Temporal trends in the use and outcomes of temporary mechanical circulatory support as a bridge to cardiac transplantation in Spain. Final report of the ASIS-TC study

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ABSTRACT

BACKGROUND: We aimed to describe recent trends in the use and outcomes of temporary mechanical circulatory support (MCS) as a bridge to heart transplantation (HTx) in Spain.

METHODS: Retrospective case-by-case analysis of 1,036 patients listed for emergency HTx while on temporary MCS in 16 Spanish institutions from January 1st, 2010 to December 31st, 2020. Patients were classified in 3 eras according to changes in donor allocation criteria (Era 1: January 2010/May 2014; Era 2: June 2014/May 2017; Era 3: June 2017/December 2020).

RESULTS: Over time, the proportion of candidates listed with intra-aortic balloon pumps decreased (Era 1 = 55.9%, Era 2 = 32%, Era 3 = 0.9%; $p < 0.001$), while the proportion of candidates listed with surgi- cal continuous-flow temporary VADs (Era 1 = 10.6%, Era 2 = 32%, Era 3 = 49.1%; $p < 0.001$) and per- cutaneous VADs (Era 1 = 0.3%, Era 2 = 6.3%; Era 3 = 17.2%; $p < 0.001$) increased. Rates of HTx increased from Era 1 (79.4%) to Era 2 (87.8%), and Era 3 (87%) ($p = 0.004$), while rates of death before HTx decreased (Era 1 = 17.7%; Era 2 = 11%, Era 3 = 12.4%; $p = 0.037$) Median time from list- ing to HTx increased in patients supported with intra-aortic balloon pumps (Era 1 = 8 days, Era 2 = 15 days; $p < 0.001$) but remained stable in other candidates (Era 1 = 6 days; Era 2 = 5 days; Era 3 = 6 days; $p = 0.134$). One-year post-transplant survival was 71.4% in Era 1, 79.3% in Era 2, and 76.5% in Era 3 ($p = 0.112$). Preoperative bridging with ECMO was associated with increased 1-year post-trans- plant mortality (adjusted HR=1.71; 95% CI 1.15-2.53; $p = 0.008$).

CONCLUSIONS: During the period 2010 to 2020, successive changes in the Spanish organ allocation protocol were followed by a significant increase of the rate of HTx and a significant reduction of wait- ing list mortality in candidates supported with temporary MCS. One-year post-transplant survival rates remained acceptable.

KEYWORDS: mechanical circulatory support; heart transplantation; ventricular assist devices; ECMO

Abbreviations: BIVAD, biventricular assist device; CI, Confidence interval; ECMO, extracorporeal membrane oxygenation; HR, hazard ratio; HTx, heart transplantation; IABP, intra-aortic balloon pump; INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; LVAD, left ventricu- lar assist device; MCS, mechanical circulatory support; RVAD, right ventricular assist device; UNOS, United Network for Organ Sharing; VAD, ventricular assist device

Heart transplantation (HTx) is recommended for patients with advanced heart failure refractory to medical and device therapy who do not present absolute contraindications[1] after a careful evaluation of candidacy.[2]

Timely availability of organ donors is the Achilles heel of HTx. Standard waiting times often result too long for HTx candidates with more severe disease, as is the case of those with lower Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) profiles,[3] which in most cases will require bridging with mechanical circulatory support (MCS).

Some organ donor sharing systems enable an expedite route to *emergency* HTx for candidates in critically ill condition, by giving them priority over candidates who are in stable condition.[4-7] Prioritization is particularly important for those treated with temporary devices like intra-aortic balloon pump (IABP), venoarterial extracorporeal membrane oxygen- ation (ECMO) or temporary ventricular assist devices (VADs), given the short period of support for which they are conceived.

Clinical criteria that define levels of waiting list pri- ority are dynamic and vary over time. Modifications of the donor allocation protocol may result in significant changes in transplant rates and waiting list times, so a continuous monitoring of the performance of the system is important to ensure equity of access and good clinical outcomes.

Our aim was to describe temporal trends in the use and outcomes of temporary MCS as a bridge to emergency HTx in Spain during the period 2010 to 2020, and to correlate them with successive changes made in the allocation protocol over time.

Methods

Study description

The ASIS-TC study (*Empleo de los dispositivos de ASIStencia circulatoria mecánica de corta duración como puente a Trasplante Cardiaco urgente en España*; in English, *Use of short-term MCS devices as a bridge to* HTx *in Spain*) was a retrospective registry conducted in the 16 Spanish institutions which had an active HTx program for adult patients during the period 2010 to 2020. A detailed list of the participating institutions and study collaborators is included as *Supplementary Material*. As of August 4th, 2022,

the number of active HTx programs for adult patients in Spain is currently 18, as 2 additional centers which did not participate in the ASIS-TC registry have begun this surgical activity in the most recent years.

The ASIS-TC registry aimed to include consecutive adult patients who were listed for emergency HTx while being supported with an IABP, venoarterial ECMO or temporary (nondi- schargeable) VADs, either percutaneous (Impella or similar) or surgical (pulsatile flow: Abiomed BVS5000 or similar; continuous flow: Centrimag or similar), in any of the participant institutions since January 1st, 2010, to December 31st, 2020. Patients listed for second HTx or for multiorgan transplantation were excluded.

The Committee of Ethics for Clinical Research of Galicia (Spain) approved the study protocol. Some early results of the ASIS-TC study that corresponded to patients enrolled until December 31st, 2015 were published elsewhere.[4,8-11]

Listing criteria for emergency HTx

Table 1 shows a summary of the evolution of listing criteria used for prioritizing HTx candidates in Spain during the study period. Listing criteria have been historically based in the level of MCS required by the patient, with a few additional *exception* indications, but until now no specific hemodynamic criteria have been adopted to define the emergency status.

The donor allocation protocol changed twice during the period 2010 to 2020 (in June 2014 and June 2017). Thus, study patients were classified in 3 subgroups according to the temporal era in which they were listed (Era 1 = January 1st, 2010 to May 31st, 2014; Era 2 = June 1st, 2014 to May 31st, 2017; and Era 3 = June 1st, 2017 to December 31st, 2020). The major changes introduced in the allocation protocol during this time were the following:

1. The downgrade of the status 1 level applied to candi- dates listed with an IABP from national priority (during Era 1) to regional priority (during Era 2), and later, the elimination of IABP support from the accepted indica- tions for emergency HTx (during Era 3).[12]
2. The restriction of the duration of the *status 0 level*, which confers national priority, to a maximum period of 7 days −extensible to 10 days if extubated and free of end-

organ dysfunction− for candidates supported with ECMO or percutaneous VADs (during Era 3).[12]

Follow-up and study outcomes

All-cause mortality was the major endpoint of this study. Patients were followed up to 1 year after HTx or, in case that transplantation was not performed, up to 1 year after hospital discharge. One- year follow-up information about their vital status (dead or alive) was known for all patients enrolled in the registry.

We estimated the cumulative rates of relevant outcomes that occurred during the index hospitalization following emergency HTx listing, like HTx, death without HTx, discharge without HTx and transition to a different mode of temporary MCS. Time from the initiation of temporary MCS to emergency HTx listing and time from emergency HTx listing to HTx were also assessed.

Specific definitions of post-transplant outcomes assessed in this study are detailed as *Supplemental Material*.

Statistical analysis

In this manuscript, categorical variables are expressed as propor- tions, while quantitative variables are expressed as means stan- dard deviation or as medians (interquartile range), as appropriate. Temporal trends across eras were assessed by means of the chi-square test for linear trends in the case of categorical variables, and by means of ANOVA for linear trends or the Kruskal-Wallis test in the case of quantitative ones.

One-year post-transplant survival curves were depicted with the Kaplan-Meier method and compared with the log rank test. Multivariable Cox regression was used to control the effect of potential confounders on the statistical association observed between temporal eras and 1-year post-transplant survival, as well as between the mode of temporary MCS used for bridging and 1- year post-transplant survival. We constructed 2 different multivar- iable models to estimate the adjusted hazard ratios (HR) for post-transplant mortality in Era 2 and Era 3 as compared to Era 1, as well as in the subgroups of patients bridged with percutaneous VADs, surgical continuous-flow LVADs, surgical continuous- flow BIVAD/RVADs, venoarterial ECMO and surgical pulsatile- flow

VADs as compared to the subgroup of patients bridged with an IABP, which was considered the reference category.

The first model was an *extended* one, as it included all co-variables which were considered as potential confounders based on clinical judgment and previous knowledge (age of the recipient, gender of the recipient, cardiogenic shock related to myocardial infarction, cardiogenic shock following cardiac surgery, history of cardiac arrest, diabetes mellitus, previous sternotomies, INTER- MACS profile, preoperative need for renal replacement therapy, preoperative mechanical ventilation, preoperative need for vaso- pressors, preoperative active infection, age of the donor, gender of the donor, cold ischemic time, preoperative mode of temporary MCS, temporal eras), while the second model was a *parsimonious* one, as it included only those co-variables of the extended model that remained as independently associated with post-transplant survival after a backward stepwise process with a *p*-out criterion < 0.10 (age of the recipient, gender of the recipient, preoperative infection, preoperative need for vasopressors, preoperative need for renal replacement therapy, cold ischemic time, preoperative mode of temporary MCS, temporal eras). The proportional haz- ards assumption was checked for compliance by means of the analysis of scaled Schoenfeld residuals.

Statistical significance was set as a *p*-value < 0.05 for all con- trasts. Statistical analyses were performed with SPSS 25.

Results

Patients and devices

The study cohort included 1,036 patients who were listed for emergency HTx while being supported with temporary MCS devices in 16 Spanish centers during the period 2010 to 2020. The number of patients included in each one of the participating institutions is detailed in Supplementary Figure 1.

At the time of emergency listing, 317 (30.6%) patients were supported with an IABP; 79 (7.6%) patients were sup- ported with percutaneous VADs; 313 (30.1%) patients were supported with venoarterial ECMO; 308 (29.7%) patients were supported with

nondischargeable surgical continuous- flow VADs and 19 (1.8%) patients were supported with nondischargeable surgical pulsatile-flow VADs.

Seventy-nine (7.6%) patients required a change of the mode of temporary MCS after emergency HTx listing. Cumulative rates of transition to a different mode of temporary MCS after listing were 13.6%, 11.4%, 7.7%, 1%, and 0% in patients listed with IABPs, percutaneous VADs, ECMO, surgical continuous-flow VADs and surgical pulsa-tile-flow VADs, respectively ($p < 0.001$). Table 2 shows a detailed description of the specific type of devices which were implanted in the study population. A flow chart of patients and devices is shown in Supplementary Figure 2.

Figure 1 shows the distribution of different modes of temporary MCS used in study patients according to the year of listing. The proportion of patients listed with IABP support decreased over time (Era 1 = 55.9%, Era 2 = 32%, Era 3 = 0.9%; p for trend < 0.001); meanwhile, there was a steady increase of the proportion of patients listed with percutaneous VADs (Era 1 = 0.3%, Era 2 = 6.3%; Era 3 = 17.2%; p for trend < 0.001) and surgical continuous flow VADs (Era 1 = 10.6%, Era 2 = 32%, Era 3 = 49.1%; p for trend < 0.001). The proportion of patients listed with venoarterial ECMO remained stable over time (Era 1 = 28.2%, Era 2 = 29.8%, Era 3 = 32.8%; p for trend = 0.182).

Clinical profile of transplant candidates

Table 3 shows the baseline clinical characteristics of study patients according to the era of emergency HTx listing. There was a statistically significant, increasing trend of the mean age of candidates over time, as well as in the prevalence of cardiogenic shock related to acute myocardial infarction, previous cardiac arrest, and previous defibrillator implantation. Meanwhile, the prevalence of active infection requiring intravenous antibiotics at the time of emergency HTx listing decreased significantly. Also, we observed a significant change of the INTERMACS profile of emer- gency HTx candidates over time. Profiles 3 and 4 become more frequent, while the prevalence of profiles 1 and 2 decreased.

In-hospital outcomes following emergency listing

Overall, 875 (84.5%) patients were transplanted during the index hospitalization that followed emergency HTx listing, while 144 (13.9%) died without having received a donor heart. Seventeen (1.7%) patients were discharged alive from hospital without having been transplanted, 5 (0.5%) of them on long-term VAD support. Among these 17 patients, 2 died and 6 underwent HTx during the subsequent 12 months after hospital discharge.

In-hospital rates of HTx were similar for patients who were listed as *status 1* (83.6%) than for those listed as *status 0* (84.8%) (p = 0.611). However, the cumulative rate of HTx without transitioning to a second mode of MCS was significantly lower among patients listed as *status 1* (74.7%) than among those listed as *status 0* (81.8%) (p = 0.012).

Figure 2 shows a graphical representation of the tempo- ral trend of the cumulative rates of HTx, death and dis- charge without HTx during the index hospitalization that followed emergency HTx listing. The rate of HTx increased from Era 1 (79.4%) to Era 2 (87.8%) and Era 3 (87%) (p for trend = 0.004); accordingly, the rate of death without HTx decreased (Era 1 = 17.7%; Era 2 = 11%, Era 3 = 12.4%) (p for trend = 0.037). Excluding the COVID-19 pandemic period following March 1st, rates of HTx and death without HTx during Era 3 reached 88.7% and 10.5%, respectively.

The proportion of patients who were discharged alive from hospital without having been transplanted decreased over the study period (Era 1 = 2.9%; Era 2 = 1.2%; Era 3 = 0.6%; p for trend = 0.014).

Waiting times

Figure 3 shows a graphical representation of the temporal trend of waiting times in the study population, stratified by priority status.

In the *status 1* group, median time elapsed from IABP implantation to emergency HTx listing was < in Era 1 and Era 2. However, median time elapsed from listing to HTx increased significantly (Era 1 = 8 days; Era 2 = 15 days; p for trend < 0.001).

In the *status 0* group, there was a statistically signifi- cant prolongation of the time elapsed from device insertion to emergency HTx listing during Era 3 (4 days), as compared with Era 1 (2 days) and Era 2 (2 days) (p for trend = 0.015). However, time elapsed from listing

to HTx remained stable over the study period (Era 1 = 6 days; Era 2 = 5 days; Era 3 = 6 days; *p* for trend = 0.134).

Preoperative clinical status before transplantation

Table 4 shows the preoperative clinical status and supportive therapies of 875 patients who underwent emergency HTx. There was a significant decrease of preoperative hemoglobin, creatinine, and albumin levels over the study period, as well as a significant increase of the leucocyte count.

The proportion of patients with preoperative inotropic support decreased over the study period; however, no other significant variations of preoperative supportive therapies were observed.

The use of donors older than 50 years increased over time, while the use of female donors decreased. Mean cold ischemic times remained >3 hours during the whole study period.

Post-transplant survival

Two hundred and thirteen (24.3%) patients died during the first year after HTx. One-year post-transplant survival was 71.4% during Era 1, 79.4% during Era 2, and 76.5% during Era 3 (log rank *p* for trend = 0.112; Figure 4). Excluding the COVID-19 pandemic period following March 1st, 2020, 1-year post-transplant survival during Era 3 was 77.5%.

By means of a parsimonious multivariable model (Table 5), we estimated an adjusted HR for post-transplant mortality during Era 2 vs. Era 1 of 0.66 (95% CI 0.47-0.94; $p = 0.021$), while adjusted HR for post-transplant mortality during Era 3 vs Era 1 was 0.74 (95% CI 0.51-1.08; $p = 0.115$). Excluding the COVID-19 pandemic period following March 1st, 2020, adjusted HR for post-transplant mortality during Era 3 vs Era 1 was 0.70 (95% CI 0.47- 1.04; $p = 0.080$). No relevant change in these statistical associations was observed when an extended multivariable model of confounders was used for adjustment (Table 3).

Overall survival after listing

Overall survival from emergency HTx listing to 1 year increased from 59.6% during Era 1 to 70.2% during era 2, and 67.2% during Era 3 (p for trend = 0.029). Excluding the COVID-19 pandemic period following March 1st, 2020, 1- year survival after emergency HTx listing during Era 3 was 69.2%.

Figure 5 shows the annualized trends of 1-year survival following emergency HTx listing in the whole cohort and among patients who were transplanted during the index hospitalization.

Other postoperative outcomes after transplantation

In-hospital postoperative outcomes following emergency HTx are detailed in Table 6. Cumulative rates of cardiac reoperation decreased from 21.6% during Era 1 to 14.6% during Era 2, and to 14.3% during Era 3 (p for trend = 0.007).

No statistically significant temporal trend was observed regarding the cumulative incidence of other postoperative outcomes (Supplementary Figure 3).

Median duration of postoperative stay at the Intensive Care Unit and total postoperative hospital stay increased over the study period (Table 4).

Post-transplant survival with different modes of support

Figure 6 shows the Kaplan-Meier post-transplant survival curves of study patients, categorized in 5 subgroups according to the last mode of temporary MCS with which they were managed before HTx.

One-year post-transplant survival was 79.4% in patients bridged to HTx with an IABP, 84.9% in patients bridged with percutaneous VADs, 79.9% in patients bridged with surgical continuous-flow LVADs, 74.4% in patients bridged with surgical continuous-flow BIVADs/RVADs, 67.8% in patients bridged with ECMO and 60% in patients bridged with surgical pulsatile-flow VADs (log rank p = 0.001).

After multivariable adjustment, preoperative bridging with ECMO was an independent predictor of lower post- transplant survival (Table 3). Adjusted HR for 1-year post-transplant mortality for patients supported with ECMO vs. patients supported with an

IABP −reference category− was 1.74 (95% CI 1.13-2.69; *p* = 0.013), as estimated by an *extended* multivariable model, and 1.71 (95% CI 1.15-2.53; *p* = 0.008), as estimated by a *parsimonious* multivariable model. One-year post-transplant mortality rates of patients bridged on ECMO until and before the last policy change adopted in June-2017 were 35% and 26.8%, respectively (*p* = 0.198).

As compared to patients bridged with an IABP, adjusted risk of 1-year post-transplant mortality was numerically higher in patients bridged with surgical continuous flow BIVADs/RVADs and in patients bridged with surgical pul- satile flow VADs, and numerically lower in patients bridged with percutaneous VADs. However, none of these associa- tions reached statistical significance (Table 3).

Globally, 1-year post-transplant survival was 79.9% in patients who were bridged with isolated left ventricular support of any type −that is, those supported with IABP or surgical or percutaneous LVADs−, while it was 70.2% in the rest of the cohort −that is, patients supported with ECMO, BIVADs, or RVADs−. Preoperative isolated left ventricular support was associated with statistically signif- icant lower 1-year post-transplant mortality, both in the *extended* multivariable model (Adjusted HR = 0.70, 95% CI 0.52-0.95; *p* = 0.023) and in the *parsimonious* multivar- iable model (Adjusted HR = 0.68, 95% CI 0.52-0.90; *p* = 0.008).

Discussion

In this manuscript, we describe the clinical characteristics and outcomes of a cohort of >1,000 patients who were listed for emergency HTx while being treated with different modes of temporary MCS in 16 Spanish institutions during the period 2010 to 2020. The global cumulative rate of HTx in this population was 85% and showed an increasing ten- dency over the study period, following successive changes in donor allocation policies. One-year post-transplant sur- vival of the whole cohort was 76% and resulted inferior in candidates bridged on venoarterial ECMO or temporary pulsatile-flow devices.

Emergency procedures represent more than one-third of all HTx performed in Spain every year.[13] This proportion experienced 2 historical peaks of 50% in the years 2013 and 2016,[13] which led regulatory authorities to introduce changes in the prioritization policy to contain the excess of emergency indications of HTx.

The first relevant change of the donor allocation protocol was set in June-2014 and consisted in downgrading the waiting list *status 1*, which was applied to patients with IABP support, from national to regional priority. Median waiting times for these candidates increased until overcom- ing 3 weeks; often, this resulted in the need for escalating support, and IABP therapy was finally removed from the accepted indications for emergency HTx since June-2017. In contrast, IABP has become the most popular mode of mechanical bridging to HTx in the American United Net- work for Organ Sharing (UNOS) in the current era,[7] with excellent reported outcomes.[14] Good results are facilitated by an increasing use of the transaxillary access for IABP implantation, given the advantages of this approach for physical rehabilitation and functional recovery of patients waiting for a donor.[15]

Median waiting time for candidates waitlisted as *status 0,* which requires ongoing support with ECMO or tempo- rary VADs and implies national priority, remained less than 1 week during the whole study period. These extremely short waiting times resulted in high rates of HTx; in the most recent years of the registry, just before the COVID-19 outbreak, almost 90% of all candidates listed as *status 0* were able to get a heart during the index hospitalization. This is a proof of the efficiency of the Spanish national net- work for organ sharing, which inspired several other systems around the world.[16]

An important insight of the study is the changing clinical picture of emergency HTx candidates over time. Interestingly, there was a temporal trend to increasing age of prioritized patients, in parallel to a shift from lower to higher INTERMACS profiles. Anticipating the initiation of MCS to a less critical clinical scenario is advocated to achieve good postoperative outcomes, especially among older patients.[17] A better selection of candidates, as well as the progressive substitution of the IABP as the preferred mode of bridging for temporary VADs, which can provide more complete hemodynamic support, contributed to the progressive reduction of waiting list mortality observed over the study period.

Weaning from temporary MCS because of cardiac recovery was an unusual outcome in our study (<2%), which become progressively less frequent over time. This finding is consistent with an analysis of the UNOS registry[18]that revealed that, in a recent era, only 1.5% patients waitlisted with ECMO or a non-dischargeable BIVAD and 0.2% patients waitlisted with an IABP, a percutaneous VAD or a non-dischargeable surgical LVAD

experienced recovery. The authors of this study[18] questioned whether the immediate availability of organs for candidates on tem- porary MCS is a barrier for offering them an adequate time for recovering, weaning, and delisting. Although this is an important concern, we think that most of our patients had a low potential for recovery. Taken together, potentially reversible causes of cardiogenic shock like myocardial infarction, post-cardiac surgery and acute myocarditis accounted for 1/3 of the cases, while in most of the remaining patients, initiation of temporary MCS was moti- vated by the deterioration of preexistent cardiac conditions.

This fact is reflected by the high proportion of patients of our registry who carried implantable devices and who have been listed previously for elective HTx.

One-year survival following emergency HTx was <70% during the earlier years of this registry and came to exceed 80% during the prepandemic year of 2019; then, it worsened abruptly again in the year 2020, probably because of the severe impact of the COVID-19 outbreak in the Spanish healthcare system. However, we did not observe a secular variation in the incidence of other adverse postoperative outcomes, except for a moderate reduction of the rate of cardiac reoperation. Postoperative survival was comparable to that reported for patients undergoing emergency HTx in Germany or France,[6] but somewhat inferior to that reported in the UNOS,[7,19] where cardiac donors are, as an average, >10 years younger than in Europe.[20] Over the last 2 deca- des, Spanish transplant activity has been maintained at the expense of a constant increase of the use of cardiac donors aged >50 years,[13] which may be associated with less opti- mal post-transplant outcomes.[20]

Our results reflect that performing emergency HTx in patients on temporary MCS is a high-risk procedure, so raising the question whether, to optimize organ donor usage, some of these patients should be offered a durable VAD as a bridge to candidacy instead of being transplanted immediately. Short-term devices can be used to bridge acutely ill patients to durable VAD implantation; however, postoperative outcomes of these individuals seem to be inferior to those of patients bridged on medical therapy.[21] Postoperative mortality after durable VAD implantation is particularly high in patients who require preoperative biventricular support or ECMO, probably related to a more deteriorated right ventricular function. In Spain, the use of durable VADs as a bridge to HTx or candidacy has been historically low, a fact that, to a certain extent, may have been favored by the broad availability of organ donors.

The mode of temporary MCS used for preoperative bridging also has a significant impact on post-transplant outcomes. Consistently with previous analyses of UNOS[19] and ISHLT[22] registries, we found a significant association between preoperative support with venoarterial ECMO and increased post-transplant mortality. Candidates bridged to HTx with ECMO often present a worse clinical condition than those who can be managed with other modes of temporary MCS; however, the consistency of the adjusted survival results reported by different studies suggest that this association is not purely explained by confusion bias. The inherent adverse physiological effects of venoarterial ECMO, like increased left ventricular afterload,[23] hydrostatic pulmonary edema and intrinsic lung tissue damage,[24] platelet dysfunction,[25] enhanced inflammatory response[26] and increased oxidative stress[26] might led to higher risk of early adverse events after HTx like surgical bleeding, need for transfusions, excessive vasodilatation, respiratory distress, and graft failure.

In candidates supported with ECMO, optimal timing of HTx is a challenge. Transplant surgery should take place late enough to allow the recovery of end-organ function, but also early enough to avoid adverse events associated with prolonged support. This is the reason why regional networks use to set a maximum length of the high-priority status for these patients −for example, 7 or 10 days. A recent American study revealed a secular increase of the postoper- ative survival of patients bridged to HTx with ECMO,[27] which might be related to, among other improvements, a better assessment of transplant candidacy.

This study has a few limitations. As a retrospective investigation, it may be subjected to bias of various sources. While a significant effort has been done to adjust for the most relevant potential confounders, missing values have precluded an even more extensive adjustment. The study has the strength of including all the activity from all the centers with an active adult HTx program in Spain. This has the counterpart of some potential differences in selection protocols and therapeutic management among centers that has not been controlled for in the analysis and that the clinical events were adjudicated by local investigators, rather by an independent committee. Finally, while our results can be safely directly applied to Spain, some caution is needed in applying them to other countries with organ sharing donor systems that may differ from the Spanish one.

In summary, we analyzed the temporal trends in the use of temporary MCS as a bridge to emergency HTx within the Spanish organ donor sharing network during the period 2010 to 2020, putting them in the perspective of subsequent changes of donor allocation policies introduced over time. The study supports the efficiency of the system, which was able to maintain high rates of HTx and short waiting periods during the whole study period. Rates of survival to and after HTx were acceptable and improved over time, just until before the COVID-19 pandemic year of 2020. Consistently with other studies, we observed an excess post-transplant mortality among HTx candidates bridged on ECMO, which calls for the need to revisit the prioritization policy in these cases.

Disclosure statement

Some of the authors of this study are members of the *Centro de Investigación Biomédica en Red de Enfermedades Cardiovasculares* (CIBERCV), of the Carlos III Institute of Health of the Spanish Ministry of Science. The authors have no conflicts of interest to declare.

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A list of participant institutions and study collaborators is presented as Supplementary Material.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.healun.2022.10.020.

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TABLE 1 Specific clinical criteria used to define waiting list priority levels in adult heart transplant candidates in the Spanish organ donor allocation system: changes over the period 2010-2020

Waitlist priority status	Era 1 (Jan 2010-May 2014)		Era 2 (June 2014-May 2017)		Era 3 (June 2017-December 2017)	
	Qualifying criteria		Specifications	Qualifying criteria	Specifications	Qualifying criteria
Specifications						
Status 0 (High urgency)	Temporary devices (nondischargeable)[a] • ECMO • Percutaneous VAD • Surgically implanted non-dischargeable VAD Durable devices (dischargeable)[b] • Paracorporeal VAD • Intracorporeal VAD	National priority[c]	Temporary devices (non-dischargeable)[a] • ECMO • Percutaneous VAD • Surgically implanted non-dischargeable VAD Durable devices (dischargeable)[b] • Paracorporeal VAD with device-related complications • Intracorporeal VAD with device related complications	National priority[c]	Temporary devices (nondischargeable)[a] • ECMO • Percutaneous VAD • Surgically implanted nondischargeable VAD Durable devices (dischargeable)[b] • Paracorporeal VAD with major device-related complications[f] • Intracorporeal VAD with major device-related complications[f]	National priority[c] Specific additional conditions are defined for candidates listed with ECMO or percutaneous VAD[e]
Status 1 (Urgency)	Temporary devices (nondischargeable)[a] • IABP	National priority[c]	Temporary devices (non-dischargeable)[a] • IABP Durable devices (dischargeable) • Paracorporeal VAD without device-related complications • Intracorporeal VAD without device-related complications Other indications • Refractory arrhythmic storm	Regional priority[d]	Temporary devices (nondischargeable)[a] • IABP Durable devices (dischargeable)[b] • Paracorporeal VAD with minor device-related complications[g] • Paracorporeal VAD without device-related complications • Intracorporeal VAD with minor device-related complications[g] Other indications • Post-desensitization candidates	Regional priority[d]
Status 2 (Elective)	• All other candidates	No priority	• All other candidates	No priority	All other candidates	No priority

ECMO, Extracorporeal membrane oxygenation; VAD, ventricular assist device.

[a]Examples of percutaneous devices: Impella 2.5, Impella CP, Impella 5.0, Tandemheart, or similar. Examples of surgically implanted, nondischargeable devices: Centrimag (continuous flow), Abiomed BVS5000 (pulsatile flow), Abiomed AB5000 (pulsatile flow), or similar.

[b]Examples of durable, dischargeable paracorporeal VADs (pulsatile flow): Berlinheart Excor, Thoratec PVAD or similar. Examples of durable, dischargeable intracorporeal VADs (continuous flow): Heartware HVAD, Heartmate II, Heartmate III.

[c]*National priority* implies that these patients have priority over candidates listed with inferior levels for getting the first suitable donor heart which was retrieved within the whole nation of Spain.

[d]*Regional priority* implies that these patients have priority over candidates listed in *status 2* for getting the first suitable donor heart retrieved within the reference geographical area of their attending hospitals, but not for organs retrieved in other regions of Spain.

[e]Specific additional conditions defined for patients listed as *status 0* with ECMO or percutaneous VAD during Era 3 are the following: a. A minimum period of 48 hours must have been elapsed since device implantation before the patient is listed for emergency HTx. b. Patients must be free of multiorgan failure at the time of emergency HTx listing. c. Patients can stay in the waiting list as *status 0* for a maximum period of 7 days, which can be extended to a maximum of 10 days if they are extubated and continue to be free of multi-organ failure. Once this time period has expired, the candidate is downgraded to *status 1*.

[f]Major device-related complications are pump thrombosis or mechanical dysfunction.

gMinor device-related complications are driveline infection, severe right ventricular failure, or gastrointestinal bleeding.

TABLE 2 Modes of temporary mechanical circulatory support and devices used in study patients, both at the time of emergency transplant listing and before transplantation

DEVICES	Mode of t-MCS upon emergency transplant listing (*n* = 1,036)	Last mode of t-MCS before transplantation (*n* = 875)
Intraaortic balloon pump	317 (30.6%)	238 (27.2%)
Veno-arterial ECMO	313 (30.1%)	245 (28%)
Peripheral cannulation	293	230
Central cannulation	20	15
Percutaneous VADs	79 (7.6%)	73 (8.3%)
Impella CP	71	64
Impella 5.0	6	7
Impella 2.5	1	1
Impella CP + Impella RP	1	1
Surgically implanted pulsatile-flow VADs	19 (1.8%)	15 (1.7%)
Abiomed BVS5000 BIVAD	12	10
Abiomed BVS5000 LVAD	5	3
Abiomed AB5000 BIVAD	1	1
Abiomed AB5000 LVAD	1	1
Surgically implanted continuous-flow VADs	308 (29.8%)	304 (34.8%)
Centrimag LVAD	191	179
Centrimag BIVAD	111	120
Centrimag RVAD	4	4
Maquet Rotaflow LVAD	1	0
Sorin Revolution BIVAD	1	1

BIVAD, biventricular assist device; ECMO, extracorporeal membrane oxygenation; HTx, Heart transplantation; LVAD, left ventricular assist device; RVAD, right ventricular assist device; t-MCS, temporary mechanical circulatory support; VAD, ventricular assist device

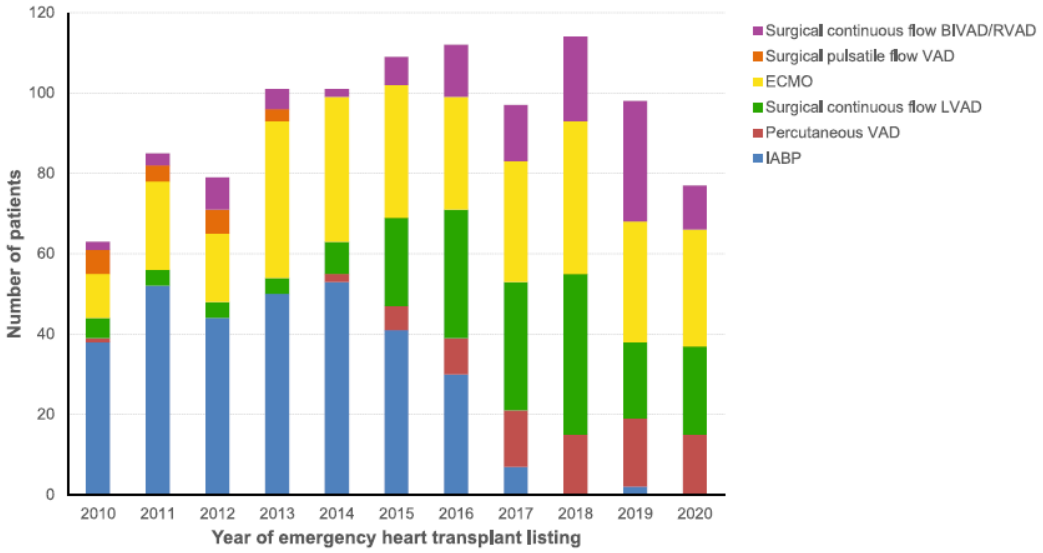


Figure 1 Trends of the mode of temporary mechanical circulatory used in 1,036 patients listed for emergency heart transplantation in 16 Spanish institutions during the period 2010 to 2020. BIVAD, biventricular assist device; ECMO, extracorporeal membrane oxygenation; IABP, Intraaortic balloon pump; LVAD, left ventricular assist device; RVAD, right ventricular assist device; VAD, Ventricular assist device.

TABLE 3 Baseline clinical characteristics of 1,036 patients who were listed for emergency heart transplantation while being supported with temporary devices in 16 Spanish institutions during the period 2010 to 2020

	Era 1 Jan 2010 - May−2014 (*n* = 379)	Era 2 Jun 2014 to May−2017 (*n* = 319)	Era 2 Jun−2017 to Dec−2020 (*n* = 338)	*p* value for trend
Mode of temporary MCS				<0.001
Intraaortic balloon pump	212 (55.9%)	102 (32%)	3 (0.9%)	
Percutaneous VAD	1 (0.3%)	20 (6.3%)	58 (17.2%)	
Surgical continuous flow LVAD	21 (55.5%)	75 (23.5%)	96 (28.4%)	
Surgical continuous flow BIVAD or RVAD	19 (5%)	27 (8.5%)	70 (20.7%)	
Venoarterial ECMO	107 (28.2%)	95 (29.8%)	111 (32.8%)	
Surgical pulsatile flow VAD	19 (5%)	0	0	
Age (years), mean § standard deviation	52 ± 11.4	52.4 ± 12.5	53.9 ± 11.5	0.034
Body mass index (kg/m^2)[a], mean ± standard deviation	25.5 ± 4.3	25.5 ± 4	25.9 ± 3.9	0.263
Women	97 (25.6%)	55 (17.2%)	72 (21.3%)	0.143
Previous listing for heart transplantation	137 (36.1%)	134 (42%)	103 (30.5%)	0.135
Diabetes	85 (22.4%)	82 (25.7%)	68 (20.1%)	0.492
Hypertension	130 (34.3%)	102 (32%)	123 (36.4%)	0.579
Hypercholesterolemia	141 (37.2%)	105 (32.9%)	130 (38.5%)	0.763
Current or former smoker	237 (62.5%)	192 (60.2%)	185 (54.7%)	0.097
Type of heart disease				0.689
Ischemic	182 (48%)	156 (48.9%)	171 (50.6%)	
Dilated	129 (34%)	112 (35.1%)	120 (35.5%)	
Valvular	23 (6.1%)	15 (4.7%)	11 (3.3%)	
Congenital	8 (2.1%)	10 (3.1%)	6 (1.8%)	
Myocarditis	11 (2.9%)	8 (2.5%)	5 (1.2%)	
Hypertrophic	10 (2.6%)	7 (2.2%)	15 (4.4%)	
Arrhythmogenic	2 (0.5%)	2 (0.6%)	3 (0.9%)	
Restrictive/Infiltrative	6 (1.6%)	6 (1.9%)	4 (1.2%)	
Toxic	5 (1.3%)	3 (0.9%)	3 (0.9%)	
Other	3 (0.8%)	0	1 (0.3%)	
Cardiogenic shock related to acute myocardial infarction	99 (26.1%)	82 (25.7%)	114 (33.7%)	0.027
Cardiogenic shock following cardiac surgery	21 (5.5%)	16 (5%)	26 (7.7%)	0.241
Previous sternotomy	67 (17.7%)	53 (16.6%)	48 (14.2%)	0.210
Implantable defibrillator	145 (38.3%)	160 (50.2%)	158 (46.7%)	0.019
Cardiac resynchronization therapy	53 (14%)	56 (17.6%)	50 (14.8%)	0.733
History of ventricular tachycardia	127 (33.5%)	111 (34.8%)	112 (33.1%)	0.928
History of cardiac arrest	54 (14.2%)	51 (16%)	69 (20.4%)	0.029
History of atrial fibrillation	114 (30.1%)	94 (29.5%)	95 (28.1%)	0.565
Chronic obstructive pulmonary disease	34 (9%)	29 (9.1%)	17 (5%)	0.053
Prior stroke	20 (5.3%)	21 (6.3%)	23 (6.8%)	0.390
Peripheral artery disease	18 (4.7%)	9 (2.8%)	11 (3.3%)	0.275
Malignancy	12 (3.2%)	11 (3.4%)	12 (3.6%)	0.774
Active infection requiring iv antibiotics	38 (10%)	33 (10.3%)	16 (4.7%)	0.012

TABLE 3 Baseline clinical characteristics of 1,036 patients who were listed for emergency heart transplantation while being supported with temporary devices in 16 Spanish institutions during the period 2010 to 2020

	Era 1 Jan 2010 - May−2014 (*n* = 379)	Era 2 Jun 2014 to May−2017 (*n* = 319)	Era 2 Jun−2017 to Dec−2020 (*n* = 338)	*p* value for trend
Left ventricular ejection fraction (%)a, mean ± standard deviation	23.3 ± 10.9	23.3 ± 10.4	22.6 ± 10.9	0.437
Cardiac index (l/min/m^2)[a], mean ± standard deviation	2.26 ± 0.77	2.10 ± 0.68	2.19 ± 065	0.303
Central venous pressure (mm Hg)[a], mean ± standard deviation	13.5 ± 6.1	12.4 ± 5.6	12.0 ± 5.9	0.008
Pulmonary wedge pressure (mm Hg)[a], mean ± standard deviation	22.7 ± 8.6	22.4 ± 8.2	21.3 ± 8.1	0.098
Mean pulmonary pressure (mm Hg)[a], mean ± standard deviation	31.7 ± 11.1	30.9 ± 11.9	29.7 ± 10.5	0.066
Pulmonary vascular resistance (Wood Units)[a], mean ± standard deviation	2.51 ± 1.90	2.75 ± 1.78	2.57 ± 1.70	0.967
INTERMACS profile				<0.001
INTERMACS 1	101 (26.6%)	51 (16%)	48 (14.2%)	
INTERMACS 2	198 (52.2%)	138 (43.3%)	124 (36.7%)	
INTERMACS 3	68 (17.9%)	97 (30.4%)	124 (36.7%)	
INTERMACS 4	11 (2.9%)	33 (10.3%)	42 (12.4%)	
Indetermined	1 (0.3%)	0 (0%)	0	

BIVAD, biventricular assist device; ECMO, extracorporeal membrane oxygenation; INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; LVAD, Left ventricular assist device; MCS, Mechanical circulatory support; RVAD, right ventricular assist device; VAD, ventricular assist device.

[a]Missing values: Body mass index (*n* = 123), Left ventricular ejection fraction (*n* = 48), Cardiac Index (*n* = 469), Central venous pressure (*n* = 454), Pulmonary wedge pressure (n = 476), Mean pulmonary pressure (*n* = 425), Pulmonary vascular resistance (*n* = 540).

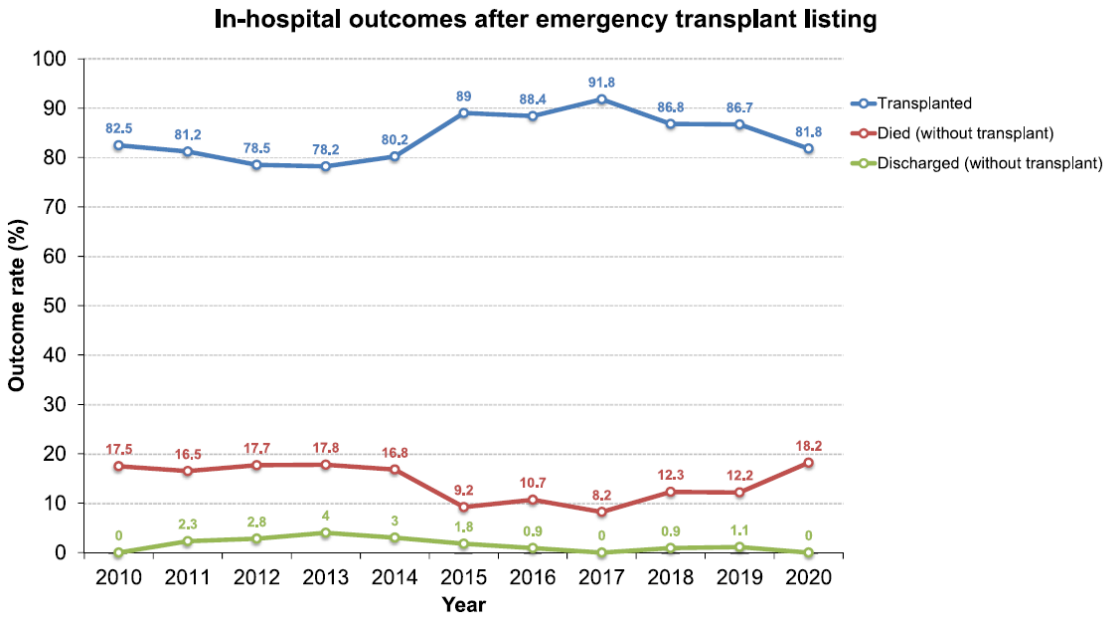


Figure 2 Trends of the in-hospital rate of major clinical outcomes following emergency heart transplant listing (transplantation, death before getting a cardiac donor or discharge without having been transplanted) during the period 2010 to 2020.

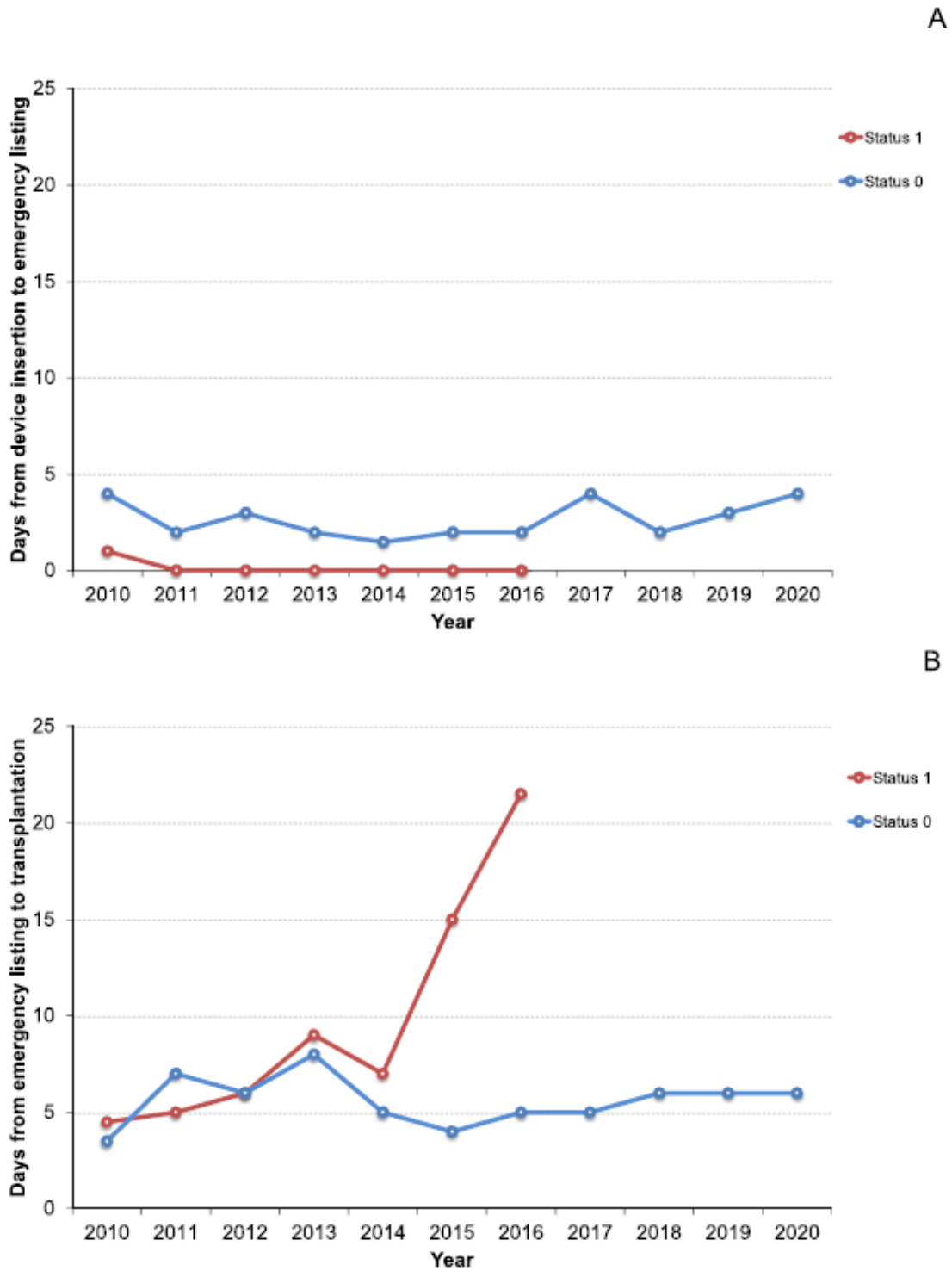


Figure 3 Trends of the median time from mechanical device insertion to emergency heart transplant listing (panel A) and from emergency listing to transplantation (panel B) during the period 2010−2020, in the subgroups of patients listed either with intraaortic balloon pump support or with other modes of temporary mechanical circulatory support. IABP, intraaortic balloon pump; t-MCS, temporary mechanical circulatory support.

TABLE 4 Preoperative clinical status of the recipient and characteristics of donors in 875 patients who underwent emergency heart transplantation in 16 Spanish hospitals during the period 2010 to 2020

	Era 1 Jan 2010- May−2014 (*n* = 301)	Era 2 Jun 2014-May 2017 (*n* = 280)	Era 3 Jun 2017- Dec 2020 (*n* = 294)	*p* value for trend
Recipients− supportive therapies before transplantation				
Mode of temporary mechanical circulatory support				<0.001
Intraaortic balloon pump	157 (52.2%)	79 (28.2%)	2 (0.7%)	
Percutaneous ventricular assist device	3 (1%)	19 (6.8%)	51 (17.3%)	
Venoarterial extracorporeal membrane oxygenation	83 (27.6%)	80 (28.6%)	82 (27.9%)	
Surgical continuous flow LVAD	21 (7%)	73 (26.1%)	85 (28.9%)	
Surgical continuous flow BIVAD or RVAD	22 (7.3%)	29 (10.4%)	74 (29.2%)	
Surgical pulsatile flow ventricular assist device	15 (1.7%)	0	0	
Inotropes	203 (67.4%)	155 (55.4%)	128 (43.5%)	<0.001
Vasopressors	99 (32.9%)	83 (29.6%)	81 (27.6%)	0.155
Mechanical ventilation	124 (41.2%)	103 (38.7%)	103 (35%)	0.123
Renal replacement therapy	14 (4.7%)	17 (6.1%)	22 (7.5%)	0.148
Recipients− clinical status & lab tests before transplantation				
Systolic blood pressure (mm Hg)[a], mean ± standard deviation	101.4 ± 16.1	102.6 ± 18.1	100.9 ± 15.6	0.739
Resting heart rate (beats per minute)[a], mean ± standard deviation	92.4 ± 18.9	87.7 ± 18.5	90.6 ± 17.7	0.280
Haemoglobin (g/dl)[a], mean ± standard deviation	10.3 ± 1.9	9.8 ± 1.9	9.4 ± 1.2	<0.001
Leucocytes (n x 10^9/L)[a], mean ± standard deviation	11.04 ± 5.07	11.29 ± 5.91	12.1 ± 5.21	0.018
Platelets (n x 10^9/L)[a], mean ± standard deviation	175.2 ± 97.5	180.1 ± 92.9	170.8 ± 85.3	0.565
Creatinine (mg/dl)[a], mean ± standard deviation	1.07 ± 0.47	1.08 ± 0.60	0.99 ± 0.46	0.049
Bilirubin (mg/dl)[a], mean ± standard deviation	1.59 ± 2.16	1.79 ± 2.3	1.56 ± 1.32	0.904
Albumin (g/l)[a], mean ± standard deviation	3.29 ± 0.89	3.21 ± 0.71	3.05 ± 0.68	0.001
AST (UI/L)[a], mean ± standard deviation	86 ± 205	59 ± 75	71 ± 137	0.252
ALT (UI/L)[a], mean ± standard deviation	92 ± 190	57 ± 88	69 ± 122	0.051
pH[a], mean ± standard deviation	7.43 ± 0.07	7.43 ± 0.06	7.43 ± 0.06	0.287
Donors− clinical characteristics				
Age (years), mean ± standard deviation	41.1 ± 12.1	44.5 ± 12.7	44.6 ± 12.1	0.001
Donor age > 50 y	83 (27.6%)	117 (41.8%)	124 (42.2%)	<0.001
Female donora	87 (28.9%)	81 (28.9%)	60 (20.5%)	0.020

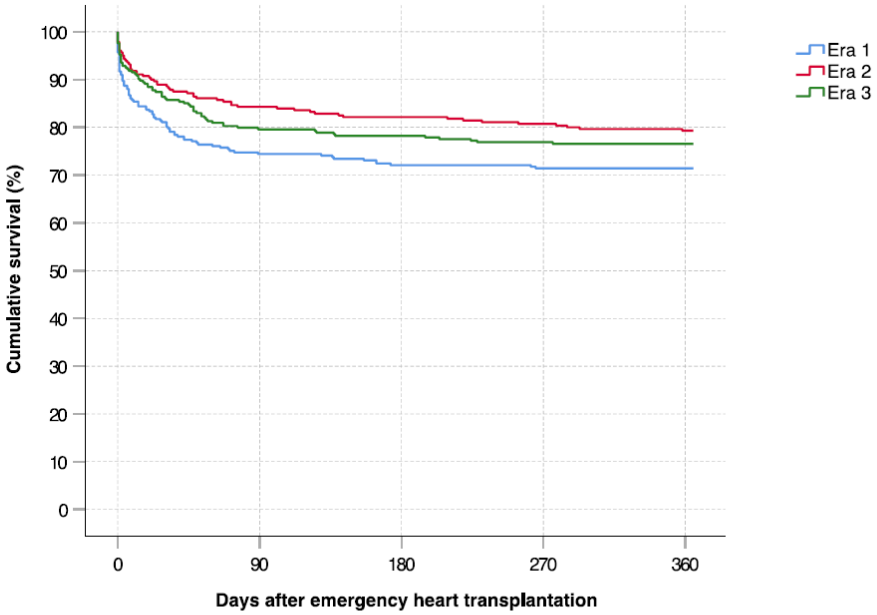
TABLE 4 Preoperative clinical status of the recipient and characteristics of donors in 875 patients who underwent emergency heart transplantation in 16 Spanish hospitals during the period 2010 to 2020

	Era 1 Jan 2010- May−2014 (*n* = 301)	Era 2 Jun 2014-May 2017 (*n* = 280)	Era 3 Jun 2017- Dec 2020 (*n* = 294)	*p* value for trend
Cold ischemic time (min)[a], mean ± standard deviation	212.9 ± 59	204.5 ± 64.8	212.1 ± 66.7	0.875
Cold ischemic time > 240 min	108 (36.1%)	91 (32.5%)	114 (38.8%)	0.505

ALT, alanine aminotransferase; AST, aspartate aminotransferase; BIVAD, biventricular assist device; LVAD, left ventricular assist device; RVAD, right ventricular assist device.

Missing values: Systolic blood pressure (*n* = 144), Resting heart rate (*n* = 153), Leucocytes (*n* = 10), Platelets (*n* = 9), Creatinine (*n* = 8), Bilirubin (*n* = 91), Hemoglobin (*n* = 13), AST (*n* = 95), ALT (*n* = 66), pH (*n* = 128), Albumin (*n* = 316), Female donor (*n* = 1), Cold ischemic time (*n* = 2).

[a]Denotes variables with missing values.



N at risk

Era 1 (Jan–2010 to May–2014)	301	224	217	215	215
Era 2 (Jun–2014 to May–2017)	280	236	230	226	222
Era 3 (Jun–2017 to Dec 2020)	294	234	230	226	225

Figure 4 Kaplan-Meier curves for 1-year post-transplant survival, stratified according to temporal eras.

TABLE 5 Univariate and multivariate statistical associations between temporal eras, the mode of preoperative temporary mechanical circulatory support and 1-year post-transplant outcomes

	Univariable analysis		Extended multivariable model[a]		Parsimonious multivariable model[b]	
	Non-adjusted HR (95% CI)	P value	Adjusted HR (95% CI)	P value	Adjusted HR (95% CI)	P value
Era análisis						
Era 1 (Jan 2010-May 2014)	Reference		Reference		Reference	
Era 2 (Jun 2014-May 2017)	0.67 (0.48-0.94)	0.020	0.69 (0.48-0.99)	0.043	0.66 (0.47−0.94)	0.021
Era 3 (Jun 2017-Dec -2020)	0.78 (0.57-1.07)	0.127	0.80 (0.54-1.19)	0.277	0.74 (0.51−1.08)	0.115
Era 3 prepandemic (Jun 2017-Feb-2020)	0.75 (0.53-1.05)	0.092	0.78 (0.71-1.18)	0.236	0.70 (0.47−1.04)	0.080
Preoperative mechanical circulatory support						
Intraaortic balloon pump	Reference		Reference		Reference	
Percutaneous VAD	0.71 (0.37-1.36)	0.301	0.87 (0.43-1.77)	0.700	0.87 (0.43−1.76)	0.704
Surgical continuous Flow LVAD	0.97 (0.63-1.48)	0.872	1.24 (0.75-2.04)	0.405	1.12 (0.70−1.81)	0.638
Surgical continuous Flow BIVAD or RVAD	1.25 (0.80-1.96)	0.321	1.45 (0.87-2.42)	0.149	1.40 (0.86−2.29)	0.177
ECMO	1.73 (1.21-2.47)	0.003	1.74 (1.13-2.69)	0.013	1.71 (1.15−2.53)	0.008
Pulsatile flow VAD	2.42 (1.04-5.64)	0.041	1.74 (0.70-4.32)	0.233	1.66 (0.69−3.96)	0.257

BIVAD, biventricular assist device; ECMO, extracorporeal membrane oxygenation; HR, Hazard ratio; LVAD, left ventricular assist device; VAD, ventricular assist device.

[a]Multivariable Cox,s regression model that included all co-variables that were considered as potential confounders based on clinical judgement and pre- vious knowledge: age of the recipient, gender of the recipient, cardiogenic shock related to myocardial infarction, cardiogenic shock following cardiac surgery, history of cardiac arrest, diabetes mellitus, previous sternotomies, INTERMACS profile, preoperative need for renal replacement therapy, preoper- ative mechanical ventilation, preoperative need for vasopressors, preoperative active infection, age of the donor, gender of the donor, cold ischemic time, preoperative mode of temporary mechanical circulatory support, temporal eras.

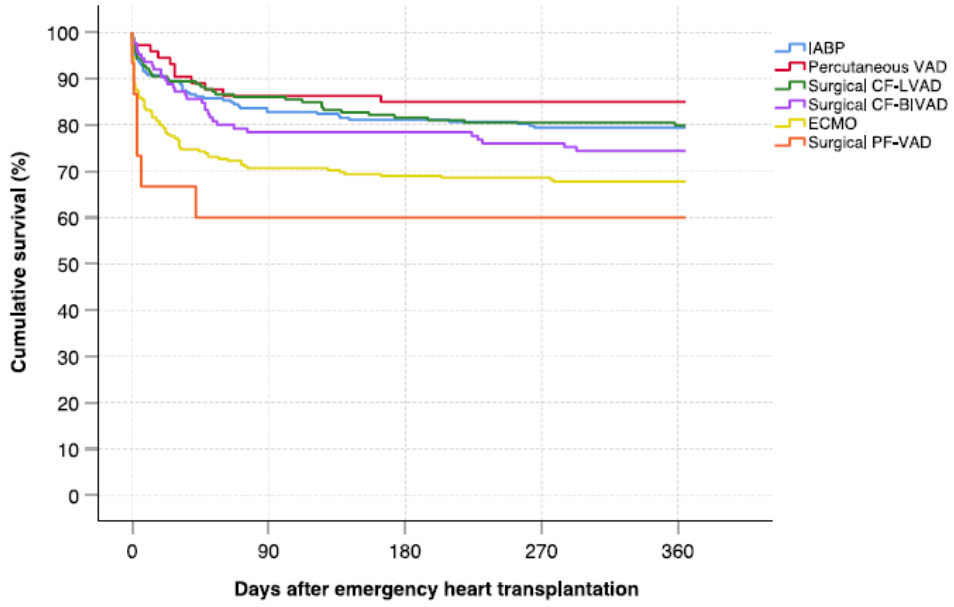
[b]This multivariable model included the co-variables of the extended model which remained as independent predictors of 1-year post-transplant mortality after a backward stepwise selection process with a *p*-out criterion <0.10: age of the recipient, gender of the recipient, preoperative need for renal replacement therapy, preoperative need for vasopressors, cold ischemic time, preoperative infection, preoperative mode of temporary mechanical circulatory support, temporal eras.

TABLE 6 In-hospital postoperative outcomes in 875 patients who underwent emergency heart transplantation. ICU, Intensive Care Unit

	Era 1 (Jan 2010-May 2014) *N* = 301	Era 2 (Jun 2014-May 2017) *N* = 280	Era 3 (Jun 2017-Dec 2020) *N* = 284	*p* value for trend
Postoperative infection[a]	137 (45.5%)	109 (38.9%)	118 (40.1%)	0.181
Postoperative renal failure[a]	79 (26.2%)	65 (23.2%)	82 (27.9%)	0.653
Postoperative graft failure[a]	51 (16.9%)	41 (14.6%)	56 (19%)	0.499
Postoperative isolated right ventricular failure[a]	51 (16.9%)	37 (13.2%)	43 (14.6%)	0.425
Postoperative mechanical circulatory support[a]	35 (11.6%)	34 (12.1%)	55 (18.7%)	0.014
Excessive surgical bleeding[a]	81 (26.9%)	56 (20%)	76 (25.9%)	0.753
Open-chest cardiac reoperation[a]	65 (21.6%)	41 (14.6%)	42 (14.3%)	0.017
Duration of postoperative mechanical ventilation[b] (days), median (interquartile rank)	2 (8)	3 (8)	3 (7)	0.040
Duration of postoperative ICU stay[b] (d), median (interquartile rank)	8 (15)	9 (14)	11 (13)	0.013
Total duration of postoperative hospital stay[b] (days), median (interquartile rank)	25 (30)	29 (29)	31 (37)	0.278
Postoperative 90-d mortality	77 (25.6%)	44 (15.8%)	60 (20.4%)	0.116
Postoperative 1-y mortality	86 (28.6%)	58 (20.4%)	69 (23.5%)	0.144

[a] Specific definitions of in-hospital postoperative outcomes following transplantation are detailed in Supplementary Material.

[b]Missing values: Duration of postoperative mechanical ventilation (*N* = 33), Duration of postoperative ICU stay (*N* = 25), Total duration of postoperative hospital stay (*N* = 22).



N at risk

IABP	238	197	193	189	189
Percutaneous VAD	73	63	62	62	62
Surgical CF-LVAD	179	154	146	144	143
Surgical CF-BIVAD/RVAD	125	98	98	95	93
ECMO	245	173	169	168	166
Surgical PF-VAD	15	9	9	9	9

Figure 6 Kaplan-Meier curves for 1-year post-transplant survival, stratified according to the last mode of temporary mechanical circulatory support used preoperatively.BIVAD, biventricular assist device; CF, continuous flow; ECMO, extracorporeal membrane oxygenation; HR, hazard ratio; IABP, intraaortic balloon pump; LVAD, left ventricular assist device; PF, pulsatile flow; RVAD, right ventricular assist device; VAD, ventricular assist device.