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Impact of MELD 30-allocation policy on liver transplant outcomes in Italy

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ABSTRACT

Background & Aims: In Italy, since August 2014, LT candidates with MELD \geq 30 receive a national allocation priority. This multi-center cohort study aims to evaluate waiting time in the list, dropout rate, and graft survival before and after introducing the macroarea sharing policy.

Methods: 4,238 patients registered from 2010 to 2018 have been enrolled and categorized in an ERA-1 Group (n=2,013; before August 2014) and an ERA-2 Group (n=2,225; during and after August 2014). Cox proportional hazard model was used to estimate the HR of receiving LT or death between the two ERAs. The Fine-Gray model was used to estimate the HR for dropout from the waiting list and graft loss, considering death as a competing risk event. A Fine-Gray model was also used to estimate risk factors of graft loss.

Results: MELD \geq 30 patients had a lower median waiting time in the list for LT (4vs.12 days, p<0.001) and a higher probability to be transplanted (HR=2.27, 95%CI 1.78-2.90; p=0.001) in the ERA-2 when compared to ERA-1. The subgroup analysis on 3,515 LTs confirmed ERA-2 (odds ratio=0.56, 95%CI=0.46-0.68; p=0.001) as a protective factor for better graft survival rate. The protective variables for lower dropouts on the waiting list were: ERA-2, high volume centers, no competition centers, male recipients, and hepatocellular carcinoma. The protective variables for graft loss were high volume center and ERA-2, while MELD \geq 30 remained related to a higher risk of graft loss.

Conclusions: The national MELD \geq 30 priority allocation was associated with improved patient outcomes, although MELD \geq 30 had a higher risk of graft loss. The transplant centers volume and competition among centers may have a role in the recipient prioritization and outcome.

LAY SUMMARY:

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2 After introducing the Italian national MELD \geq 30 priority, more LT, fewer dropouts, and shorter
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4 waiting times were observed in patients with MELD \geq 30. However, a higher risk of graft loss still
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6 burdens these cases compared to MELD $<$ 30. The volume of transplant centers and competitions
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8 among centers may have a role in the recipient prioritization and outcome.
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INTRODUCTION

1
2 Liver transplantation (LT) is the only effective therapy for patients with end-stage liver disease, but
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4 donor shortage limits its applicability. Most allocation policies are based on the model for end-stage
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6 liver disease (MELD) score, developed in 2002, and aim at prioritizing the sickest patients at higher
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8 risk of death or dropout from the waiting list¹⁻². In many countries, patients with MELD score above
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10 a pre-defined cut-off (30, 35, or 40, depending on the allocation system) are granted a preferential
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12 allocation for LT within a determined geographical area³⁻⁴. The rationale for transplanting the
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14 sickest patients is to shorten the delay with the final goal of avoiding renal and infectious
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16 complications that may negatively affect post-transplant outcomes and/or preclude LT. This
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18 allocation strategy is nonetheless exposed to criticism as it may lead to reduced overall survival
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20 after LT⁵⁻⁶, limiting access to LT for low-MELD patients, particularly those suffering from
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22 hepatocellular carcinoma (HCC). Additionally, another critique that has been raised is related to
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24 increased costs of postoperative care of globally sicker recipients⁷⁻⁸.

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31 However, for the criticisms mentioned above, variability has been observed among centers having a
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33 different experience, a different volume of liver transplantation performed yearly⁹, and extended
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35 criteria donors (ECD), which were described to have a substantial impact on LT outcome in high-
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37 MELD patients. Therefore, when comparing clinical outcomes between allocation policies, such
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39 factors should be considered in statistical analysis.
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44 In Italy, since August 2014, LT candidates with MELD \geq 30 have the benefit of being allocated
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46 even outside the geographical area of the transplant center where they are waitlisted. In particular,
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48 two extended areas (so-called “macroareas”) were established: Center-North and Center-South.
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51 Currently, patients with MELD \geq 30 are allocated the first available liver from an adult donor in their
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53 macroarea if there is no concomitant higher-degree emergency (e.g., fulminant hepatic failure)
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55 having priority allocation on a national basis. If more patients with MELD \geq 30 are waitlisted in the
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57 same macroarea, the first available liver is allocated to the one that has been signalled first. This
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1 new allocation scheme was introduced to reduce waiting list time and perform LT in better clinical
2 conditions while preserving the allocation algorithm's equity.
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4 Whether the introduction of MELD \geq 30 scheme has effectively reduced waiting list time in these
5 patients without negatively affecting waiting list time in patients with MELD $<$ 30 has not been
6 evaluated so far. Moreover, the effects of this new rule on patient and graft survival have not been
7 investigated.
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10 Thus, this multicentre national study aimed to evaluate the effects of introducing MELD \geq 30
11 allocation scheme on waiting list time, dropout rate, and patient and graft survival in Italy.
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PATIENTS AND METHODS

Study design

This study was designed as a multi-center cohort study involving six Italian transplant centers. A total of 4,330 LT candidates were initially considered for the study. Exclusion criteria for the study were: candidates aged <18 years (n=0), combined transplantation (n=21), living donor liver transplantation (n=6), and deceased cardiac donation (n=65). In the end, 4,238 LT candidates were enrolled for the present study. The patients included in the study were adult (≥ 18 years) candidates for isolated liver transplantation. All the indications for LT, also comprehending the cases of re-transplantation and acute liver failure, were considered. Only donors after brain death were considered in the study. Prospectively collected data from each participating center were retrospectively analyzed.

Study cohorts

According to their waiting list entry date, patients were divided into ERA-1 Group (August 2010 - July 2014) and ERA-2 Group (August 2014 - July 2018).

All the patients were categorized in high- or low-MELD (≥ 30 or < 30) according to the MELD score calculated at the time of entering the waiting list. The rationale for this choice was to preserve the intention-to-treat design of the study. Therefore, cases with an initial MELD < 30 presenting a progressive worsening of the liver function during the waiting period overpassing the threshold value of 30 were maintained in the initial low-MELD group.

Italy is characterized by heterogeneity in terms of geographical distribution and volume of LT centers. Some regions have a single transplant center, while other regions have multiple transplant centres with patients inscribed into a common regional list and access to the same donor pool. Moreover, organ availability is highly variable among regions, with some regions presenting more than 40 donors per million inhabitants per year and others less than 10. Consequently, we classified the centres participating in this study as SCR (single center per region; non-competitive allocation) or MCR (multiple centers per region; presence of allocation competition). Additionally, as

previously reported,¹⁰ centers performing ≥ 70 cases per year were defined as high-volume (HV), whereas centers performing < 70 cases per year were defined as low volume (LV).

Data collection

Collected data for donors and recipients included age, sex, height, weight, medical history of hepatocellular carcinoma (HCC), anti-HCV and HBV-anticore positivity, the dropout from the waiting list, overall and graft survival, and the MELD score. The MELD score was calculated at the time of listing using serum creatinine, serum total bilirubin and INR according to the following formula: $9.57 * \log_{10}(\text{creatinine (mg/dL)}) + 3.78 * \log_{10}(\text{bilirubin (mg/dL)}) + 11.20 * \log_{10}(\text{INR}) + 6.43$ ^{1,11,12}.

Definition of ECD was based on the presence of one of the following: hemodynamic instability, age > 65 years, BMI > 30 kg/m², bilirubin > 3 mg/dL, aspartate aminotransferase (AST) or alanine aminotransferase (ALT) \geq three times the reference level, sodium > 165 mmol/l, days on intensive care unit (ICU) > 7 , macrovesicular steatosis $\geq 40\%$.¹³

Study endpoints

The study's primary endpoint was the time on the waiting list, a surrogate of physical and functional decline in LT candidates.¹⁴ The waiting time was calculated from the time of waiting list inscription to the time of LT, dropout, or last follow-up in the patients still waiting in the list at the time of censoring. The waiting time calculated for the entire enlisted population was adopted in the analyses without excluding delisted cases. This approach was used for maintaining the initial intention-to-treat design of the study.

Secondary endpoints were death within 365 days after LT, the cumulative hazard of death, graft loss within 365 days after LT, the cumulative hazard of graft loss, prognostic factors related to waitlist dropout, and graft loss.

Follow-up period

Patients were followed up from the waiting list entry date and censored at the occurrence of LT, end of the follow-up period, or end of data coverage. Patients receiving LT were followed from the day

1 of LT to the date of the occurrence of the study outcome, end of the follow-up period, or end of data
2 coverage.
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4 *Ethics*

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7 Local institutional review boards of the six Italian transplant centers approved the study. The study
8
9 has been registered as an observational study on ClinicalTrials.gov (NCT04530240).
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11 *The Italian allocation system for liver transplantation*

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14 Before August 2014, each region in Italy had a different MELD-based allocation scheme. Super-
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16 urgent cases (i.e., acute liver failures and early retransplants) were granted national priority
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18 allocation, whereas all other candidates had access exclusively to the regional donor pool. The
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20 minimum MELD score to access the waiting list was 15, except for patients HCC who can enter the
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22 list with lower MELD values.
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26 Internal Regional rules for prioritization were based on the principle of “urgency” for which the
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28 sickest patients had priority for allocation. Patients with HCC were even more prioritized for
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30 allocation based on their cancer stage and the MELD score.
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34 Since August 2014, the allocation process changed with the introduction of macroareas to allocate
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36 organs for LT candidates with MELD score ≥ 30 (<http://www.trapianti.salute.gov.it/>).¹⁵ When a
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38 patient entered the waiting list of a macroarea, there were no additional prioritization principles for
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40 LT.
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43 *Statistical analysis*

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46 Socio-demographic and clinical characteristics of patients in ERA-1 and ERA2 were compared at
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48 the time of entrance in the waiting list and at the time of LT using the analysis of variance
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50 (ANOVA) F test, Student T-test, and Fisher’s exact test.
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54 The propensity score of being in ERA-2 rather than ERA-1 was computed using a logistic
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56 regression model based on covariates (**Table 1**) at the time of entrance on the waiting list and at the
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58 time of LT¹⁶⁻¹⁸. In particular, the propensity score at the time of entrance on the waiting list was
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60 computed using the following variables: age (years), sex, height (cm), weight (kg), blood group
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1 (AB-B), HCC, HCV positivity, MELD, high-volume center, and regional competitive status. The
2 propensity score at the time of LT was computed using the following variables: recipient age,
3 recipient sex, recipient height (cm), recipient weight (kg), recipient HCC, recipient HCV positivity,
4 MELD, high-volume center, regional competitive status, donor age, donor sex, donor height (cm),
5 donor weight (kg), donor HCV positivity, donor HBcAb positivity.
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11 To inspect the exchangeability between the two ERAs given socio-demographic and clinical
12 characteristics, we plotted the kernel density estimates of the propensity score at the time of
13 entrance in the waiting list. We computed the area of overlap between the two density functions. To
14 assess exchangeability between ERAs in terms of patients' socio-demographic and clinical
15 characteristics, we tested if half of the propensity score distributions was between 0.3 and 0.7.
16 Additionally, we tested if the overlap of the propensity score was greater than 75%. Density
17 functions of MELD between the two ERAs among centers with different volumes and regional
18 allocation were plotted.
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31 Cause-specific Cox proportional hazard model was used to estimate the HR of receiving LT or
32 death between the two ERAs. Cumulative hazards were then derived and used to estimate median
33 waiting list time. This model was considered advisable over the Fine-Gray regression for this
34 specific analysis because the cause-specific Cox regression presents the advantage of giving
35 detailed insights into the relationship between a risk factor and each separate outcome, which was
36 the purpose of this analysis¹⁹.
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46 The Fine-Gray model was used to estimate the hazard ratio for patient death and graft loss,
47 considering dropout from the waiting list as a competing risk event. In this model, sub-distribution
48 hazards are computed that are interpreted as the hazard of dropout from the waiting list and patient
49 death / graft loss, given that a subject has survived. Otherwise noted, the term hazard for these two
50 outcomes refers to sub-distribution hazards. Fine-Gray model was used to estimate risk factors of
51 graft loss.
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1 Graft loss was defined as patient death or documented graft failure requiring relisting for second
2 transplantation.
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4 In the adjusted analyses, the propensity score was added to the statistical models. In particular, for
5 the outcomes LT, dropout from the waiting list, and death, we used the propensity score computed
6 at the time of entrance in the waiting list. For graft loss, we used the propensity score computed at
7 the time of LT. We decided to adjust the models with the propensity score instead of creating a
8 pseudo-population using a propensity score or an inverse probability weighting. The decision to use
9 this approach should be controversial. For survival data analyses with proportional hazards models,
10 adjustment on the propensity score should entail a, although minimal, bias in estimating the
11 marginal treatment effect,²⁰ and optimal full matching, mainly using an inverse probability of
12 treatment weighting,²¹ may be preferable. However, some simulations comparing the effect of using
13 the different models showed significant overlaps in the confidence interval estimates, which did not
14 conclude the statistical superiority of one method versus the other.²² Therefore, we decided to use
15 the adjustment with the propensity score, although it should not appear as the best approach to use,
16 because it was the most reader-friendly approach, considering that the differences of the different
17 approaches to use may be smaller in practice than the uncertainty of estimates.
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19 The cumulative hazards for LT, graft loss, and death were plotted, and the cumulative hazard
20 functions were compared using the Gray test.
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22 A P value<0.05 was considered statistically significant. The statistical analysis was carried out
23 using R (R Development Core Team, Austria, Vienna).
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RESULTS

Study population

4,238 LT candidates waitlisted from August 2010 to July 2018 were enrolled. The last date of follow-up was December 2018. The median follow-up period of the entire population from the time of waiting list inscription was 29 months (interquartile ranges: 9-56). None of the patients was lost to follow up. A total of 3,515/4,238 (82.9%) patients were transplanted, with 529/3,515 (15.0%) cases of post-LT death reported. As for the post-LT graft losses, 511/3,515 (14.5%) cases were reported.

In detail, patients were recruited from LT centres located in Bologna (n=961), Pisa (n=980), Turin (n=897), Milan Niguarda (n=859), Rome Sapienza (n=268), and Rome Cattolica (n=273). The transplant volume of study centers represented close to half of the entire Italian liver transplant activity in the same period. Two centers (Pisa and Turin) were SCR, whereas the others (Bologna, Milan Niguarda, Rome Sapienza, and Rome Cattolica) were MCR. Pisa, Turin, Bologna, and Milan Niguarda were defined as HV centers, whereas Rome Sapienza and Rome Cattolica were defined as LV (**Supplementary Table 1**).

A total of 2,013 patients were waitlisted in ERA-1 and 2,225 in ERA-2. A total of 1,725 and 1,790 patients were transplanted in ERA-1 and ERA-2, respectively, with 324 and 205 cases of post-LT graft losses reported. As for the post-LT death, 329 and 182 cases were reported, respectively. A total of 414 cases (319 LT, 88 dropouts) initially enlisted in ERA-1 were transplanted or dropped out during the ERA-2 period. However, only the limited number of 18/4,238 (0.4%) with MELD ≥ 30 presented a potential allocative benefit passing from an era without macroarea allocation to another one with this opportunity.

Socio-demographic and clinical characteristics of the study population are reported in **Table 1**. The median recipient age was 56 years, with 77% of male recipients. At the time of waiting list inscription, patients with MELD ≥ 30 were 327/4,238 (7.7%), and they were equally distributed between the two eras (ERA-1=155/2,013 cases [7.7%] vs. ERA-2=172/2,225 cases [7.7%]). During

1 the waiting time period, 66/4,238 (1.6%) patients initially presenting a MELD<30 overpassed the
 2 threshold of MELD 30. They were similar between the two eras (ERA-1=31/2,013 cases [1.5%] vs.
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 4 ERA-2=35/2,225 cases [1.6%]).
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 8 The median waiting time of MELD \geq 30 patients was significantly shorter in ERA-2 (4 vs. 12 days;
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 10 p<0.001), and the percentage of MELD \geq 30 was different according to the transplant volume and the
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 12 presence of single or multiple transplant centers per region, and it did not change between the two
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 14 ERAs (**Figure 1A and 1B**).
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 18 With the intent to exclude the possibility that the shorter waiting time observed in ERA 2 resulted
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 20 from a more significant number of patients dropping out more often and quicker in this ERA, we
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 22 performed a separate analysis in only transplanted cases. Also, in this case, the median waiting time
 23
 24 in the sub-group of patients with MELD \geq 30 who underwent LT was significantly shorter in ERA-2
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 26 when compared to ERA-1 (3 vs. 9 days; p<0.001).
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 32 Single transplant center per region with high volume had 4% MELD \geq 30 in ERA 2 vs. 2% in ERA-1
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 34 (P<0.001). Multiple transplant centers per region with high volume had 11% MELD \geq 30 in ERA 2
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 36 vs. 10% in ERA-1 (P=0.75), and multiple transplant centers per region with low volume had 13%
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 38 MELD \geq 30 in ERA 2 vs. 12% in ERA-1 (P=0.81).
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 43 Density functions of the propensity score of patients in ERA-1 and ERA-2 are provided in
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 45 **Supplementary Figure 1**. The overlap of propensity score was 77%, with more than 90% of
 46
 47 density functions included in the range 0.3 and 0.7 of the propensity score, confirming comparable
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 49 socio-demographic and clinical patient characteristics between two ERAs.
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52 *Liver transplantation & time on the waiting list*

53
 54 The cumulative hazard of LT within 365 days from the first day in the waiting list among patients
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 56 with MELD<30 and MELD \geq 30 in ERA-1 and -2 is provided in **Figure 2A**. Patients with
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 58 MELD \geq 30 in ERA-2 had the highest cumulative hazard for LT (3.29, 95%CI 2.35-4.23) if
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1 compared to patients with MELD \geq 30 in ERA-1 (cumulative hazard 2.64, 95%CI 1.93-3.35), and
 2 MELD<30 in ERA-2 (cumulative hazard 1.49, 95%CI 1.47-1.51) and ERA-1 (cumulative hazard
 3 1.40, 95%CI 1.39-1.41). Analogously, patients with MELD \geq 30 in ERA-2 had the lowest median
 4 time in the waiting list (4 days, 95% 3-5 days) if compared to patients with MELD \geq 30 in ERA-1
 5 (median 12, 95%CI 9-20), and MELD<30 in ERA-2 (median 87, 95%CI 77-100) and ERA-1
 6 (median 126, 95%CI 116-135) (**Figure 3**). The hazard ratio of LT of patients in ERA2 with
 7 MELD \geq 30 was 2.27 (95%CI 1.78-2.90) compared to patients with MELD \geq 30 in ERA-1 (**Table 2**).
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 9

10 *Risk factors of dropout from the waiting list*

11 Six different variables were identified as statistically significant factors of dropout from the waiting
 12 list (**Figure 4**). In detail, patient age at the time of enlisting was a hazard factor for dropout, with a
 13 1% increase in the hazard of dropping out for each one-year increase of age (hazard ratio=1.01,
 14 95%CI=1.01-1.02). HCC as main indication of LT (hazard ratio=0.57, 95%CI=0.47-0.69), SCR
 15 status (hazard ratio=0.31, 95%CI=0.25-0.39), ERA-2 (hazard ratio=0.79, 95%CI=0.67-0.94), high-
 16 volume center (hazard ratio=0.69, 95%CI=0.56-0.84), and male gender (hazard ratio=0.73,
 17 95%CI=0.57-0.93) were all protective factors for the hazard of drop-out (**Figure 4**).
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 19

20 *Overall survival and graft loss*

21 The cumulative hazard of death within 365 days from LT among patients with MELD<30 and
 22 MELD \geq 30 in ERA-1 and 2 is provided in **Figure 2B**. Patients with MELD \geq 30 in ERA-2 had a
 23 similar cumulative hazard for death (0.32, 95%CI 0.21-0.43) than patients with MELD \geq 30 in ERA-
 24 1 (cumulative hazard 0.37, 95%CI 0.26-0.49). Similarly, patients with MELD<30 in ERA-2
 25 (cumulative hazard 0.08, 95%CI 0.06-0.09) and ERA-1 (cumulative hazard 0.10, 95%CI 0.08-0.11)
 26 had similar cumulative hazards for death within 365 days from LT.
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37 In both crude and adjusted analyses, being in ERA-2 and having a MELD \geq 30 was not associated
 38 with an increased hazard of death compared to patients receiving LT in ERA-1 among those having
 39 MELD \geq 30 (**Table 2**). In both crude and adjusted analyses, being in ERA-2 and having a MELD \geq 30
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1 was not associated with an increased hazard of graft loss than patients receiving LT in ERA-1
2 among those having MELD \geq 30 (**Table 2**).
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4
5 MELD \geq 30 (HR=2.98, 95%CI=2.20-4.03) was identified as a statistically significant factor of graft
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7 loss following LT (**Figure 5**). Vice versa, age at the time of LT (HR=0.98, 95%CI=0.97-0.99), and
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9 high volume centers (HR=0.61, 95%CI=0.43-0.86) were associated with a lower probability of
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11 undergoing graft loss (**Figure 5**).
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DISCUSSION

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3 This multi-center study shows improved LT outcomes after introducing a prioritization scheme for
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5 candidates with MELD \geq 30 in a European series.
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8 The introduction of the MELD score as a criterion for the prioritization of LT candidates was
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10 associated with an improvement of their intention-to-treat survival^{1,2}. Subsequently, implementing
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12 national sharing models aimed at favoring high-MELD patients has represented a further step to
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14 improve outcomes in sickest patients^{3,4}.
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17 Different priority cut-offs have been applied worldwide^{11,23}. The MELD \geq 30 cut-off has been
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19 chosen in Italy. Our study results show that the new allocation policy was associated with a
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21 reduction of the median waiting time of these patients, also showing a global protective effect on
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23 the risk of dropout.
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27 In this European study, differently from other U.S. series^{3,12,24}, the MELD \geq 30 sharing scheme
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29 introduction did not improve graft and patient survival rates of high-MELD patients after LT. In our
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31 series, MELD \geq 30 was an independent risk factor of poor graft survival.
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35 This last observation is open to multiple potential explanations. For example, the ECD rate reported
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37 in the present series was high (approximately 40% of the cases), and it was related in most cases to
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39 advanced donor age. Typically, optimal grafts are allocated to a high-MELD patient, whereas ECD
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41 to low-MELD cases (i.e., HCC patients)²⁵. This strategy might not be applicable, at least
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43 consistently, in the Italian setting, where roughly 40% of donors are ECD. These results are in
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45 keeping with the results from studies reporting improved outcomes in high-MELD patients after
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47 introducing the MELD sharing schemes due to improved donor-recipient matching, in which use of
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49 ECD donors in recipients with severe liver failure was minimized^{7,12}.
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53 MELD \geq 30 patients received grafts from significantly younger donors in our series compared to the
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55 MELD $<$ 30, but the median donor age was still high (approximately 60 vs. 55 years in MELD $<$ 30
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57 vs. \geq 30). The impossibility of obtaining a better donor-recipient allocation process due to the great
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1 number of ECD observed on the national territory may explain the lack of an evident outcome
2 improvement in MELD \geq 30 patients, despite faster allocation.
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4 Another factor with a possible detrimental effect on graft survival is the high rate of HCV-positive
5 patients among LT candidates²⁶, in a country like Italy, in which HCV has been endemic for a long
6 time. Longer follow-up will probably be needed to appreciate the statistical effect of the
7 introduction of new antivirals. Undoubtedly, the improvement achieved in HCV treatment may
8 have accounted for part of the positive effect observed for ERA-2.
9

10 It should be highlighted that the observed 5-year patient survival rates observed in patients with
11 MELD \geq 30 are well above the proposed futile threshold of 50%^{5,15}, showing similarities with the
12 results of a recent series of LTs performed for acute-on-chronic liver failure²⁷.
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14 Similarly, the equity principle^{16,28,29} was maintained because recipients with MELD $<$ 30, including
15 those with HCC, improved their overall outcomes, showing similarities with previous experiences
16 using a MELD-35 sharing scheme¹⁵.
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18 As for the other risk factors for dropout observed in our study, we noted that HCC as the main
19 indication for transplantation was associated with a lower risk of dropout. HCC patients represented
20 more than 40% of the entire investigated population. The high percentage of HCC cases justifies the
21 different MELD \geq 30 rates on the waiting list observed in our study compared to the US series (10-
22 15% vs. 30%)^{8,11}. The protective effect of HCC for the risk of the dropout was probably due to
23 different factors, like specific peculiarities of the regional allocation systems and a propensity of the
24 Italian centers to allocate grafts from ECD to this category of patients^{15,25}. The strategy to favor
25 equity among HCC and non-HCC is still debated,³⁰ and it was not the aim of our study. We can
26 only report that in the HCC patients, representing more than 40% of the entire investigated
27 population, no disadvantage in terms of dropout risk was observed after introducing the MELD \geq 30
28 scheme.
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30 Other variables connected with a lower risk of dropout were the waiting list inscription in a high-
31 volume center and the absence of a regional competition.
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1 The positive effect of the center volume was expected, having been already demonstrated in
2 previous studies^{31,32}. The presence of a single center able to perform a high number of LTs seems to
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4 be the ideal condition for minimizing the risk of death or the deterioration of the LT candidate
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6 clinical conditions in the waiting list.
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9 The role of the regional competition is more complex to explain. In this scenario, we can argue that
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11 patient selection before wait listing may play a role. Indeed, centers competing in the same region
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13 may have an attitude to select more severe cases to implement their activity, whereas the same
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15 pressure is likely not an issue for mono-regional centers. Accordingly, we observed a significantly
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17 higher rate of MELD \geq 30 in centers with a regional competition. It has been observed that
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19 competition among transplant centers favors the attitude to "push the limits" and reduce risk
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21 avoidance policy⁹, and the introduction of the national share for MELD \geq 30 allocation policy may
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23 further favor this trend.
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29 Interestingly, the national share MELD \geq 30 allocation policy seemed to favor the waiting list
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31 inscription of the sickest patients in centers without regional competition. An increased rate of more
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33 severe patients on the waiting list was reported in these centers in the second era.
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37 However, as confirmed in our series, the tendency to transplant more clinically advanced cases
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39 should be carefully analyzed, taking into account the worse results observed in these patients after
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41 transplantation. A balancing between costs and benefits in transplanting severely sick patients
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43 should be considered⁸.
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47 Our study clearly shows how difficult it is to maintain a balance among risk avoidance, prevalence
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49 of high MELD patients, dropout rate, and satisfactory postoperative outcomes. Furthermore, our
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51 analysis confirms the importance of continuous monitoring of any MELD-based prioritization
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53 scheme. Policymakers should weigh the benefit of shortening waiting list time in sickest patients
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55 against the decreased graft survival observed in this subset.
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59 This study presents some limitations. This study did not include all the transplant centers of Italy
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61 due to the difficulty to meet the approval and to recruit all the data, even if the study was discussed
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1 during the annual Italian meeting of the S.I.T.O. (Italian Organ Transplantation Society) and the
2 total number of cases represent half of the transplant series in Italy. Furthermore, our analyses did
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4 not account for improvements in medical practices from ERA-1 to ERA-2 that may have accounted
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6 for the clinical and therapeutic improvements observed in the transplant centers during this latter
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8 ERA. We explored if the shorter waiting time observed in the ERA-2 patients should be artificially
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10 caused by the shorter follow-up observed in these patients. However, only 62/4,238 (1.5%) ERA-2
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12 cases were still on the waiting list at the time of the study enrolment interruption (i.e., July 2018),
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14 and only 24 (0.6%) of them were enlisted within the year 2018. So, we can say that 4,214 (99.4%)
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16 of the cases enrolled in our study were followed up for at least one year from the time of their
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18 enlisting. Consequently, we considered minimal the impact on our results of the shorter waiting
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20 time in ERA-2 patients. Another unexplored aspect of the study is the unexplored impact of the
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22 direct-acting antivirals in the present series. Given the consideration that HCV represents a common
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24 indication for LT in Italy, unfortunately, the study's retrospective nature impaired us to investigate
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26 this important aspect in the present analysis. We did not adjust the models present in our analyses
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28 using exception MELD points but using only the laboratory MELD values. Such a decision should
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30 impact the results, mainly considering a large number of HCC patients present in our analysis.
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32 However, considering that the study explored the impact of the MELD-30 rule, the MELD
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34 progression in all the exception-point cases was stopped when a value of MELD 29 was reached,¹⁵
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36 therefore not impacting the obtained results. Only Exception P1 patients (i.e., Rendu-Osler-Weber
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38 disease, young adult hepatoblastoma, Kasabach-Merritt disease, and retransplant >10 days but ≤30
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40 days from the first transplant) were able to reach the macroarea allocation no matter on their MELD
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42 value. Only 34 “late” reLT were enrolled in this series, thus minimally impacting the observed
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44 results.
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55 Another limit is that all the patients initially showing a MELD value <30 and showing a MELD
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57 worsening during the waiting time remained categorized in the MELD <30 group. Such a decision
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59 derived from the necessity to maintain the study's initial intention-to-treat design and avoid placing
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1 a “mobile” starting time point for calculating the waiting time. Understanding the potential bias of
2 such a decision, we considered it the best way to capture a complex dynamic process in which the
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4 waiting-list patients present continuous oscillations of their MELD score. As a partial limitation of
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6 the potential bias, the cases involved in this process only represented 1.6% of the entire population.
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9 We should also report that we used two different propensity scores for adjusting our analyses. In
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11 detail, the propensity score computed at the time of entrance in the waiting list was used for
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13 adjusting the models with the outcomes LT, dropout from the waiting list, and death. For graft loss,
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15 we used the propensity score computed at the time of LT. With the intent to observe if a significant
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17 effect derived from this methodological decision, we performed a sub-analysis in which we used the
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19 propensity score measured at the time of waiting list inscription for adjusting the model for graft
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21 loss. As reported in **Supplementary Table 2**, no relevant differences were observable using the
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23 adjustment of the two different propensity scores, therefore showing a minimal impact on the
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25 reported results. However, it should be highlighted that due to the observational nature of this
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27 study, we will never be able to claim the complete absence of residual confounding.
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32 Lastly, as for the causes of dropout, in a small percentage of cases (i.e., 62/658 cases), they were
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34 composed of patients showing improved clinical conditions (i.e., HCC complete response or MELD
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36 decline), poor compliance, or the decision to move to other LT centers. The retrospective nature of
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38 the study limited our capacity to clarify these patients further. However, considering their small
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40 number, we decided to consider them as “dropouts” in the competing risk models due to their only
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42 marginal impact on the observed results.
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49 In conclusion, after adopting the Italian national MELD \geq 30 priority allocation, we observed more
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51 LT for patients with MELD \geq 30, a shortening of their time on the waiting list, and improved graft
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53 survival. Transplant centers volume and competition between different centers in the same region
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55 may impact on recipient prioritization and outcome and should be considered in future studies on
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57 the subject.
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ABBREVIATIONS

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LT Liver Transplantation

MELD Model for End-stage Liver Disease

HCC Hepatocellular Carcinoma

ECD Extended Criteria Donors

SCR Single Centre per Region

MCR Multiple Centres per Region

HV High-Volume

LV Low-Volume

HCV hepatitis C virus

HBcAb hepatitis B core antibody

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Table 1. Recipient- and donor-related characteristics in the two ERAS. Level of significance: $p < 0.05$ (ANOVA test, Student T-test, and Fisher's exact test).

Variables	Data at waiting list		P
	ERA-1 (n=2,013)	ERA-2 (n=2,225)	
	Median (IQR) or N (%)		
Age (years)	56 (51-62)	55 (49-61)	<0.001
Male gender	1,544 (76.7)	1,673 (75.2)	0.27
Height (cm)	170 (165-176)	170 (165-176)	0.25
Weight (kg)	74 (65-83)	73 (65-80)	<0.001
Blood group (AB-B)	369 (18.3)	392 (17.6)	0.55
HCC	954 (47.4)	871 (39.1)	<0.001
HCV positivity	790 (39.2)	973 (43.7)	0.003
MELD	13 (8-18)	14 (10-20)	<0.001
High-volume center	1,729 (85.9)	1,968 (88.4)	0.01
Regional competitive status	1,069 (53.1)	1,292 (58.1)	0.001
Variables	Data at transplant		P
	ERA-1 (n=1,725)	ERA-2 (n=1,790)	
Recipient age	56 (50.61)	55 (49-61)	<0.001
Recipient male gender	1,341 (77.7)	1,361 (76.0)	0.25
Recipient height (cm)	170 (165-176)	170 (165-176)	0.59
Recipient weight (kg)	74 (65-83)	73 (65-80)	0.001
Recipient HCC	844 (48.9)	762 (42.6)	<0.001
Recipient HCV positivity	677 (39.2)	783 (43.7)	0.007

MELD	13 (9-20)	15 (10-21)	0.001
High-volume center	1,503 (87.1)	1,617 (90.3)	0.02
Regional competitive status	807 (46.8)	893 (49.9)	0.07
Donor age	65 (51-76)	63 (49-74)	0.001
Donor male gender	948 (55.0)	958 (53.5)	0.40
Donor height (cm)	170 (162-175)	170 (162-175)	0.60
Donor weight (kg)	73 (65-80)	73 (65-80)	0.93
Donor HCV positivity	28 (1.6)	32 (1.8)	0.80
Donor HBcAb positivity	317 (18.4)	356 (19.9)	0.27

Abbreviations: n, number; IQR, interquartile ranges; HCC, hepatocellular carcinoma; HCV, hepatitis C virus; MELD, Model for End-stage Liver Disease; HBcAb=hepatitis B core antibody.

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Table 2. Hazard ratio estimates from head-to-head comparisons. Level of significance: $p < 0.05$ (cause-specific Cox proportional hazard analysis).

Outcome	Group	Hazard ratio (95% Confidence Interval)	Reference group	Type
LT	ERA 2 - MELD \geq 30	2.27 (1.78-2.90)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD $<$ 30	0.36 (0.30-0.44)	ERA 1 - MELD \geq 30	Adjusted
	ERA 1 - MELD $<$ 30	0.29 (0.24-0.35)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD \geq 30	2.07 (1.62-2.63)	ERA 1 - MELD \geq 30	Crude
	ERA 2 - MELD $<$ 30	0.42 (0.35-0.51)	ERA 1 - MELD \geq 30	Crude
	ERA 1 - MELD $<$ 30	0.36 (0.29-0.43)	ERA 1 - MELD \geq 30	Crude
All-cause mortality	ERA 2 - MELD \geq 30	0.86 (0.54-1.36)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD $<$ 30	0.31 (0.21-0.46)	ERA 1 - MELD \geq 30	Adjusted
	ERA 1 - MELD $<$ 30	0.34 (0.23-0.49)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD \geq 30	0.89 (0.57-1.41)	ERA 1 - MELD \geq 30	Crude
	ERA 2 - MELD $<$ 30	0.24 (0.17-0.35)	ERA 1 - MELD \geq 30	Crude
	ERA 1 - MELD $<$ 30	0.27 (0.18-0.38)	ERA 1 - MELD \geq 30	Crude
Graft loss	ERA 2 - MELD \geq 30	0.83 (0.53-1.31)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD $<$ 30	0.34 (0.23-0.49)	ERA 1 - MELD \geq 30	Adjusted
	ERA 1 - MELD $<$ 30	0.37 (0.25-0.53)	ERA 1 - MELD \geq 30	Adjusted
	ERA 2 - MELD \geq 30	0.84 (0.53-1.32)	ERA 1 - MELD \geq 30	Crude
	ERA 2 - MELD $<$ 30	0.28 (0.19-0.40)	ERA 1 - MELD \geq 30	Crude
	ERA 1 - MELD $<$ 30	0.30 (0.21-0.43)	ERA 1 - MELD \geq 30	Crude

FIGURE LEGENDS

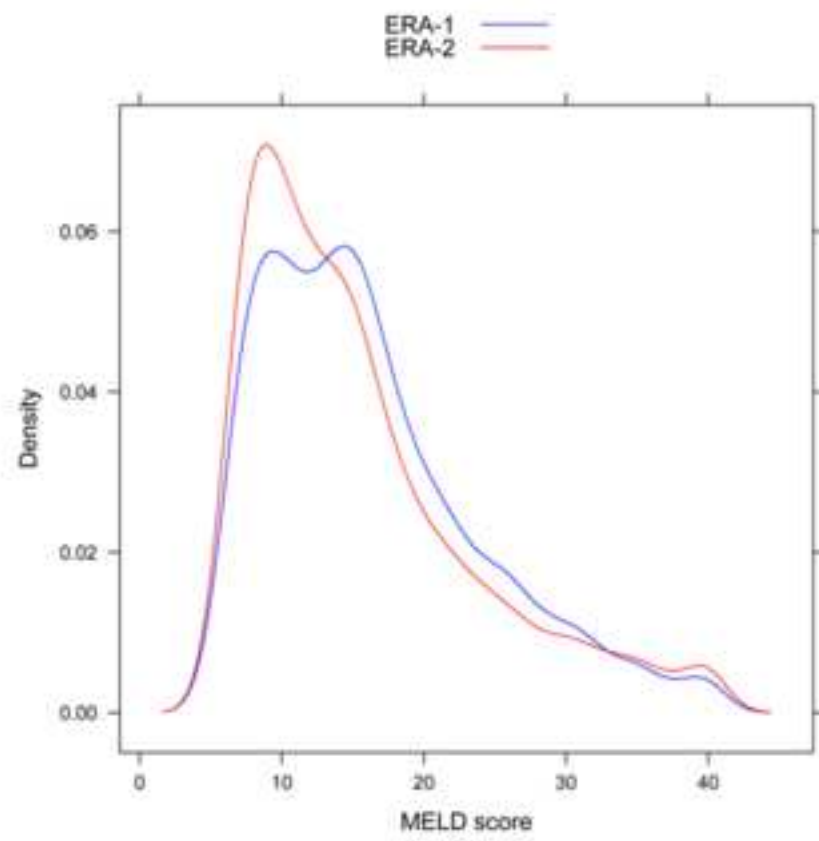
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5 **Figure 1.** Density functions of the MELD-score. (A) Patients in the list for LT between the two
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7 ERAs. (B) Patients in the list for LT between the two ERAs and divided according to the center
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9 volume and centers in the same region. Level of significance: overlap of the curves >75% (Kernel
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11 density estimates of the propensity scores). Abbreviations: V70, high-volume; MCR, multiple
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13 centers in the same region; SCR, single center in the region; V, low-volume. MELD scores were
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15 calculated according to the laboratory values, without considering the exception additive points.
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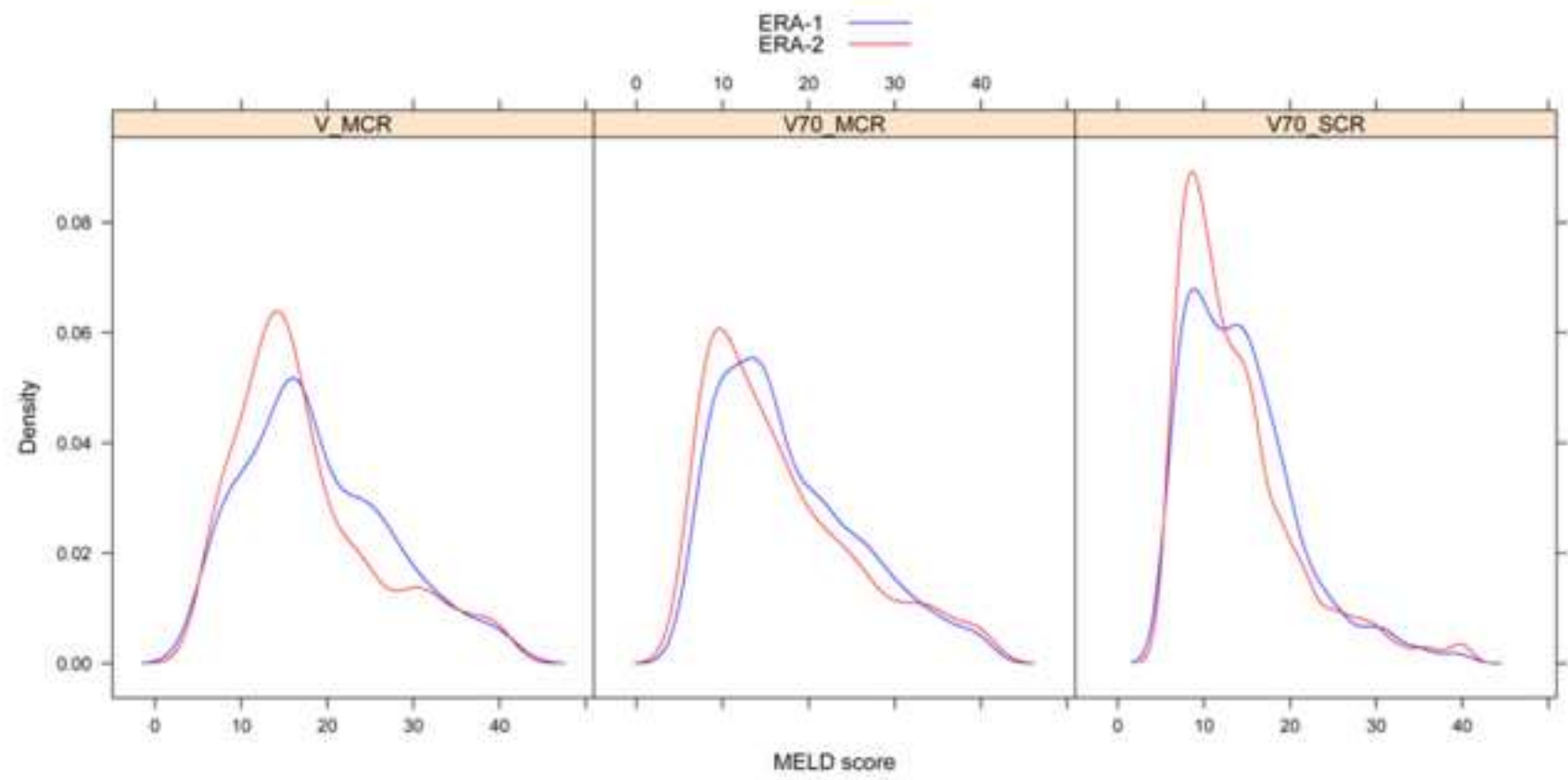
21
22 **Figure 2.** Level of significance: overlap of the curves >75% (Kernel density estimates of the
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24 propensity scores). Abbreviations: V70, high-volume; MCR, multiple centers in the same region;
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26 SCR, single center in the region; V, low-volume. MELD scores were calculated according to the
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28 laboratory values, without considering the exception additive points.
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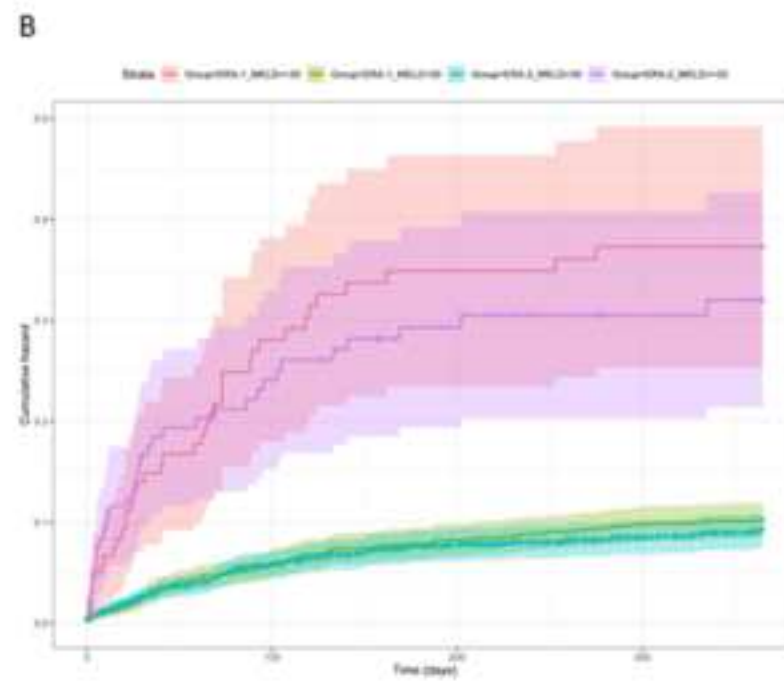
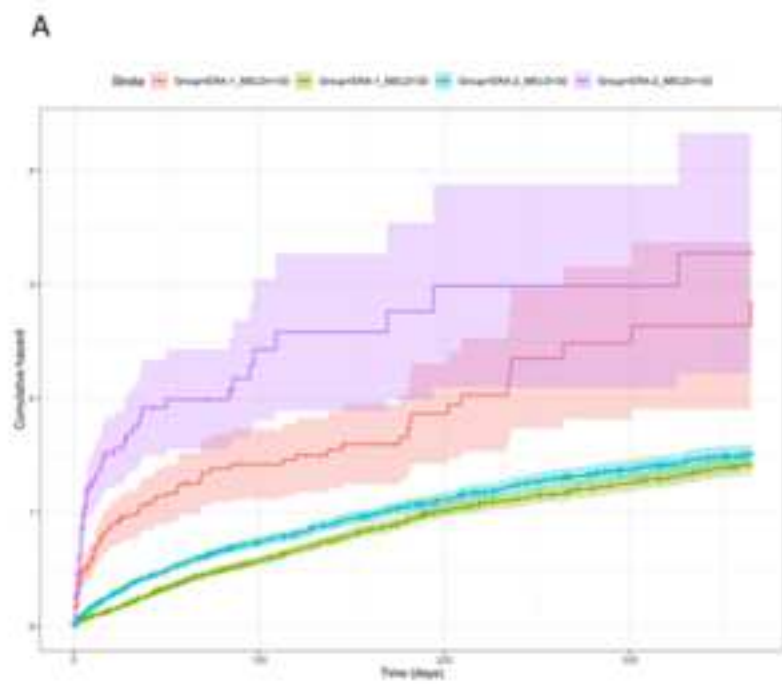
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34 **Figure 3.** Boxplot of the waiting time in the list for liver transplantation. Box plots represent the
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36 25%-75% values; dashed lines are the largest or the smallest values within 1.5 times the
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38 interquartile ranges above the 75% or beyond the 25% percentiles; black circles are the median
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40 waiting times; the blue circles are the outside values. Levels of significance: $p < 0.05$ (Mann-
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42 Whitney U-test).
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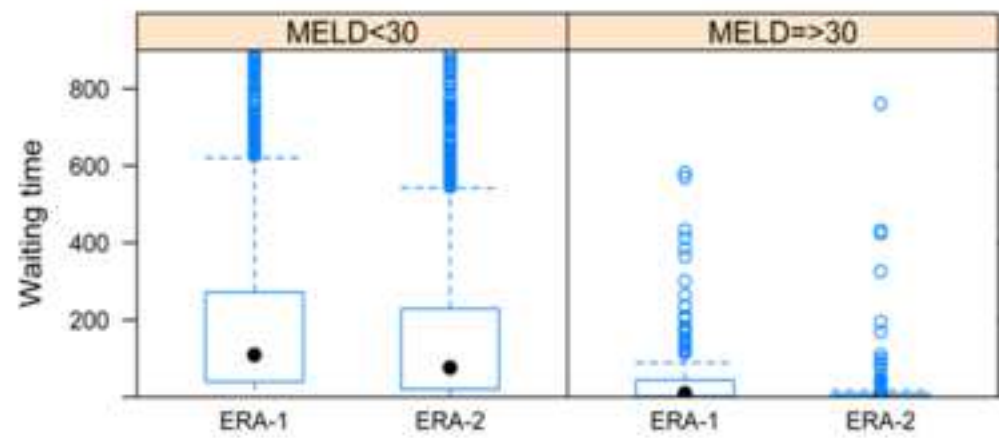
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49 **Figure 4.** Risk factors of dropout from the waiting list. Level of significance: $p < 0.05$ (Cause-
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51 specific Cox proportional hazard model).
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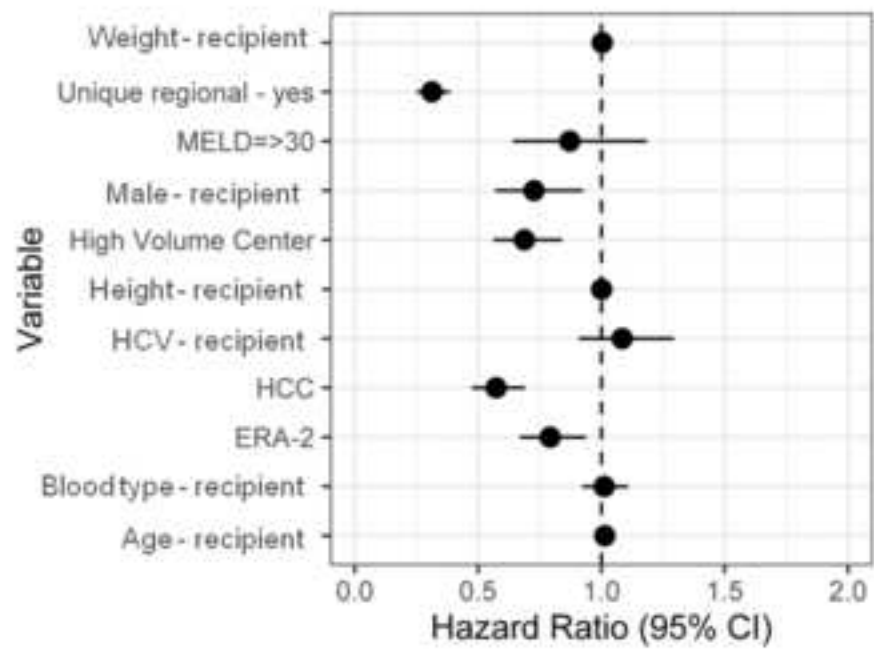
56 **Figure 5.** Risk factors of graft-loss. Level of significance: $p < 0.05$ (Fine-Gray test).
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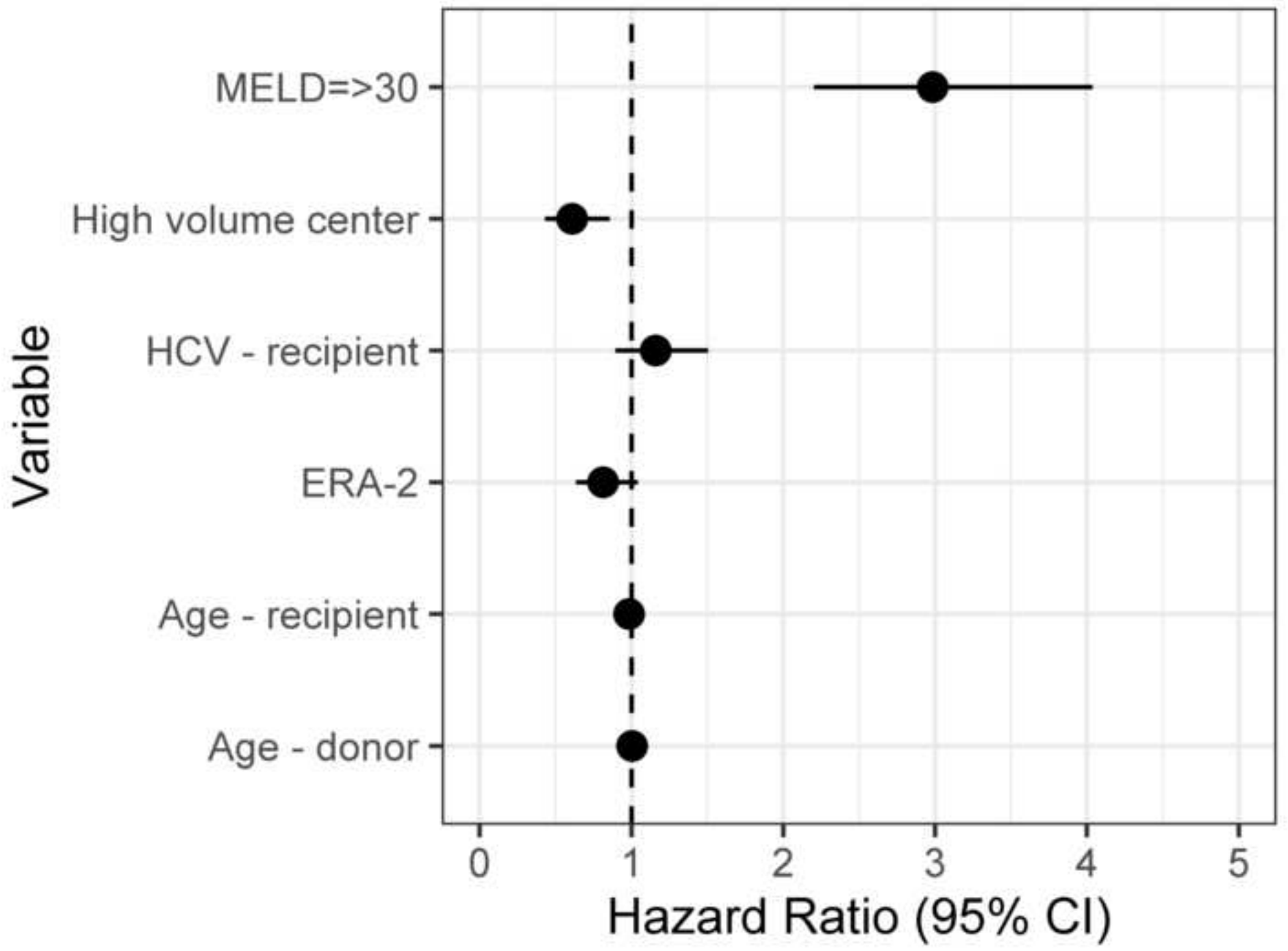


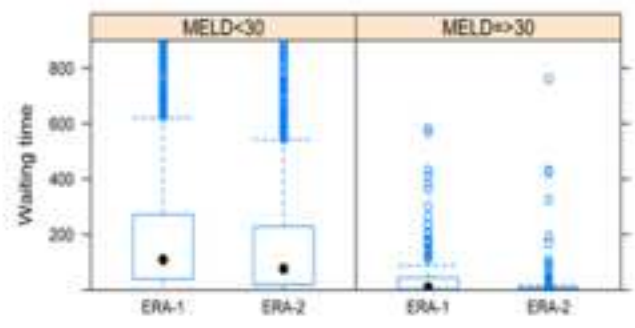




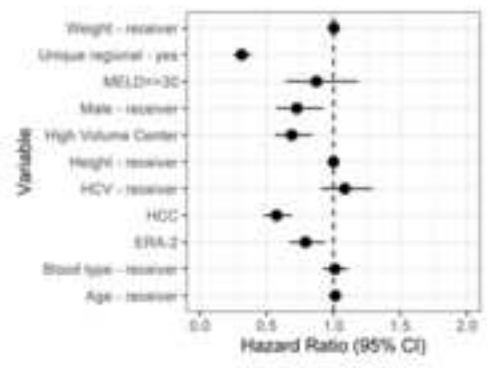




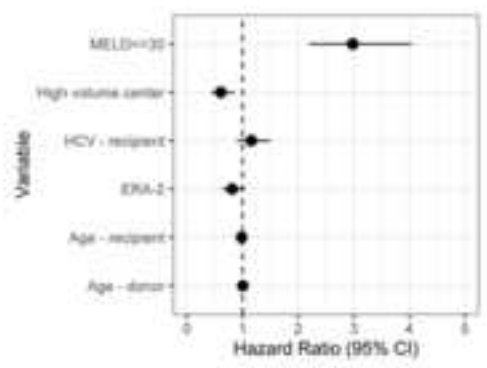




Boxplot of the waiting time in list for liver transplantation



Risk factor of dropout from the waiting list.



Risk factor of graft-loss.

HIGHLIGHTS:

- Priority allocation for MELD ≥ 30 candidates for liver transplantation
- Donor age, MELD ≥ 30 and ERA-1 were independent predictors of worst graft survival
- MELD ≥ 30 patients had lower median waiting time in the list in the ERA-2
- Low-volume and multiple regional transplant centres were independent predictors of higher dropout rate