovery rates) as well as adverse events including neurological dysfunction, device malfunction, major infection and bleeding.

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RESULTS: Twenty-five hospitals contributed 537 registered implants in 480 patients. The most frequent aetiology of heart failure was any form of cardiomyopathy (59%), followed by congenital heart disease and myocarditis (15% and 14%, respectively). Competing outcomes analysis revealed that a total of 86% survived to transplant or recovery or are ongoing; at the 2-year follow-up examination, 21.9% died while on support. At 12 months, 45.1% received transplants, 7.5% were weaned from their device and 20.8% died. The 3-month adverse events rate was 1.59 per patient-year for device malfunction including pump exchange, 0.7 for major bleeding, 0.78 for major infection and 0.71 for neurological events.

CONCLUSIONS: The overall survival rate was 79.2% at 12 months following ventricular assist device implant. The comparison of survival rates of the early and later eras shows no significant difference. A focus on specific subgroups showed that survival was less in patients of younger age (<1 year of age; $P = 0.01$) and lower weight (<20 kg; $P = 0.015$). Transplant rates at 6 months continue to be low (33.2%).

Keywords: Mechanical circulatory support • Ventricular assist device • Paediatric patients • Registry • End-stage heart failure • Congenital heart disease

INTRODUCTION

The lack of European registration on durable mechanical circulatory support (MCS) led to the foundation of European Registry for Patients with Mechanical Circulatory Support (EUROMACS) in 2009. Since 2021, the EUROMACS affairs are in the hands of a committee of the European Association for Cardio-Thoracic Surgery (EACTS), and hereby fulfil all by-laws of the association. In 2019, a paediatric subcommittee was established with the goal to prospectively collect data relevant to the unique aspects of ventricular assist device (VAD) support in children. Data are submitted by the participating centres represented by their clinicians. The objectives are to offer a robust repository of clinical data on long-term MCS from a large international community for scientific and benchmarking purposes. Ultimately, providing these data on survival and morbidity for clinicians and industry representatives facilitate and enable them to understand the factors that influence the results of MCS therapy in children in more detail.

Paediatric EUROMACS reports data analysis on a biannual basis. This report represents the third edition and summarizes the current data in EUROMACS.

METHODS

Structure of EUROMACS

The EUROMACS registry is organized and maintained by the EACTS. The EACTS Council is advised by the EUROMACS Committee with respect to its strategy and policy. A paediatric sub-committee has been established among the EUROMACS Committee members to focus on specific data concerning the treatment of children with MCS. Representatives of participating centres can submit proposals that are evaluated for originality, innovativeness, focus, methodology and feasibility. If the proposal is accepted the principle investigator will receive an anonymized data set to execute the study.

Data from patients whose parents, or in some cases—depending on the local regulatory regiment from patients themselves, have given permission to the hospital to share data with EUROMACS, are included in the registry.

Patient selection

EUROMACS collects data from patients in whom a CE-marked durable assist device was implanted, excluding data from the use of short-term devices as primary implant. This report focuses on patients ≤19 years of age (Table 1) and VAD implantation from 2001 through 2020. Data of 25 paediatric centres in 14 countries (Supplementary Material, Table S1) with a total of 537 registered assist device implantations for durable use in 480 paediatric patients, as in Fig. 1, were included in the analyses.

Data from 17 patients of centres that ceased their programme (4 centres), and of whom no follow-up was received >6 months, were excluded. Likewise records with missing data ($n = 3$), RVADs ($n = 10$) and total artificial heart ($n = 2$) were excluded (Fig. 1). After exclusion of these patients, we investigated 472 implants in 446 patients.

For this analysis, 369 primary left VAD (LVAD) and 77 primary biventricular assist device (BiVAD) implantations were analysed. A flowchart of included patients is shown in Fig. 1.

Data completeness and quality

Baseline and follow-up data were reviewed to check for completeness and chronology. Improbable records were corrected or eliminated after reconfirmation with the on-site data managers of participating centres. This resulted in completeness of follow-up in the EUROMACS registry of 96% is high. The end date for follow-up was 1 June 2021. The EUROMACS database includes 570 baseline variables, of which, respectively, 26 are included in this report.

Various measures were taken to safeguard the completeness and correctness of the data that have been submitted by the participating centres to improve data quality. These methods include data input control, onsite audits and statistical analyses.

Statistical analyses

Continuous variables are presented as mean ± standard deviation or median and range depending on the distribution of data. For statistical analyses, the Student's *t*-test or Wilcoxon rank-sum test was applied. Categorical variables are presented as number (*n*) and percentages of population. Analyses were performed using the chi-squared test or the Fisher's exact test as appropriate. A competing outcomes analysis was performed for a heart transplant, recovery/weaning, patients still on the device or death. Kaplan–Meier curves were generated for the complete group of patients supported by either a LVAD or a BiVAD. All adverse events for the first 3 months and after 3 months were collected and calculated to determine events per patient-year. Adverse events, which included device malfunction, infection, neurological dysfunction and major bleeding, were captured according to INTERMACS Adverse Events definitions. Statistical analyses were performed using Stata 15.0 (StataCorp, College Station, TX, USA).

Table 1: Patient characteristics

	Overall ($n = 461$)	Era I (≤2014) ($n = 181$)	Era II (≥2015) ($n = 280$)	*P*-value
Age (years)				0.523
Median (range)	8 (0–19)	9 (0–19)	8 (0–19)	
Mean ± SD	8.13 ± 6.53	8.37 ± 6.85	7.97 ± 6.32	
Age categories (years), *n* (%)				0.068
<1 y	90 (19.52)	42 (23.20)	48 (17.14)	
1–5 y	110 (23.86)	37 (20.44)	73 (26.07)	
6–10 y	68 (14.75)	20 (11.05)	48 (17.14)	
11–19 y	193 (41.87)	82 (45.30)	111 (39.64)	
Sex, *n* (%)				0.663
Male	254 (55.10)	102 (56.35)	152 (54.29)	
Female	207 (44.90)	79 (43.65)	128 (45.71)	
Weight, *n* (%)				0.102
<5 kg	40 (8.8)	22 (12.15)	18 (6.43)	
5–9 kg	84 (18.22)	37 (20.44)	47 (16.79)	
10–20 kg	95 (20.1)	32 (17.68)	63 (22.50)	
21–40 kg	87 (18.87)	29 (16.02)	58 (20.71)	
41–70 kg	108 (23.43)	45 (24.86)	63 (22.50)	
71–100 kg	38 (8.24)	15 (8.29)	23 (8.21)	
>101 kg	9 (1.95)	1 (0.55)	8 (2.86)	
Body surface area (m^2)				0.076
Median (range)	0.86 (0–12.57)	0.78 (0–2.93)	0.89 (0–12.57)	
Mean ± SD	0.99 ± 0.93	0.91 ± 0.64	1.05 ± 1.08	
Body mass index (kg/m^2)				0.193
Median (range)	15.28 (0–127.31)	15.05 (0–127.31)	15.47 (0–37.65)	
Mean ± SD	15.52 ± 8.36	14.81 ± 11.12	15.99 ± 5.81	
Total bilirubin levels (mg/dl)				0.33
Median (range)	0.48 (0–25)	0.41 (0–25)	0.52 (0–25)	
Mean ± SD	1.21 ± 2.72	1.06 ± 2.53	1.31 ± 2.84	
Creatinine (mg/dl)				0.21
Median (range)	0 (0–2.5)	0 (0 2.5)	0 (0–1.6)	
Mean ± SD	0.07 ± 0.25	0.09 ± 0.30	0.06 ± 0.21	
Primary diagnosis, *n* (%)				0.357
Dilated cardiomyopathy	247 (53.58)	90 (49.72)	157 (56.07))	
Congenital heart disease	69 (14.97)	33 (18.23)	36 (12.86)	
Myocarditis	65 (14.01)	26 (14.36)	39 (13.93)	
Restrictive cardiomyopathy	20 (4.34)	6 (3.31)	14 (5.00)	
Hypertrophic cardiomyopathy	5 (1.08)	2 (1.10)	3 (1.07)	
Valvular heart disease	4 (0.87)		4 (1.43)	
Cancer	1 (0.22)		1 (0.36)	
Unknown	50 (10.85)	24 (13.26)	26 (9.29)	
INTERMACS patient profile, *n* (%)				0.255
INTERMACS 1	122 (26.52)	51 (28.18)	71 (25.36)	
INTERMACS 2	228 (49.46)	87 (48.07)	141 (50.36)	
INTERMACS 3	67 (14.53)	33 (18.23)	34 (12.14)	
INTERMACS 4	21 (4.56)	7 (3.87)	14 (5.00)	
INTERMACS 5–7	12 (2.60)	2 (1.10)	10 (3.57)	
Unknown	11 (2.39)	1 (0.55)	10 (3.57)	
Number of inotropes, *n* (%)				0.227
0	53 (11.50)	19 (10.50)	34 (12.14)	
None–2	225 (48.81)	80 (44.20)	145 (51.79)	
3–4	72 (15.62)	33 (18.23)	39 (13.93)	
≥5	4 (0.87)	3 (1.66)	1 (0.36)	
Unknown	107 (23.21)	46 (25.41)	61 (21.79)	
Mechanical ventilation, *n* (%)	125 (27.11)	42 (23.20)	83 (29.64)	0.047
Circulatory support, *n* (%)				
IABP	6 (1.30)	4 (2.21)	2 (0.71)	0.228
ECLS	86 (18.66)	27 (14.92)	59 (21.07)	0.043
Device type, *n* (%)				0.002
LVAD	369 (80.04)	133 (73.48)	236 (84.29)	
RVAD	10 (2.17)	3 (1.66)	7 (2.50)	
BiVAD	77 (16.70)	44 (24.31)	33 (11.79)	
Total artificial heart	2 (0.43)		2 (0.71)	
Unknown	3 (0.65)	1 (0.55)	2 (0.71)	
Current device strategy, *n* (%)				0.535
Bridge to transplantation listed	291 (63.12)	113 (62.43)	178 (63.57)	
Possible bridge to transplant	117 (25.38)	44 (24.31)	73 (26.07)	
Destination therapy	1 (0.22)		1 (0.36)	
Bridge to recovery	25 (5.42)	12 (6.63)	13 (4.64)	
Other	23 (4.99)	12 (6.63)	11 (3.93)	
Unknown	4 (0.87)		4 (1.43)	

Continued

Table 1: Continued

	Overall (n = 461)	Era I (≤2014) (n = 181)	Era II (≥2015) (n = 280)	P-value
Device Brand, *n* (%)				0.000
HeartAssist 5	2 (0.43)	1 (0.55)	1 (0.36)	
HeartMate II	17 (3.69)	13 (7.18)	4 (1.43)	
HeartWare HVAD	125 (27.11)	40 (22.1)	85 (30.36)	
HeartMate 3	19 (4.12)		19 (6.79)	
HeartWare MVAD	1 (0.22)	1 (0.55)		
Berlin Heart INCOR	3 (0.65)		3 (1.07)	
Berlin Heart EXCOR	246 (53.36)	109 (60.22)	137 (48.93)	
Thoratec PVAD	5 (1.08)	5 (2.76)		
Other[a]	43 (9.33)	12 (6.63)	31 (11.07)	

[a]Other: Jarvik 2000 (2), Berlin Heart Incor (3), HeartWare MVAD (1) and excluded temporary devices (37).

BiVAD: biventricular assist device; ECLS: extra corporeal life support; IABP: intra-aortic balloon pump; LVAD: left ventricular assist device; RVAD: right ventricular assist device; SD: standard deviation.

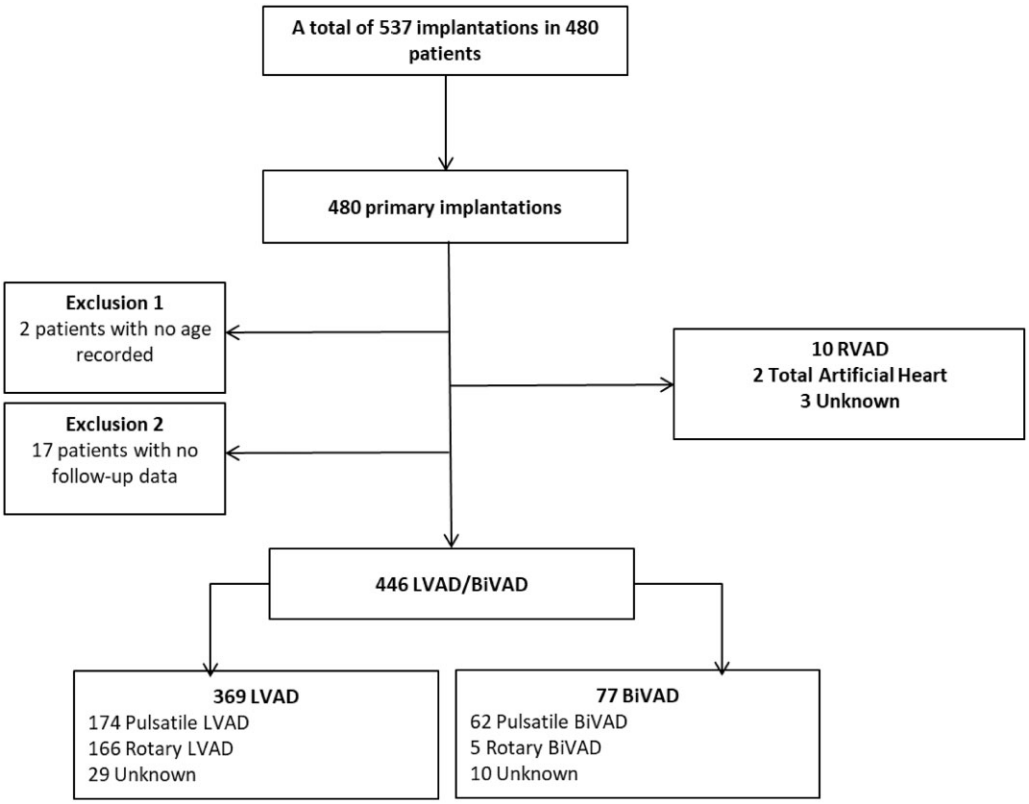

Figure 1: Selection flowchart.

RESULTS

Patient population

A total of 65.3% of the children were on inotropic support and 125 (27.1%) were on mechanical ventilation and 86 (18%) on extra corporeal life support prior to VAD implantation. Patients (91.9%) treated with extra corporeal life support were in Intermacs profiles 1 and 2 (Table 1). A breakdown of Intermacs profiles learns that 122 (26.5%) of implantations were done in an emergency indication (Intermacs 1), 228 (49.5%) were in Intermacs profile 2, 67 (14.5%) in Intermacs profile 3, 21 (4.5%) in Intermacs profile 4, 12 (2.6%) in Intermacs profile 5–7 and from 11 (2.4%) patients the Intermacs profile was unknown.

In Table 1, a breakdown of characteristics of included patients in 2 eras, before 2015 (n = 181) and 2015 and beyond (n = 280), as well as a total of enrolled patients (n = 461) is provided.

The age distribution in these children includes 90 (19.5%) patients younger than 1 year of age, 110 (23.9%) from 1 to 5 years of age, 68 (14.8%) from 6 to 10 years of age and 193 (41.9%) from 11 to 19 years of age.

Dilated cardiomyopathy was found in 247 (53.6%) patients, 65 (14%) patients were diagnosed with myocarditis, and 20 (4.3%) had restrictive cardiomyopathy and 5 (1.1%) patients suffered from hypertrophic cardiomyopathy.

Congenital heart disease (CHD) was diagnosed in 69 (15%) patients, while 4 (0.9%) patients had a valvular disease and 1 (0.2%) suffered from cancer. For 50 patients (10.9%), the primary diagnosis was unknown. CHDs are specified; 28.3% of the diagnoses concerned a univentricular heart (Supplementary Material, Table S3).

Hospitals that implanted more than 30 devices during the entire observation period represent 54% ($n = 5$) of the volume, hospitals implanted 15–30 devices 36% ($n = 9$) and 10% were implanted in hospitals implanting <15 devices ($n = 11$; Supplementary Material, Table S4). A breakdown of volumes of all sites learns that the volume varies from 1 to 95 implantations (Supplementary Material, Table S5).

Device type and strategy

Paracorporeal pulsatile devices were the most frequently used VAD and were implanted in 236 patients (52.9%), intracorporeal rotary devices were implanted in 171 (38.3%) patients, while from 39 devices (8.7%), the characteristics were unknown (Fig. 1). Of all patients, 53.4% were supported by the Berlin Heart EXCOR® (Berlin Heart, Berlin, Germany), 3.7% by the HeartMate II® (Abbott, Chicago, IL, USA), 4.1% by the HeartMate 3® (Abbott, Chicago, IL, USA), 0.4% by HeartAssist 5® (Micromed, Houston, TX, USA) and 27.1% by HeartWare HVAD® (Medtronic, Minneapolis, MN, USA; Supplementary Material, Table S2). A pulsatile device was primarily implanted as an LVAD in 174 patients, and 64 as a BiVAD, while this was the case in, respectively, 166 and 5 rotary devices (Supplementary Material, Table S7). Most patients (88.5%) were treated with the intention to transplant (i.e. bridge to transplant or possible bridge to transplant—the latter is a bridge to decision); and this was the case across all age groups (Tables 1 and 2). In 25 (5.4%) patients, an assist device was implanted as bridge to recovery, while 23 patients were implanted for another strategy.

LVADs were implanted in 369 (80.04%) patients, RVADs in 10 (2.17%) and BiVADs in 77 (16.7%). In relation to the total number implantations, comparison between Era I and Era II shows an almost 50% less implantation of BiVADs in the second Era from 24.31% to 11.79% (Table 1).

Table 2: Device strategy at the time of first implant, stratified by age categories

Device strategy	<1 y	1–5 years	6–10 years	11–19 years	Total
Bridge to recovery	8	7	2	8	25
Bridge to transplant	50	74	44	123	291
Possible bridge to transplant	25	23	19	50	117
Rescue therapy	0	0	0	1	1
Unknown/other	7	6	3	11	27
Total	90	110	68	193	461

Twenty-seven out of 480 patients needed temporary RVAD support (6%). Out of the 27 patients, 7 (26%) needed a permanent RVAD. Four patients (15%) died while on temporary RVAD support. In 16 patients, the temporary RVAD was weaned and explanted.

Twenty-five patients received a second device after the first one, 10 patients a third one and 1 patient a fourth implant (Supplementary Material, Table S6).

Outcomes

The median support time on the device was 5.6 months (range 0–124.6 months). The median length of stay in the intensive care unit was 24 days (range 0–422 days). A total of 273 (74%) children survived to transplant or recovery or remain on MCS at the 2-year follow-up (Fig. 2). At 12 months, 45.1% of the patients and by the end of second year, 54.5% of the children received a transplant. This percentage increased to over 55% at 3 years post-VAD implantation. In Table 3, an aetiology adjusted patient outcome is provided, showing that recovery and explant because of recovery is highest in patients with myocarditis 29.2% (Table 3). In Fig. 3A–D, respectively, survival analyses, censored at transplant, by device type, per age group, by device strategy and by INTERMACS profile, is given. In the overall follow-up period, 120 patients died, 24.2% of which died of cerebrovascular accidents. Eleven patients (9.17%) died of multiorgan failure. The primary cause of death was not specified for 65 patients (Supplementary Material, Table S8).

Overall survival

Two hundred and forty-nine patients were transplanted with an average time to transplant of 253.4 days, standard deviation of 307.3.

At 12 months 45% and at 24 months 54% of patients were transplanted (Fig. 2). Overall, primary cause of death was cerebrovascular accidents with almost 25% (Supplementary Material, Table S8). Out of the total 103 deaths recorded, 59 deaths occurred during hospital admission and the remaining after discharge (Supplementary Material, Table S9).

Adverse events

Overall, 630 major adverse events were reported during VAD support. Within the first 3 months after VAD implantation, 299 events occurred whereas 331 events occurred after 3 months (Table 4). The most frequently reported major adverse event was device malfunction which included as per definition pump exchanges from paracorporeal devices due to pump thrombosis, including exchanges for upsize. No exchanges from intracorporeal to paracorporeal devices were reported. Device malfunction, including exchanges in paracorporeal exchanges for device thrombosis, occurred 126 times in the first 3 months, which resulted in 1.59 events per patient-year. After 3 months, 0.67 device malfunctions per patient-year were reported. The event rates for neurological dysfunction and infection were 0.71 ($n = 56$) and 0.78 ($n = 62$) per patient-year, respectively, for the first 3 months. After 3 months, 0.11 events of neurological dysfunction ($n = 29$) and 0.42 infections per patient-year ($n = 111$) were reported. Finally, 55 events of major bleeding were reported in the first

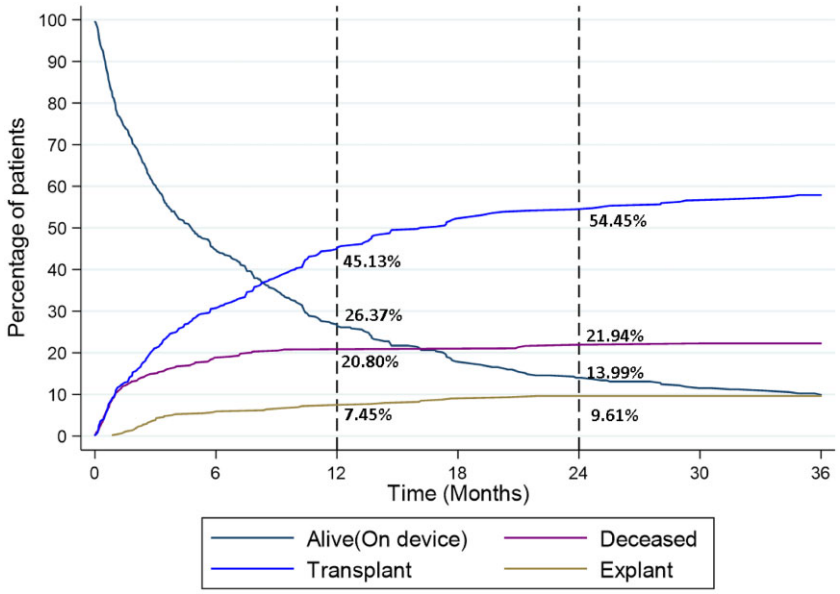

Figure 2: Competing outcomes.

Table 3: Aetiology adjusted patient outcomes

Primary diagnosis	On device	Endpoint			Total
		Dead	Transplant	Wean	
Dilated cardiomyopathy	36 (14.6)	48 (19.4)	146 (59.1)	17 (6.9)	247
Restrictive cardiomyopathy	4 (20.0)	6 (30.0)	10 (50.0)	0 (0)	20
Hypertrophic cardiomyopathy	0 (0)	1 (20.0)	3 (60.0)	1 (20.0)	5
Myocarditis	4 (6.2)	12 (18.5)	30 (46.2)	19 (29.2)	65
Congenital heart disease	3 (4.3)	22 (31.9)	34 (49.3)	10 (14.5)	69
Cancer	0 (0)	0 (0)	1 (100.0)	0 (0)	1
Valvular heart disease	0 (0)	0 (0)	4 (100.0)	0 (0)	4
Unknown	7 (14.0)	14 (28.0)	26 (52.0)	3 (6.0)	50

3 months (0.70 events per patient-year) and 13 events after 3 months (0.05 events per patient-year). While patients with paracorporeal are seldom discharged to home, an analysis of adverse events in patients with continuous-flow devices learns that infection is the most frequently occurring event out of hospital (Supplementary Material, Table S9).

DISCUSSION

This report represents the third edition of the Paediatric EUROMACS reports, which are data analysis on a biannual basis from 14 different countries. When looking at the annual performed numbers per centre, the number of high-volume centres is much lower in European countries compared to North America (Supplementary Material, Table S4) [1]. This underlines the importance to share data among the paediatric MCS community.

Over the last years, the number of reported implantations increased from 270 for the first report [2] to 398 for the second and reached now the number of over 450 implantations which translates into an increase of 15% compared to the last report [3].

Selection and application of devices

This report comes also at a moment in the development of MCS at which the choice of devices has been reduced by the withdrawal of one of the mainstream devices for durable support, the HeartWare HVAD [4]. It was shown that children on intracorporeal VADs, also feasible in small children [5], will benefit from outpatient management [6–9] and it was shown that implantable BiVAD was feasible with intracorporeal CF devices [10, 11]. While paracorporeal devices represent still the largest group of durable VADs, the HeartWare HVAD was used in almost 30% of the whole population. When looking at the age distribution of this report over 40% of registered patients are below 6 years of age. It is known that the BH Excor is rarely used in children above 20 kg except in those patients needing biventricular support or who may recover [12]. There seems also to be consensus among paediatric VAD centres that intracorporeal CF devices may be generally considered in children >15–20 kg [12, 13]. With the withdrawal of the HeartWare HVAD, it has to be investigated if the same age and weight limits may be applied for alternative intracorporeal CF. Data from the ACTION networks show that the Heartmate 3 device has been implanted in children as young

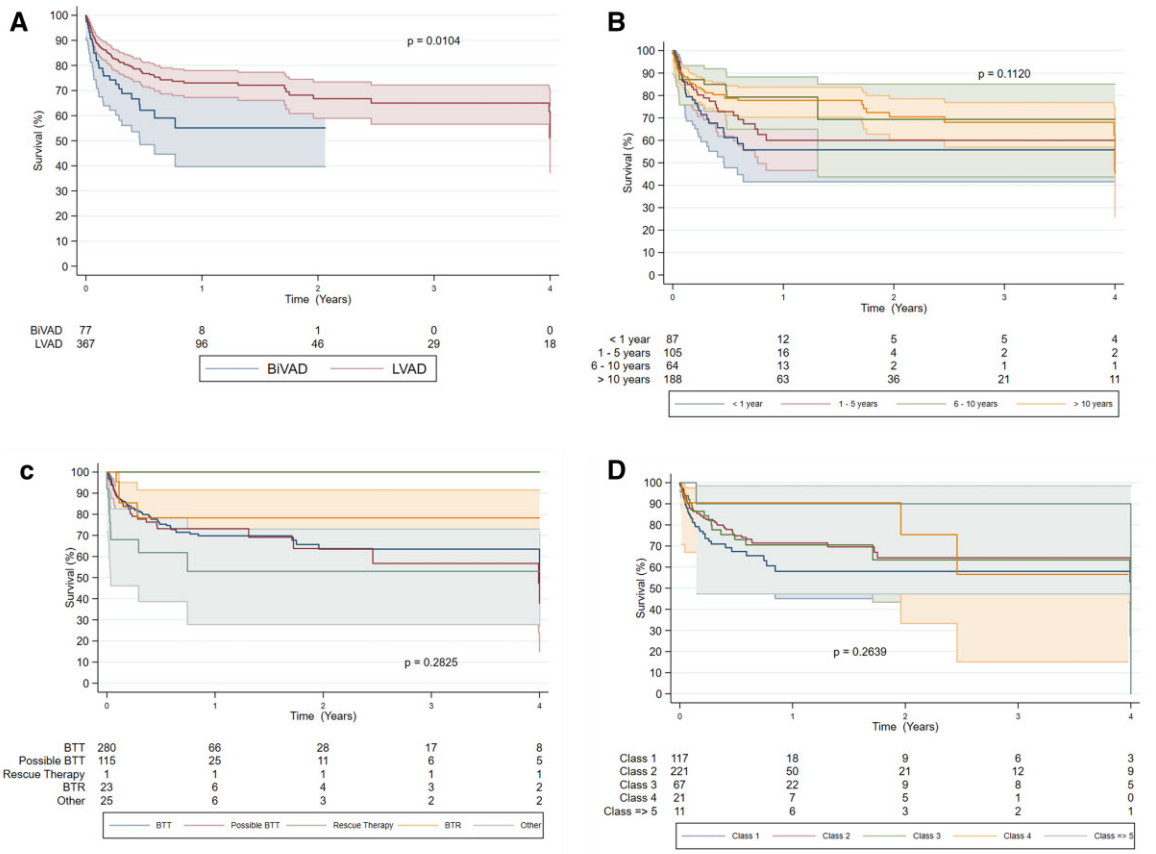

Figure 3: (**A**) Survival analysis by device type. (**B**) Survival analysis by age. (**C**) Survival analysis by device strategy. (**D**) Survival analysis by INTERMACS profile.

Table 4: Major adverse events

Major adverse events	Within 3 months after implant		More than 3 months after implant	
	Event counts	Events per patient–year	Event counts	Events per patient–year
Device Malfunction	126	1.59	178	0.67
Major bleeding	55	0.70	13	0.05
Major infection	62	0.78	111	0.42
Neurological event	56	0.71	29	0.11

as 8 years, with a lowest BSA of 0.78 and the lowest weight of 19 kg [14]. Data from this Paedi-EUROMACS report revealed that the youngest patient provided with a HeartMate 3 device was 14 years old with a weight of 39 kg and a body surface area of 1.26 m^2 [15]. Clearly, further studies are needed to evaluate the feasibility to implant HeartMate 3 device in small children. An analysis of the EUROMACS database is currently elaborated.

Aetiology, age and size

There were no changes in terms of aetiology and its apportionments leading to VAD implantation with the leading diagnosis of cardiomyopathy. The percentage of biventricular support stayed steady around 16.7% compared to the second EUROMACS report (17%) [3] and seems to be comparable to the North American cohort [1]. However, the decrease of the use of BiVAD support between Era I and Era II may indicate that there has been a learning curve with respect to indication and timing with respect to whether or not to implant a BiVAD. The earlier the implant, the less likely the need for a BiVAD. Additionally, experience learned to find the lowest limit for placement of intracorporeal devices.

When looking at the age distribution, there seems to be some differences at younger age. While almost 25% of children were below 1 year of age in North America, this percentage was below 20% for the European cohort. Even more interesting seems the fact that there is an era effect. While this percentage was well above 20 (23%) before 2014 it dropped to 17% since then.

Dilated cardiomyopathy stays the predominant diagnosis with above 50% of all patients. Other forms of cardiomyopathy still are seldom. The percentage of CHD in the EUROMACS database remains around 15%. Not surprisingly single ventricle pathologies,

including left heart syndrome, account for almost one-third. Unfortunately, the register does not (yet) record at which state of the single ventricle pathway a VAD implantation was needed. There is evidence that outcome in CHD patients relies on the complexity of the CHD [16]. Other CHD diagnosis included Ebstein disease, transposition of the great arteries but also rather 'simple' defects like VSDs.

Congenital heart defects

The frequency of CHD differs in the EUROMACS and Pedimacs registries. While CHD was the underlying diagnosis in only 15% of patients in Europe, this is the case in 25% of the North American cohort [1]. So far the authors do not have a good explanation for this difference. If it is underreporting or true patient selection remains unclear.

Ventricle recovery/weaning

Despite progress in medical therapy, the explantation rate of durable VAD due to myocardial recovery is stable over the last years. It remains below 10% since the first report was published. This is also reflected by the fact that still almost 90% of patients were treated with the intention to transplant. This was true across all age groups.

Adverse events

Cerebrovascular accidents are the main reason for death while on support. Events per patient-year are highest in the first 3 months after implantation but remain a constant threat throughout the support time with 0.11 events per patient-year. In terms of adverse events, major infections are the most common after 3 months pots implantation. It can be speculated if there is a relation between major infections and cerebrovascular accidents, but this was not investigated in this report.

Limitations

Contrary to registries in other parts of the world, participation in EUROMACS is not mandatory. Therefore, surveillance and improvement of data quality are ongoing efforts. We were faced, as other multicentre international registries, with missing data and incomplete follow-up. This may introduce bias. Various measures were taken to safeguard the completeness and correctness of the data submitted by the participating centres to improve data quality. These methods include data input control, statistical analyses and on-site audits. Another limitation is the observational origin of the data, so unaddressed confounding may influence outcomes.

CONCLUSION

The data and the analyses in this third Paedi-EUROMCS report have been generated at the brink of a new era in which the HVAD is no longer available and which creates new challenges for children >15 kg. Given that challenge, it is questionable if the need for BiVADs will remain at the lower level it reached in the second era as presented in this report.

For the first time, we were able to get a better insight into the composition of the CHD cohort, for the registry, the next step should be to determine decision point for implantation along the pathway of the CHD patient.

Another challenge is to gather more statistics on factors leading to cerebrovascular accidents, which may lead to a better understanding of optimal composition of anticoagulant administration protocols.

The analyses in this third report learned that, while survival on device has improved since the publication of the second Paedi-EUROMACS report, a lagging amount of heart transplants can be observed. It is likely that the inference of this unfortunate determination has led to a much longer life on device and an increased mortality for children dependent on MCS.

Since its inception, the EUROMACS registry has become a point of reference for durable paediatric MCS data and outcomes source. Given the low global number of annual performed durable MCS implantation in children, it is crucial to have registries like EUROMACS as a source for scientific analyses and to keep track of developments in the field.

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SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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Author contributions

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