Clin Transplant 2012: 26: E269–E276 DOI: 10.1111/j.1399-0012.2012.01658.x

Clinical Transplantation

Liver transplant center risk tolerance

Johnson SR, Karp SJ, Curry MP, Barugel M, Rodrigue JR, Mandelbrot DA, Rogers CP, Hanto DW. Liver transplant center risk tolerance.

Abstract: Recent changes in Center for Medicare & Medicaid Services (CMS) condition for participation, using benchmark volume/outcomes requirements for certification, have been implemented. Consequently, the ability of a transplant center to assess its risk tolerance is important in successful management. An analysis of SRTR data was performed to determine donor/recipient risk factors for graft loss or patient death in the first year. Each transplant performed was then assigned a prospective relative risk (RR) of failure. Using a Monte-Carlo simulation, transplants were selected at random that met the centers' acceptable risk tolerance. Transplant center volume was fixed and its risk tolerance was adjusted to determine the impact on outcomes. The model was run 1000 times on centers with varying volume. The modeling demonstrates that centers with smaller annual volumes must use a more risk taking strategy than larger volume centers to avoid being flagged for CMS volume requirements. The modeling also demonstrates optimal risk taking strategies for centers based upon volume to minimize the probability of being flagged for not meeting volume or outcomes benchmarks. Small volume centers must perform higher risk transplants to meet current CMS requirements and are at risk for adverse action secondary to chance alone.

Scott R. Johnson[a], Seth J. Karp[b], Michael P. Curry[a], Martin Barugel[c], James R. Rodrigue[a], Didier A. Mandelbrot[a], Christin P. Rogers[a] and Douglas W. Hanto[a]

[a]The Transplant Center, Beth Israel Deaconess Medical Center (BIDMC), Harvard Medical School, Boston, MA, [b]Vanderbilt Transplant Center, Vanderbilt University, Memphis, TN, and [c]Minimax Consulting, LLC, Providence, RI, USA

Key words: liver transplant – outcomes – risk tolerance

Abbreviations: ANOVA, analysis of variance; CIT, cold ischemia time; CMS, Center for Medicare and Medicaid Services; CVA, cerebrovascular accident; DCD, donor after cardiac death; DRI, Donor Risk Index; ECD, extended criteria donor; MELD, model for end-stage liver disease; RR, relative risk; SEM, standard error of the mean

Corresponding author: Scott R. Johnson, MD, The Transplant Center, Beth Israel Deaconess Medical Center (BIDMC), Harvard Medical School, 110 Francis St LMOB7, Boston, MA 02215, USA.
Tel.: 1 617 632 9824; fax: 1 617 632 9820; e-mail: srjohnso@bidmc.harvard.edu

Conflict of interest: None.

Accepted for publication 12 March 2012

Risk factors for patient death or graft loss after liver transplant have been prominently featured in peer-reviewed literature (1, 2). The data from these publications have clearly identified a number of donor and recipient variables that predict failure following liver transplant (1, 3, 4). While the ability to discuss risk with potential recipients is important, the ability to assess a transplant center's risk tolerance is also fundamentally important to the management of a successful center. While the use of extended criteria organs may increase a center's transplant volume, (5, 6) this practice is associated with higher costs and worse patient and graft survival (7). The latter being metrics upon which an individual center's quality is judged.

As a condition of participation in Center for Medicare/Medicaid Services (CMS), transplant centers are required to maintain outcomes that are not statistically lower than risk-adjusted benchmarks. Failure to meet this benchmark can lead to termination of the transplant center's certification (8). Similar criteria have been established as conditions of participation for most third-party payers. CMS and insurance providers have also established minimum annual volume requirements as an additional requirement for participation. Inability of a center to meet these requirements can also lead to termination of a center's contract with CMS or third-party payers.

Successful management of a transplant center will require careful balancing of risk-taking strategies in donor/recipient selection vs. an overly risk-averse strategy that may lead to insufficient annual volume. A transplant center's risk tolerance will be

dependent upon a number of factors including donor and recipient selection, organ availability, center effect, referral volume and chance. Centers performing a large percentage of liver transplants with a high rate of failure may experience poor outcomes, whereas centers with low volumes and risk-averse strategies may see insufficient volume to meet established benchmarks for volume requirements. Both strategies can lead to loss of CMS certification or insurance contracts. Using SRTR data, we intend to explore optimal risk tolerance based upon transplant center volume.

Materials and methods

To study the risk tolerance of transplant centers, we used the SRTR/UNOS liver and donor datasets. Institutional IRB approval was obtained from Beth Israel Deaconess Medical Center. Subjects chosen for inclusion in the study were selected from among all adult, first liver transplant recipients from the inception of model for end-stage liver disease (MELD) allocation, February 27, 2002, until November 1, 2007. Subjects were excluded from analysis for the following: age <18 yr, split liver or live donor transplant and missing or absent data on patient or graft status at one yr. Transplant failure was considered patient death or graft loss within 365 d of the initial transplant date.

A univariate analysis was performed to determine risk factors for inclusion in the multivariate model. Categorical variables were compared using chi-square and continuous data were compared using Student's *t*-test or ANOVA. Missing data were imputed with the mean for the series. Center volume over the period of the study was stratified by quartiles. A backward stepwise multivariate logistic regression model was constructed using transplant failure (i.e., graft loss or patient death) as the dependent variable with removal criteria set at $p = 0.15$. In the regression model, the following continuous variables were categorized: donor age (18–45, 46–60, and >60 yr), recipient age (<50, 51–60, and >60 yr), cold ischemia time (CIT) (0–6, 7–12, and >12 h), and MELD score (<15, 15–25, and >25). A $p \leq 0.05$ was considered significant. Data are presented as mean ± standard error of the mean (SEM). All statistics were computed using SPSS 17.0 (Chicago, IL, USA).

To estimate the probability that a given center will fail, a Monte Carlo simulation was used. Each transplant was assigned a relative risk (RR) of failure, which was based on the logistic regression. Let n be the number of potential transplants a center expects to perform within a year. We drew n individuals at random (with replacement) from the sample, which constitutes a possible set of potential transplants a center may perform. We "rejected" those that had a RR higher than the maximum tolerable limit by the center. Next, based on the actual information on whether those transplants failed or not, we computed the proportion of failed transplants. With this information, we were able to tell whether, with this particular set of potential transplants, the center will fail or not. For purposes of this analysis, we set the following benchmarks for failure; transplant volume <10/yr or one-yr patient/graft survival <80%. The process was repeated 1000 times and recorded the number of instances in which the center failed (defined as C). Therefore, the estimated probability of the center failing would be $C/1000$.

Results

A total of 30 017 transplants were available for the analysis and 4826 (16.1%) of grafts met the definition of failure within the first post-transplant year. Recipient and donor characteristics of the failed and non-failed groups are noted in Table 1. Failed transplants had older donors and recipients with higher MELD scores. Donors after cardiac death (DCD), those meeting kidney extended criteria donor (ECD) criteria, cerebrovascular accident (CVA) as cause of death and shared regionally were more likely to have failed. Recipients requiring mechanical ventilation, hemodialysis, inotropic or life support and those with prior renal or liver transplant, abdominal surgery or portal venous thrombosis were more likely to have failed.

Mean transplant center volume was 254.9 ± 21.8 (range 1–1170) transplants, during the period of the study. Dividing the centers into quartiles based on volume over the period of the study yielded groups with the following volumes; very low 0–80, low 81–195, moderate 196–382, and high volume >382. Mean Donor Risk Index (DRI) for the entire cohort was 1.77 ± 0.002. Mean DRI for the very low-, low-, moderate-, and high-volume centers are 1.74 ± 0.014, 1.69 ± 0.005, 1.73 ± 0.004, and 1.81 ± 0.003, respectively ($p = 0.0001$). Post hoc analysis demonstrates no significant difference between the very low- and moderate-volume groups ($p = 0.980$). The very low- vs. low-volume groups were significantly different ($p = 0.011$) and the high-volume centers used donors with higher DRI than all the other groups ($p = 0.0001$). The difference in RR of graft loss/failure by center volume was a modest 7% between high-volume centers and very low- or moderate-volume centers and 12% between high- and low-volume centers.

Table 1. Univariate analysis

Variable	Overall	Failed	Non-failed	p
N	30 017	4826 (16.1%)	25 191 (83.9%)	
DCD	1163 (3.87%)	263 (5.44%)	900 (3.57%)	<0.0001
Donor COD				
CVA	13 184 (43.9%)	2459 (50.1%)	10 725 (42.6%)	
Trauma	12 127 (40.4%)	1668 (34.6%)	10 459 (41.5%)	
Anoxia	3914 (13.0%)	556 (11.5%)	3358 (13.3%)	
CNS tumor	236 (1.8%)	43 (0.9%)	193 (0.8%)	
Other	552 (0.8%)	96 (2.0%)	456 (1.8%)	<0.0001
Rec gender (male)	20 387 (67.9%)	3192 (66.1%)	17 195 (68.25%)	0.002
Donor gender (male)	17 892 (59.6%)	2737 (56.7%)	15 155 (60.1%)	<0.0001
Donor creat > 1.5	6777 (22.6%)	1137 (23.6%)	5640 (22.4%)	0.071
Meet ECD	7678 (25.6%)	1583 (32.8%)	6095 (24.2%)	<0.0001
Shared LTX	8689 (28.9%)	1663 (34.5%)	7026 (27.9%)	<0.0001
Inotropic support	17 514 (58.3%)	2833 (58.7%)	14 681 (59.5%)	0.357
On ventilator	657 (2.2%)	215 (4.5%)	442 (1.8%)	<0.0001
Dialysis	2510 (8.4%)	618 (12.8%)	1892 (7.5%)	<0.0001
Rec life support	2046 (6.8%)	693 (14.3%)	1353 (5.4%)	<0.0001
Prev KTX	240 (0.80%)	75 (1.56%)	165 (0.65%)	<0.0001
Prev LTX	2522 (8.4%)	784 (16.2%)	1738 (6.9%)	<0.0001
Prev abdominal surg	11 214 (37.4%)	2175 (45.1%)	9039 (35.9%)	<0.0001
PVT	1207 (4.0%)	283 (5.9%)	924 (3.7%)	<0.0001
Donor age	44.07 ± 0.26	40.46 ± 0.11		0.0001
Recipient age	52.62 ± 0.15	52.08 ± 0.06		0.001
Rec t.bili (mg/dL)	9.99 ± 0.18	7.92 ± 0.07		0.0001
Rec INR	2.04 ± 0.04	1.86 ± 0.01		0.0001
Rec creat (mg/dL)	1.81 ± 0.02	1.55 ± 0.01		0.0001
Rec albumin	2.83 ± 0.01	2.92 ± 0.004		0.0001
CIT (h)	8.00 ± 0.06	7.50 ± 0.02		0.0001
Donor final creat	1.33 ± 0.04	1.40 ± 0.04		0.523
Donor peak creat	1.47 ± 0.04	1.62 ± 0.04		0.240

CIT, cold ischemia time; CVA, cerebrovascular accident; DCD, donor after cardiac death; ECD, extended criteria donor.

In the multivariate logistic regression (Table 2), variables found to be predictive of failure within the first post-transplant year included donor and recipient age. Using donor age >60 as the reference group, donor age lower than 18 reduced likelihood of failure by 40%. Similarly, recipient age <50 reduced likelihood of failure vs. the reference group by 27% and age 50–60 by 19%. The most profound predictors of failure in the first post-transplant year were the use of DCD organs and recipients on life support, which more than doubled the risk of failure. MELD score <15 and MELD score 15–25 as well as CIT 0–6 h and 6–12 h demonstrated improved outcomes for our primary endpoint vs. the reference groups, MELD >25 and CIT >12 h, respectively. C-statistic for the model was 0.648.

Monte Carlo simulation

To obtain the most stringent modeling, we elected to include only those transplants performed that contained complete data for the variables found to be significant predictors in the multivariate model. Table 3 provides clinical examples of donor/recipient combinations and their RR of failure as determined by our model. Fig. 1A demonstrates the simulation results for a center performing 40 liver transplants annually. The graphs represent the probability of the center failing secondary to low volume, poor outcomes (high rate of graft loss or patient death), and the cumulative (probability of failure by low volume or poor outcomes) rate of failure. The graph demonstrates several important findings. First, an optimal risk strategy that minimizes the risk of transplant center failure (i.e., RR of 1.6 for the donor/recipient combination) can be identified from the inflection point (noted on Fig. 1A) on the cumulative failure rate graph. This point represents the RR of donor/recipient variables predicting transplant failure that produces the least likelihood of transplant center failure by combined poor outcomes and low volume. This center (volume = 40) should consistently perform transplants with RR >1.6 to minimize the likelihood of low-volume problems. Second, despite optimizing risk management, based on our modeling, this center carries a 12% risk of failure by chance alone. Note that the RR inflection point of 1.6 applies both to this center's risk of failure

Table 2. Multivariate analysis

Variable	Odds ratio of failure	p
Donor age		
<18 yr	0.713	0.043
18–45 yr	0.788	0.073
46–60 yr	0.986	0.894
>60 yr	Reference	
Recipient age		
<50 yr	0.785	0.003
50–60 yr	0.838	0.024
>60 yr	Reference	
COD		
CVA	0.888	0.689
Trauma	0.724	0.276
Anoxia	0.687	0.220
CNS tumor	Reference	
DCD donor	2.189	<0.0001
Meet ECD criteria	1.249	0.035
Recipient on life support	2.491	<0.0001
Recipient on ventilator	1.527	0.046
Recipient on dialysis	1.447	0.001
Recipient prev LTx	1.921	<0.0001
Recipient prev KTx	1.794	<0.0001
MELD score		
<15	0.676	<0.0001
15–25	0.768	<0.0001
>25	Reference	
CIT		
0–6 h	0.544	<0.0001
7–12 h	0.693	<0.0001
>12 h	Reference	

CIT, cold ischemia time; CVA, cerebrovascular accident; DCD, donor after cardiac death; ECD, extended criteria donor; MELD, model for end-stage liver disease.

because of low volume and well as to the risk of failure owing to either low volume or high graft failure, but these two inflection points are not necessarily the same for other centers. Contrast this to a center with annual volume of 100 (Fig. 1B). Optimal risk strategy suggests a RR of two will minimize the risk of transplant center failure and that the likelihood of experiencing low-volume problems is virtually nil. The most dramatic results are noted in low-volume centers. In Fig. 1C, the simulation results for a center with an annual transplant volume of 15 are noted. The results demonstrate that this low-volume center requires a more risk-tolerant strategy, in which the use of RR 2.8 as optimal to minimize probability of failure. Worthy of note is the 30% probability of the center's failure by chance alone. Fig. 1D demonstrates the cumulative transplant center failure rates for centers with varying annual transplant volumes. The graph clearly demonstrates that higher volume centers can be more risk-averse without jeopardizing the program's status based on low volume. This is in sharp contradistinction to low-volume programs, which must pursue a more risk-taking approach to minimize transplant center failure based upon low volume. The modeling also demonstrates a marked increase in the probability of center failure by chance alone as annual transplant center volume diminishes.

Discussion

The objective of this study is to examine the ability of transplant centers to tolerate risk based upon expected annual volume. Over the past several years, the field of transplantation has been subjected to substantial oversight, which has come with the establishment of benchmarks as conditions for participation and/or accreditation. In most instances, the benchmarks that have been established center on patient and graft survival, but recently many of these same organizations have also established annual volume requirements. While volume requirements vary widely, most are using risk-adjusted SRTR patient and graft survival at one yr as the benchmark for outcomes. Concerns have been raised that benchmarking may stifle innovation and that the current risk-adjusted model fails to consider a number of important variables that predict adverse outcomes (9). Others note that the benefits of benchmarking include the opportunity to identify centers that need corrective action or that should be emulated (10).

In this analysis, we identified a number of donor and recipient variables that predicted death or graft loss at one yr including donor age >60 yr vs. <18 yr, DCD organ, donor meeting kidney ECD criteria, recipient on life support, ventilated or on dialysis, prolonged CIT, higher MELD score, and prior liver or kidney transplant. These findings are consistent with similar analyses previously published (4, 11, 12). These findings are also consistent with data from previously published analyses of SRTR/OPTN registries and confirm the integrity of our analysis.

Literature on volume requirements for liver transplantation has shown mixed results. In one of the earliest publications examining the role of annual liver transplant volume on outcomes, centers were divided into low (<20 transplants/yr)- and high-volume (>20 transplants/yr) centers. One-yr mortality was slightly higher in the low–volume centers vs. high-volume centers, 25.9% vs. 20%. The authors also noted that a substantial portion of low-volume centers had excessive one-yr mortalities of >40% (13). In a more recent review of this subject, Axelrod et al. found that after adjustment for donor, recipient, and transplant-related variables, low-volume centers (represented by median volume of 21 annually) had a 30%

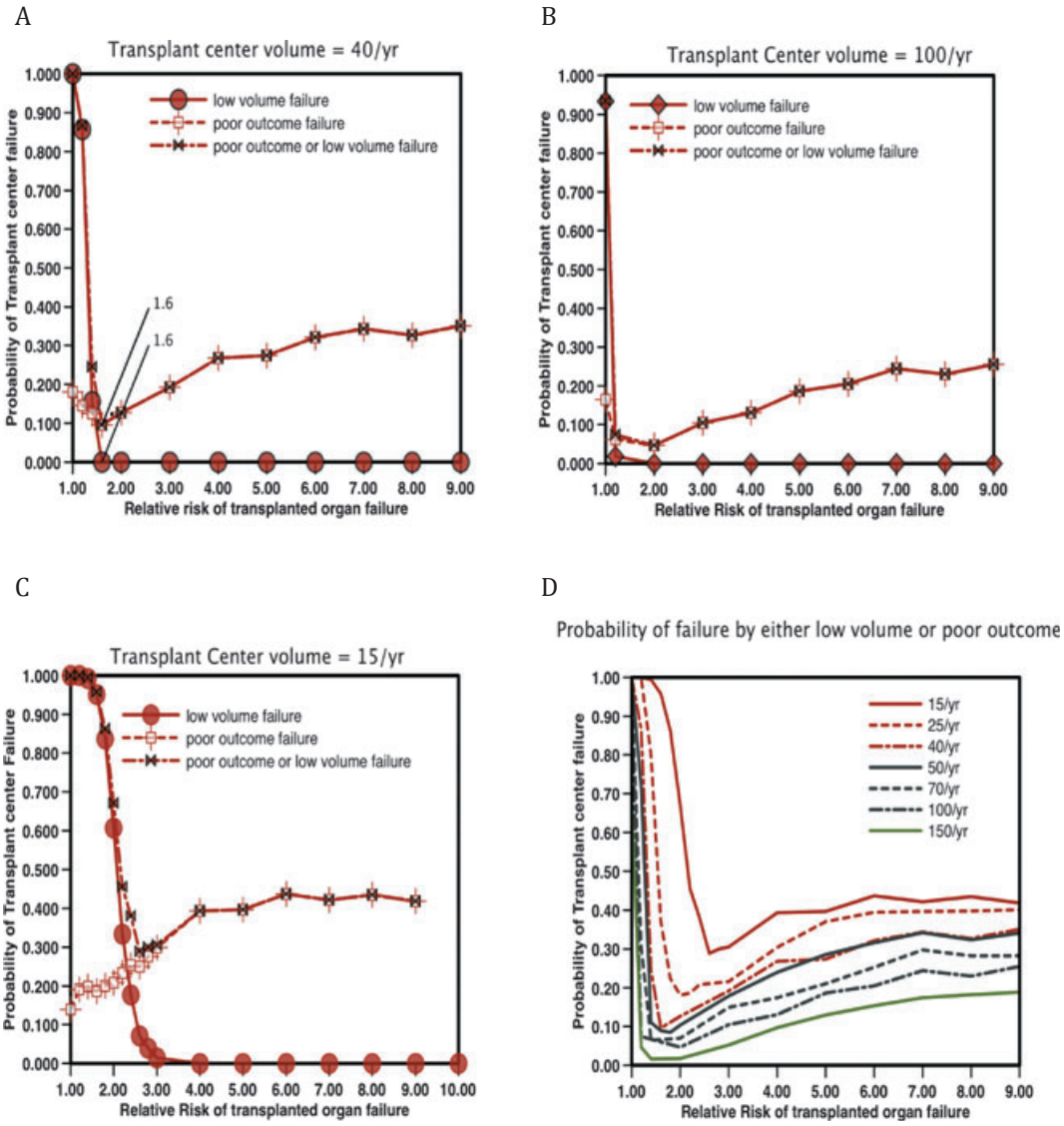

Fig. 1. (A) Modeling results from transplant center with annual volume = 40. Inflection points, labeled on the graph, demonstrate optimal risk tolerance for this center. (B) Modeling results from transplant center with annual volume = 100. Inflection points demonstrate optimal risk tolerance for this center. Note very low probability of this center being flagged for low volume. (C) Modeling results from transplant center with annual volume = 15. Inflection points demonstrate optimal risk tolerance for this center. Note that using optimal risk tolerance strategy, this center has a 30% chance of being flagged for either low volume or poor outcomes. (D) This graph demonstrates the combined risk of failure by low volume or poor outcome as center volume is varied. Note the increased risk taking required by small volume centers to minimize their risk of failure.

Table 3. Examples of transplants performed RR of failure

Transplant	Donor age	Rec Age	COD	DCD	Meet ECD	Rec Life support	Rec on vent	Rec on dialysis	Prev KTx	Prev LTx	MELD	CIT	RR
1	60	50	CVA	No	Yes	Yes	Yes	Yes	No	No	40	6	2.78
2	18	50	Trauma	No	No	No	No	No	No	No	20	6	0.169
3	40	55	Anoxia	No	No	Yes	Yes	Yes	No	Yes	38	10	4.159
4	60	60	Tumor	No	No	No	No	No	No	No	28	12	1.00
5	60	65	Tumor	Yes	Yes	No	No	No	No	Yes	28	12	5.25

CIT, cold ischemia time; CVA, cerebrovascular accident; DCD, donor after cardiac death; ECD, extended criteria donor; MELD, model for end-stage liver disease; RR, relative risk.

higher odds of graft loss or death in the first post-transplant year. The authors of this study were not able to identify a minimal threshold volume (14). In a study conducted during the MELD allocation period, using <20 transplants/yr as the definition for low volume, the authors found that in the unadjusted model the one-yr mortality was 9.5% vs. 10.5% ($p < 0.001$) in high-volume centers vs. low-volume centers, respectively. While statistically significant, the 1% difference in mortality is likely not clinically relevant. Furthermore, upon adjustment for the severity of disease, donor and recipient factors, transplant volume was not found to predict post-transplant survival (15). In a recent analysis of SRTR, risk-adjusted data, the authors examined liver transplants stratified by annual center volume from 2000 to 2007. Examining the relationship over three separate time periods, they noted high-volume centers experienced superior outcomes as compared to small volume centers for the earliest time period but no difference in outcomes in the most recent time period (16). While these publications examining outcomes for complex surgical procedures imply that center volume is important, the threshold volume, below which these complex procedures should be restricted, has been less well defined and those required by regulatory agencies and insurance providers as a condition of participation seem arbitrary at best.

Current volume requirements for CMS are 10 transplants/yr, whereas requirements for Aetna, Blue Cross, and Optum Health Care are 40 transplants/yr, 60 transplants/2 yr and >25 transplants/yr and 35 transplants/yr, respectively (17–20). Our concern was that to meet volume requirements, transplant centers would alter their risk management and that implementation of more risk-taking approach to donor/recipient selection could lead to inferior outcomes. Such inferior outcomes would then place programs at higher risk of being flagged by accreditation or certification bodies for performance irregularities. A transplant center's loss of insurance contracts could lead to a death spiral of decreasing volume and eventual loss of CMS accreditation. Our objective was to model risk tolerance for centers of varying volumes and to determine the impact of progressively more risk-taking behavior on overall center outcomes. In this analysis, we were able to determine optimal risk tolerance for individual centers and noted that there is a clear correlation between center volume and ability to tolerate risk. One of the more troubling aspects of our analysis was the high likelihood that low-volume centers would experience poor outcomes based on chance alone. Using a random selection of 15 annual transplants performed, repeated 1000 times and meeting a predefined risk tolerance, this low-volume center had a 30% chance of failure. Similarly, a center with annual volume of 25 transplants experienced a 20% annual chance of failure. In his review of condition-level deficiencies in transplant programs, Abecassis found that approximately 7% of liver programs failed to meet CMS outcomes requirements. Of this group, many had experienced prior, poor outcomes in the preceding two yr and would be disqualified from CMS certification (9). In his analysis, there seemed to be little correlation with program volume and failing to meet CMS criteria with only two low-volume centers at risk of disqualification. Our model demonstrates a robust correlation between the risk of CMS disqualification and program volume. There are several possibilities for the divergence in this link. First, our model assumes independent sampling, that is, decision makers do no not learn from prior bad decisions. Second, Abecassis' review focused on a short period of time and may not have captured all untoward events that will occur as CMS conditions for participation are tested over a longer period. In the future, it is possible that we will see elimination of small volume programs as they struggle to meet conditions for participation and transplantation may experience a "regression toward the mean" in terms of program volume and outcomes.

A number of limitations in this modeling should be expanded upon. The model requires independent sampling, implying that a surgeon's prior decision on performance of a specific donor/recipient combination would not affect future decision making. This is likely not an accurate portrayal of real-world decision making in transplantation. The modeling does not take into account regional variations in transplant rates, organ availability or MELD score at the time of transplantation. Analysis of DRI by center volume demonstrates a significant difference in the profiles of donor organs "seen" by centers. While the difference is statistically significant, it reflects a very modest 7% increase in the RR of graft loss in the high-volume centers vs. very low- and moderate-volume centers.

Clearly, organ availability plays a large role in a surgeon's decision to accept or decline an available organ. This is demonstrated by wide variations in regional import and export rates, use of expanded criteria donors and establishment of DCD programs (21, 22). The modeling does not take into account the possibility that a more risk-tolerant strategy by a transplant center may lead to higher volume (5). While the authors think this is a potentially, likely outcome of a more risk-tolerant strategy, at the present time there is not enough data in

the literature to accurately, mathematically model this event.

Using a Monte Carlo simulation of liver transplant outcomes, we were able to demonstrate a number of novel findings. First, low-volume centers must follow a more risk-tolerant strategy to avoid being flagged as a low-volume center. As annual transplant volume increases, the role of the RR of donor/recipient combinations has a lessening impact on center failure, thus allowing larger volume programs to pursue more risk-tolerant strategies with less impact on center outcomes. We believe that this model quantifies the relationship between risk tolerance and a given transplant center's volume, thus permitting permit a center to select donor/recipient risk factors for adverse outcomes to optimize patient and graft survival. We also believe this analysis is important from the perspective of a patient choosing a transplant center. Patients are likely focused on a center's patient and graft survival rather than understanding the optimal risk tolerance of a given center. The recognition that a small volume center requires a more risk-tolerant strategy to accepting deceased donor organs for liver transplant will likely lead patients and referring physicians to choose higher volume liver transplant centers when the option exists. The realization that small volume transplant centers have a high probability of failure would also be expected to play a significant role in patient and referring physician selection. Finally, the model will prove useful to centers considering new strategies to augment volume or their patients' access to vital organs and how the proposed strategy will impact overall center risk management.

Authors' contributions

S.R.J., M.P.C., S.J.K. proposed the project to be researched. M.B. constructed the statistical models and Monte Carlo simulation. S.R.J., M.P.C., S.J.K., J.R.R., D.A.M., C.R., D.W.H., and M.B. performed data analysis and discussion of significance to the project. All authors contributed to manuscript preparation and review.

Funding sources

This work was funded in part by the Julie Henry Fund and the Department of Surgery, BIDMC.

References

1. Feng S, Goodrich NP, Bragg-Gresham JL et al. Characteristics associated with liver graft failure: the concept of a Donor Risk Index. Am J Transplant 2006: 6: 783.
2. Schaubel DE, Sima CS, Goodrich NP, Feng S, Merion RM. The survival benefit of deceased donor liver transplantation as a function of candidate disease severity and donor quality. Am J Transplant 2008: 8: 419.
3. Northup PG, Pruett TL, Kashmer DM, Argo CK, Berg CL, Schmitt TM. Donor factors predicting recipient survival after liver retransplantation: the Retransplant Donor Risk Index. Am J Transplant 2007: 7: 1984.
4. Menon KVN, Nyberg SL, Harmsen WS et al. MELD and other factors associated with survival after liver transplantation. Am J Transplant 2004: 4: 819.
5. Gruttadauria S, Cintorino D, Mandala L et al. Acceptance of marginal liver donors increases the volume of liver transplant: early results of a single-center experience. Transplant Proc 2005: 37: 2567.
6. Barshes NR, Horwitz IB, Franzini L, Vierling JM, Goss JA. Waitlist mortality decreases with increased use of extended criteria donor liver grafts at adult liver transplant centers. Am J Transplant 2007: 7: 1265.
7. Axelrod DA, Schnitzler M, Salvalaggio PR, Swindle J, Abecassis MM. The economic impact of the utilization of liver allografts with high Donor Risk Index. Am J Transplant 2007: 7: 990.
8. Abecassis MM, Burke R, Cosimi AB et al. Transplant center regulations–a mixed blessing? An ASTS Council viewpoint. Am J Transplant 2008: 8: 2496.
9. Abecassis MM, Burke R, Klintmalm GB et al. American Society of Transplant Surgeons Transplant Center outcomes requirements; a threat to innovation. Am J Transplant 2009: 9: 1279.
10. Dickinson DM, Arrington CJ, Fant G et al. SRTR program-specific reports on outcomes: a guide for the new reader. Am J Transplant 2008: 8(4 Pt 2): 1012.
11. Mateo R, Cho Y, Singh G et al. Risk factors for graft survival after liver transplantation from donation after cardiac death donors: an analysis of OPTN/UNOS data. Am J Transplant 2006: 6: 791.
12. Selck FW, Grossman EB, Ratner LE, Renz JF. Utilization, outcomes, and retransplantation of liver allografts from donation after cardiac death: implications for further expansion of the deceased-donor pool. Ann Surg 2008: 248: 599.
13. Edwards EB, Roberts JP, McBride MA, Schulak JA, Hunsicker LG. The effect of the volume of procedures at transplantation centers on mortality after liver transplantation. N Engl J Med 1999: 27: 2049.
14. Axelrod DA, Guidinger MK, McCullough KP, Leichtman AB, Punch JD, Merion RM. Association of center volume with outcome after liver and kidney transplantation. Am J Transplant 2004: 4: 920.
15. Northup PG, Pruett TL, Stukenborg GJ, Berg CL. Survival after adult liver transplantation does not correlate with transplant center case volume in the MELD era. Am J Transplant 2006: 6: 2455.
16. Tracy ET, Bennett KM, Aviki EM et al. Temporal trends in liver transplant centre volume in the USA. HPB (Oxford) 2009: 11: 414.
17. Register F. Medicare Program; Hospital Conditions of Participation: Requirements for Approval and ReApproval of Transplant Centers to Perform Organ Transplants, Final Rule. In: Services HaH, editor. Washington, DC, 2007. p. 15198.
18. Association BCBS. Blue Distinction Centers for Transplants. 2008 [cited 2010]; February 19]. Available from: http://www.bcbs.com/innovations/bluedistinction/blue-distinction-transplants/transplant_midlevel-criteria_liver_042109.pdf.

19. Browning Z. Optum Health SJ, personal communication. Boston, MA, February 2010.
20. Aetna. Aetna Institutes of ExcellenceTM Transplant Facilities Summary of Criteria, 2008, p. 1.
21. Berg CL, Steffick DE, Edwards EB et al. Liver and intestine transplantation in the United States 1998–2007. Am J Transplant 2009: 9(4 Pt 2): 907.
22. Tuttle-Newhall JE, Krishnan SM, Levy MF, McBride V, Orlowski JP, Sung RS. Organ donation and utilization in the United States: 1998–2007. Am J Transplant 2009: 9 (4 Suppl 2): 879.