



# An Examination of the Application of the Kidney Donor Risk Index in British Columbia

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## Abstract

**Background:** The Kidney Donor Risk Index (KDRI) is a continuous measure of deceased donor kidney transplant failure risk that was derived in US patients based on 10 donor characteristics. In the United States, the KDRI is utilized to guide organ allocation and to inform clinical decisions regarding organ acceptance.

**Objective:** To examine the application of the US-derived KDRI in a large Canadian province.

**Patients:** All deceased donor kidney-only transplant recipients in British Columbia (BC) between 2005 and 2014.

**Methods:** We examined the predictive performance of KDRI in BC transplant recipients and compared the overall performance of KDRI with donor age alone in predicting transplant failure (from all causes including death).

**Results:** Donors in BC (N = 785) were older but included no black donors and few Hepatitis C virus (HCV)-positive donors compared with the original derivation cohort of the KDRI in the United States. The KDRI was moderately predictive of transplant failure (c statistic, 0.63) and had similar predictive performance to donor age alone (c statistic, 0.64).

**Conclusion:** Our findings suggest that the US-derived KDRI does not improve the prediction of kidney transplant failure compared with donor age alone in a Canadian cohort and highlight the need to determine the applicability of KDRI in different regions.

## Abrégé

**Contexte:** L'indice *Kidney Donor Risk Index* (KDRI) est une mesure continue du risque de rejet d'une greffe d'un rein provenant d'un donneur décédé. Cet indice est dérivé de patients étasuniens et repose sur dix caractéristiques associées au donneur. Aux États-Unis, l'indice KDRI est utilisé pour guider l'attribution des organes et pour éclairer la prise de décisions cliniques concernant l'acceptation des organes.

**Objectif de l'étude:** Vérifier l'application de l'indice KDRI étasunien dans une grande province canadienne.

**Participants:** Tous les receveurs d'une greffe rénale simple en Colombie-Britannique entre 2005 et 2014, et dont l'organe provenait d'un donneur décédé ont été inclus.

**Méthodologie:** Nous avons évalué la performance prédictive de l'indice KDRI chez les receveurs d'une greffe de rein. Nous avons aussi comparé la performance globale du KDRI pour la prédiction du rejet de la greffe (toutes causes confondues, y compris le décès) obtenue par rapport à une prédiction basée uniquement sur l'âge du donneur.

**Résultats:** Comparativement à la cohorte américaine d'où dérive l'indice KDRI, les donneurs britanno-colombiens (N = 785) étaient plus âgés, mais aucun d'eux n'était d'origine afro-américaine et quelques-uns seulement étaient porteurs du virus de l'hépatite C. L'indice KDRI s'est avéré moyennement fiable pour prédire le rejet de la greffe (statistique C = 0,63) et présentait une performance prédictive comparable à celle mesurée à partir de l'âge du donneur seulement (statistique C = 0,64).

**Conclusion:** Nos constatations évoquent que, dans une cohorte de patients canadiens, le recours à l'indice KDRI ne permet pas de prédire plus précisément le risque de rejet de la greffe que l'âge du donneur seulement. Ainsi, nos constatations mettent en lumière la nécessité d'évaluer l'applicabilité de l'indice KDRI dans différentes régions.

## Keywords

Kidney Donor Risk Index, application, validation

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## What was known before

The Kidney Donor Risk Index is a continuous metric for donor quality developed in the United States and used for allocation of deceased donor kidneys in the United States.

## What this adds

Population demographics, access to health care, and post-transplant outcomes are significantly different between Canada and the United States. This study determines the applicability of the Kidney Donor Risk Index for deceased donor allocation in a Canadian setting.

## Introduction

The number of deceased organ donors continues to be insufficient to meet the growing demand for kidney transplantation.<sup>1</sup> This has led to long-standing efforts to increase the number of organ donors, in part by broadening criteria for acceptance to include more marginal deceased donor kidneys. Mechanisms to characterize donor risk vary by country and include donor age alone or multivariable risk scores to identify donors with characteristics associated with inferior posttransplant survival. The term *expanded criteria donor* (ECD) was defined in 2002 by Port et al to identify donors with a 70% higher risk of transplant failure compared with an ideal deceased donor and is widely used to dichotomize deceased donors as either expanded criteria or standard criteria to facilitate decisions regarding organ acceptance and allocation.<sup>2</sup> An important limitation of the ECD characterization is that it simply categorizes donors into 2 groups and thereby lacks the granularity to optimally inform decisions regarding organ acceptance and utilization.

Rao et al developed a continuous measure of donor risk termed the Kidney Donor Risk Index (KDRI), which included donor and transplant characteristics associated with inferior graft survival (adjusted for recipient factors), to produce a global score for kidney donor risk<sup>3</sup> (with higher scores indicating a higher risk of all-cause graft loss [ACGL]). A 10-variable version of the KDRI (restricted to donor factors) was formally adopted as part of the Kidney Allocation System (KAS) in the United States in 2014.<sup>4</sup> The Kidney Donor Profile Index (KDPI) is a “remapping of the KDRI to a cumulative percentage scale,” such that a kidney from a donor with a KDPI of 90% has a higher expected risk of graft loss

compared with 90% of donor kidneys that were recovered in the previous year.<sup>4</sup> This KDRI-derived scale is currently used in guiding organ allocation in the United States by directing deceased donor kidneys with the lowest KDRI to wait-list candidates with the longest expected posttransplant survival. In addition, KDRI and its derivative KDPI are used by clinicians to help determine whether or not to accept an organ for transplantation for individual wait-listed patients.

In Canada, organ donation and transplantation policies are determined within each province. Most transplant programs in Canada use donor age, along with the ECD classification to characterize donor risk.<sup>5</sup> Population demographics, access to health care, and posttransplant outcomes are significantly different between Canada and the United States. Therefore, the applicability of the US-derived KDRI in Canada is uncertain.

British Columbia (BC) is the third largest province in Canada and has the highest kidney transplantation rate in the country.<sup>6</sup> In BC, kidney allocation is based on deceased donor age in an effort to balance considerations related to maximizing the utility of the available organ supply while maintaining equitable access to transplantation. Kidneys from deceased donors aged 35 years or younger are only allocated to candidates aged less than 55 years, kidneys from deceased donors aged 60 years or older are preferentially allocated to candidates aged 60 years or older, while kidneys from donors 36 to 59 years may be allocated to patients of any age.

Given the demographic and health system differences in the United States and Canada,<sup>7</sup> we sought to examine the application of the US-derived KDRI in a Canadian province by (1) examining the ability of KDRI to discriminate donor kidneys in terms of recipient posttransplantation allograft survival; and (2) compare the overall performance of the KDRI with donor age alone in predicting posttransplant allograft survival in BC.

## Methods

This study was conducted with the approval of our local hospital research ethics board (H15-00620).

### Study Population and Data Sources

We identified all adult ( $\geq 18$  years) recipients of a first kidney-only deceased donor transplant in BC between January

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1, 2005, and December 31, 2014, using the BC Transplant database (Patient Records and Outcome Management Information System [PROMIS]). The cohort was restricted to 2005 onward as the data capture was most robust during this time period. PROMIS is a provincial database that captures information for all solid organ transplant recipients in the province, as well as information for all deceased organ donors. The KDRI was calculated for each deceased donor using the 10-variable KDRI currently used in the US KAS,<sup>4</sup> and the cohort was categorized by quintile of KDRI.

Although the primary purpose of this study is not to compare US and Canadian populations, we sought to compare donor and recipient characteristics in the BC cohort with those of the original US cohort in which the KDRI was developed to determine whether differences in the BC population and the derivation cohort of KDRI may explain any differences in the performance of the KDRI in BC and the original derivation cohort.

Therefore, we recreated the KDRI development data set which included all US adult deceased donor kidney-only transplant recipients between January 1, 1995, and December 31, 2005, using data from the Scientific Registry of Transplant Recipients (SRTR).<sup>3</sup> The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the United States, submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration (HRSA), US Department of Health and Human Services, provides oversight to the activities of the OPTN and SRTR contractors.

### Statistical Analyses

The distribution of the KDRI was described in the BC cohort using the probability density function and was compared with the US KDRI derivation cohort using the Kruskal-Wallis test. Donor characteristics (age, sex, race, history of hypertension, history of diabetes, donor cause of death, donation after cardiac death [DCD] status, hepatitis C status, terminal serum creatinine, and body mass index) were described using the median for continuous variables, and frequencies and proportions for categorical variables, and were compared between the BC cohort and the US KDRI derivation cohort.

Deceased donor kidneys were additionally categorized using the Port et al definition of ECD (defined as a donor aged 60 years or older or a donor aged 50 to 59 years with at least 2 of the following characteristics: serum creatinine >132  $\mu\text{mol/L}$ , history of hypertension, or death due to stroke). The proportion of ECD recipients across various categories of KDRI was determined within the BC cohort and the US derivation cohort.

Recipient characteristics (age, sex, race, diabetes as the cause of end-stage renal disease [ESRD], body mass index, peak panel reactive antibody [PRA], and duration of pretransplant dialysis) and transplant characteristics (degree of

human leukocyte antigen [HLA] mismatch and cold ischemia time) were described and compared between quintiles of KDRI in the BC cohort. Group comparisons were performed using the Kruskal-Wallis test or chi-square test as appropriate.

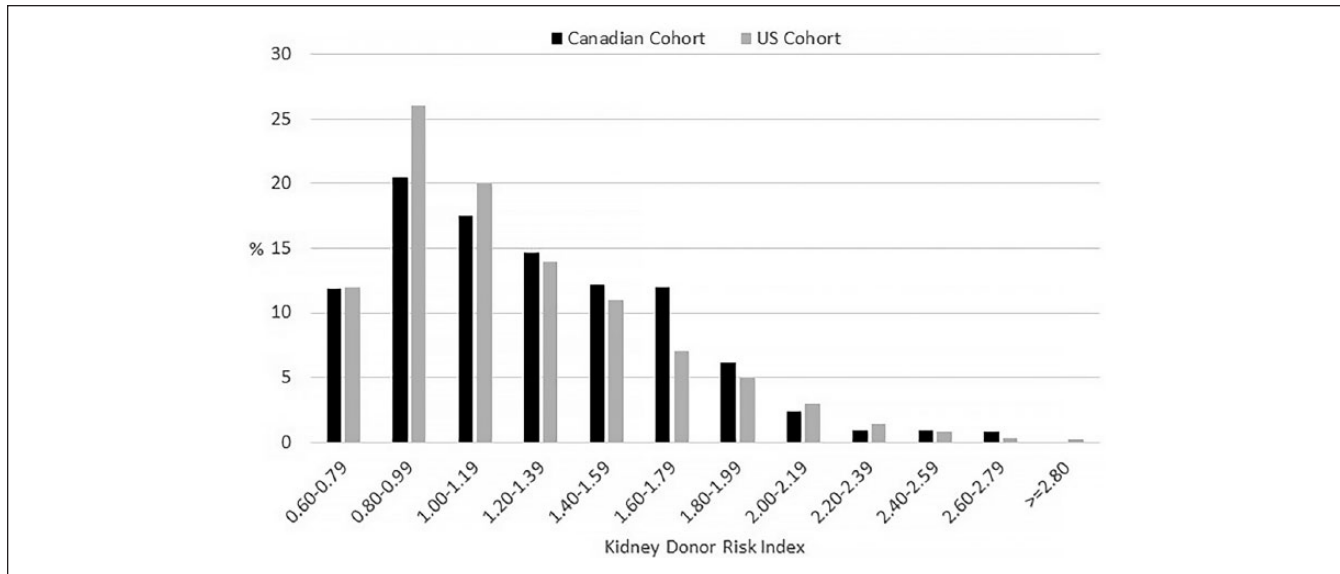
### Time to Allograft Failure

The association of KDRI with allograft failure from all causes including death was determined by calculating the time to allograft failure by quintiles of KDRI. The association of donor age with allograft failure was determined separately to compare the ability of KDRI and donor age alone to differentiate posttransplant allograft survival. The time to allograft failure from any cause including death was determined from the date of transplantation until death, transplant failure (defined by repeat transplantation, or return to chronic dialysis treatment), or until end of follow-up (December 31, 2014). The Kaplan-Meier method was used to examine allograft failure by quintiles of KDRI and donor age. Group differences were compared using the log-rank test. Cox multivariate regression models were used to examine the association of KDRI and donor age with allograft failure from any cause. Cox models were adjusted for recipient factors known to impact transplant failure including recipient age, sex, race, diabetes as cause of ESRD, body mass index, peak PRA, and duration of pretransplant dialysis. In all models, variables with missing data were assigned a category of "missing," allowing all patients to be included. The proportional hazards assumptions were tested using log-negative-log plots of the within-group survivorship probabilities versus log-time.

The power of the KDRI to discriminate allograft failure from any cause was determined using the *c* statistic. Confidence intervals were created using 1000 bootstrap samples. The *c* statistic considered all pairs of patients for which failure times were known. Specifically, the *c* statistic is the fraction of times that the ordering of the actual failure times is consistent with the ordering of the predicted failure times.

### Comparing the Predictive Performance of KDRI and Donor Age in the BC Cohort

To examine the predictive performance of the KDRI and donor age for the outcome of allograft survival, we examined measures of goodness of fit and complexity for 4 Cox proportional hazards models: model 1 including only recipient factors, model 2 recipient factors and KDRI, model 3 recipient factors and donor age, and model 4 recipient factors plus both KDRI and donor age. We used Nagelkerke's  $R^2$  as a measure of goodness of fit, describing how well the statistical model fitted the data. Similarly, we examined the Akaike information criterion (AIC) as a measure of the trade-off between each model's goodness of fit and complexity (number of parameters in model). The AIC compares the relative



**Figure 1.** Distribution of KDRI in the Canadian cohort and the KDRI derivation cohort in the United States.

Note. The distribution of KDRI in the Canadian and US KDRI derivation cohorts is outlined. The median KDRI was 1.20 (range, 0.62-3.02) in the Canadian cohort and was 1.12 (range, 0.58-4.30) in the US cohort ( $P = .0001$ ). KDRI = Kidney Donor Risk Index.

**Table 1.** Donor Characteristics in the Canadian Cohort and the US KDRI Derivation Cohort.

Donor factors	Canadian cohort (N = 785)	US cohort (N = 68 219)	P value
Median age, years (Q1, Q3)	47 (32, 58)	40 (24, 52)	<.001
Female sex (%)	58	59	.554
Race (%)			
White	88	74	<.001
Black	0	11	
Other	12	15	
Hypertension (%)	24	23	.527
Diabetes mellitus (%)	5	4	.169
Death due to stroke (%)	43	42	.549
DCD (%)	10	3	<.001
Hepatitis C positive (%)	0.4	2.6	<.001
Terminal serum creatinine, mg/dL	0.77 (0.60, 1.00)	1.00 (0.70, 1.20)	<.001
Median BMI (Q1, Q3)	23 (26, 29)	25 (22, 29)	

Note. KDRI = Kidney Donor Risk Index; DCD = donor after cardiac death; BMI = body mass index.

predictive ability of one model compared with another nested model. An increase in Nagelkerke's  $R^2$  or decrease in AIC suggest improved model fit and predictive ability.

All analyses were performed using SAS 9.4 (SAS Institute, Cary, North Carolina) and S-Plus 8.0 (TIBCO Software Inc, Palo Alto, California).

## Results

### Cohort Description

We identified N = 785 deceased donor kidney transplant recipients in BC. Figure 1 displays the distribution of KDRI

in the BC cohort and among the n = 68 219 recipients in the US derivation cohort for KDRI. In the BC cohort, the median KDRI was higher (1.20) and the range was narrower (0.62-3.02) compared with the US derivation cohort (median KDRI, 1.12; range, 0.58-4.30,  $P = .0001$ ).

Table 1 outlines the donor characteristics of the BC cohort and compares them with the US derivation cohort for KDRI. Compared with donors in the US derivation cohort, donors in the BC cohort were older but had better kidney function and were more often DCD donors. In addition, there were no donors of black race and only 3 hepatitis C-positive donors in the BC cohort. Table 2 outlines donor characteristics in the highest quintile of KDRI in the BC cohort compared with the

**Table 2.** Donor Characteristics in the Highest Quintile of KDRI Scores in the Canadian Cohort and the US KDRI Derivation Cohort.

Donor factors	Canadian cohort (N = 157)	US cohort (N = 17 286)	P value
Median age, years (Q1, Q3)	65 (61, 68)	58 (53, 63)	<.001
Female sex (%)	60	57	.469
Race (%)			
White	86	71	<.001
Black	0	17	
Other	14	12	
Hypertension (%)	49	60	<.001
Diabetes mellitus (%)	8	11	.278
Death due to stroke (%)	71	81	.001
DCD (%)	8	4	<.001
Hepatitis C positive (%)	1	5	.032
Terminal serum creatinine >132 $\mu$ mol/L (%)	13	16	.267
Median BMI (Q1, Q3)	26.6 (23.4, 30.1)	26.1 (23.0, 30.1)	.483

Note. KDRI = Kidney Donor Risk Index; DCD = donor after cardiac death; BMI = body mass index.

US derivation cohort. In the highest quintile, donors in the BC cohort were older (median age, 65 years and 58 years in the BC and US cohorts, respectively), included no black donors, and included more DCD donors (8% vs 4% in BC and US cohorts), while there were fewer high KDRI donors with hypertension and death due to stroke in the BC cohort compared with the US derivation cohort. In addition, the BC cohort included recipients that were older, but included fewer black, obese, diabetic, and sensitized recipients compared with the US cohort (see Supplementary Table 1).

Figure 2 displays the classification of ECD kidneys by categories of KDRI in the BC cohort and the US derivation cohort and outlines KDRI categories where there is overlap of kidneys classified as ECD and non-ECD. In the US cohort, donors with KDRI ranging from 1.20 to 2.59 were classified as both ECD and non-ECD, whereas the KDRI range (1.20-1.99) over which donors kidneys met ECD criteria was narrower in the BC cohort (1.20-1.99).

Table 3 compares recipient and transplant characteristics between KDRI quintiles in the BC cohort. Higher KDRI kidneys were transplanted more frequently in recent years and into recipients that were older, male, and had diabetic ESRD. There was no significant difference in race, pretransplant dialysis exposure, peak PRA, degree of HLA mismatch, and cold ischemia time between recipients across KDRI quintiles.

### Posttransplant Allograft Survival by KDRI Quintile

A total of 120 recipients in the BC cohort had allograft failure during the study period (median follow-up of 40 months), with 65 (8%) cases of death with function and 55 cases (7%) of death-censored allograft failure. Figure 3 (panel A) displays allograft survival by KDRI quintile in the BC cohort. Unlike in the KDRI derivation cohort in the United States (see Supplementary Figure 1), where there was a progressive

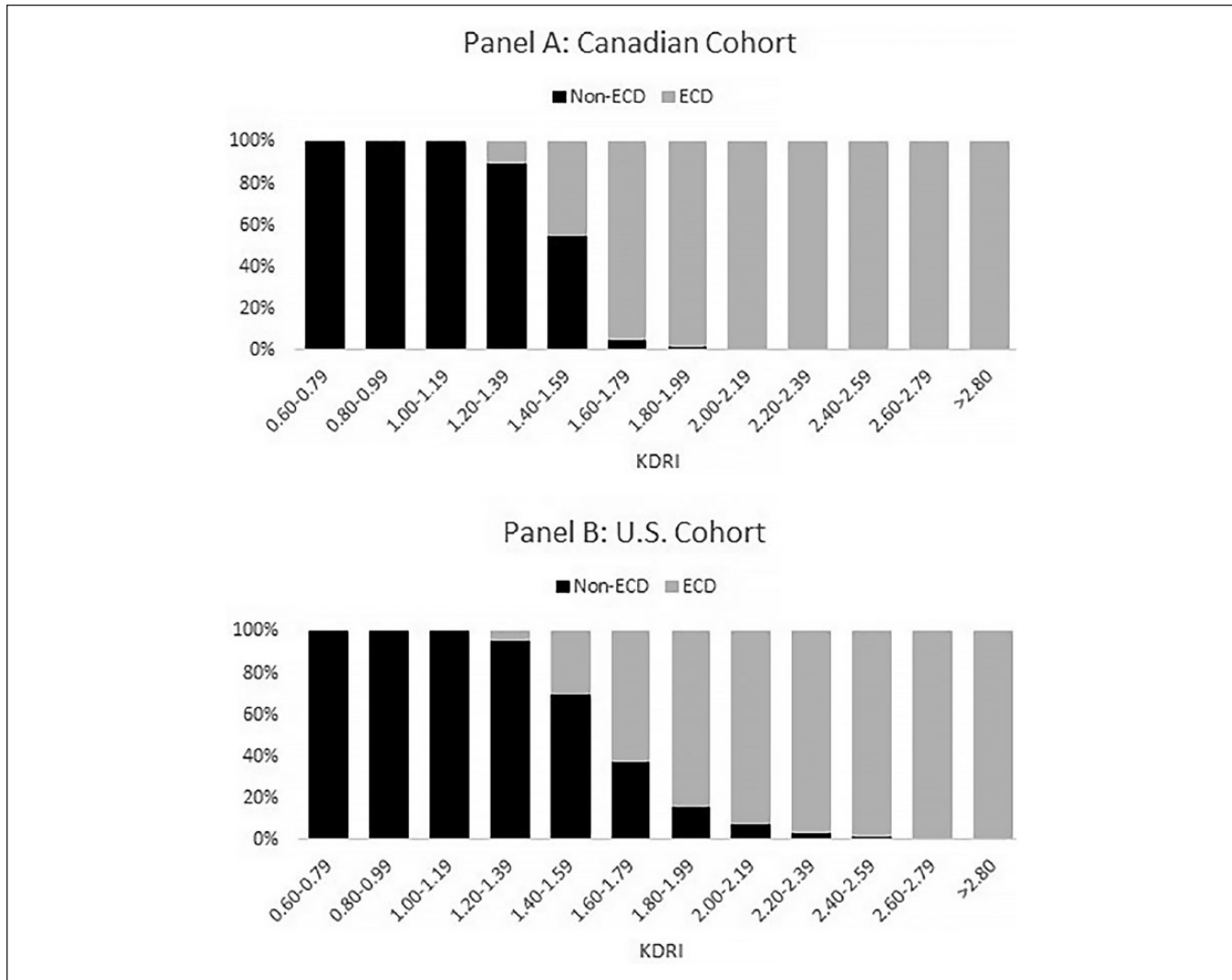
and statistically significant ( $P < .001$ ) decrease in allograft survival with each quintile of KDRI, there was no significant difference in allograft survival in the first 3 quintiles of KDRI in the BC cohort ( $P = .21$ ), and while the fourth and fifth quintiles of KDRI had significantly worse graft survival compared with the first quintile, there was no significant difference in graft survival between the fourth and fifth KDRI quintiles ( $P = .70$ ).

Table 4 shows the results of a Cox multivariate model examining the risk of ACGI in the BC cohort after adjustment for differences in recipient and transplant characteristics between KDRI quintiles. The risk of allograft failure was only significantly increased in the fourth and fifth quintiles of KDRI (hazard ratio [95% confidence interval], 3.05 [1.60-5.80] in the fourth quintile and 2.73 [1.40-5.31] in the fifth quintile). The  $c$  statistic for KDRI on allograft failure in the BC cohort was 0.63 (0.58, 0.67), indicating moderate discriminatory power.

### Comparing the Predictive Performance of KDRI and Donor Age in the BC Cohort

Figure 3 (panel B) outlines allograft survival by donor age quintile in the BC cohort. Compared with the pattern seen with KDRI quintiles (Figure 3, panel A), there was an incremental trend toward inferior graft survival with each quintile of donor age in the unadjusted analysis. After adjustment for differences in recipient and transplant characteristics, there was a trend toward an increased risk of graft loss with each quintile, but similar to the KDRI, this was only significantly different in the top 2 quintiles (see Table 4). The  $c$  statistic for donor age on allograft failure was similar to that for KDRI ( $c$  statistic 0.64 (0.61, 0.71)).

Table 5 outlines parameters of model fit and complexity in Cox proportional hazards models as a marker of the predictive performance of KDRI and donor age for the outcome



**Figure 2.** Classification of ECD kidneys by categories of KDRI in the Canadian cohort and the KDRI derivation cohort in the United States.

Note. The proportion of ECD kidneys within each KDRI category that would be classified as an ECD or non-ECD kidney is outlined in the Canadian cohort (panel A) and the US KDRI derivation cohort (panel B). ECD = expanded criteria donor; KDRI = Kidney Donor Risk Index.

of allograft survival after adjustment for recipient factors only (model 1), recipient factors and KDRI (model 2), recipient factors and donor age (model 3), and recipient factors plus both KDRI and donor age (model 4). The Nagelkerke's  $R^2$  and the AIC were used to measure the trade-off between model goodness of fit and model complexity, with an increase in Nagelkerke's  $R^2$  or a decrease in AIC suggesting better model fit and predictive ability. The AIC was similar in models using KDRI alone and donor age alone, suggesting limited additional predictive value with KDRI over donor age alone. A model incorporating both donor age and KDRI was marginally inferior to the model with donor age alone due to an increase in model complexity with limited improvement in model fit (AIC 1399.773 in model 4 compared with 1395.512 in model 3,  $P = .372$ ).

## Discussion

In this analysis, we present an examination of the application of the US-derived KDRI in a large Canadian province. We found that while KDRI discriminated overall posttransplant graft survival in transplant recipients in the BC cohort ( $c$  statistic, 0.63), there was no difference in posttransplant graft survival between the lowest 3 quintiles of KDRI (graft survival was not significantly different in recipients of kidneys within the lowest 3 quintiles of KDRI,  $P = .46$  in Cox model). We further found that KDRI and donor age alone performed similarly in their ability to predict graft survival and the addition of KDRI to donor age did not improve the predictive ability of donor age alone on graft survival in BC.

These findings may be explained by differences in donor characteristics in BC and the United States, some of which

**Table 3.** Recipient and Transplant Characteristics in the BC Cohort, by KDRI Quintiles.

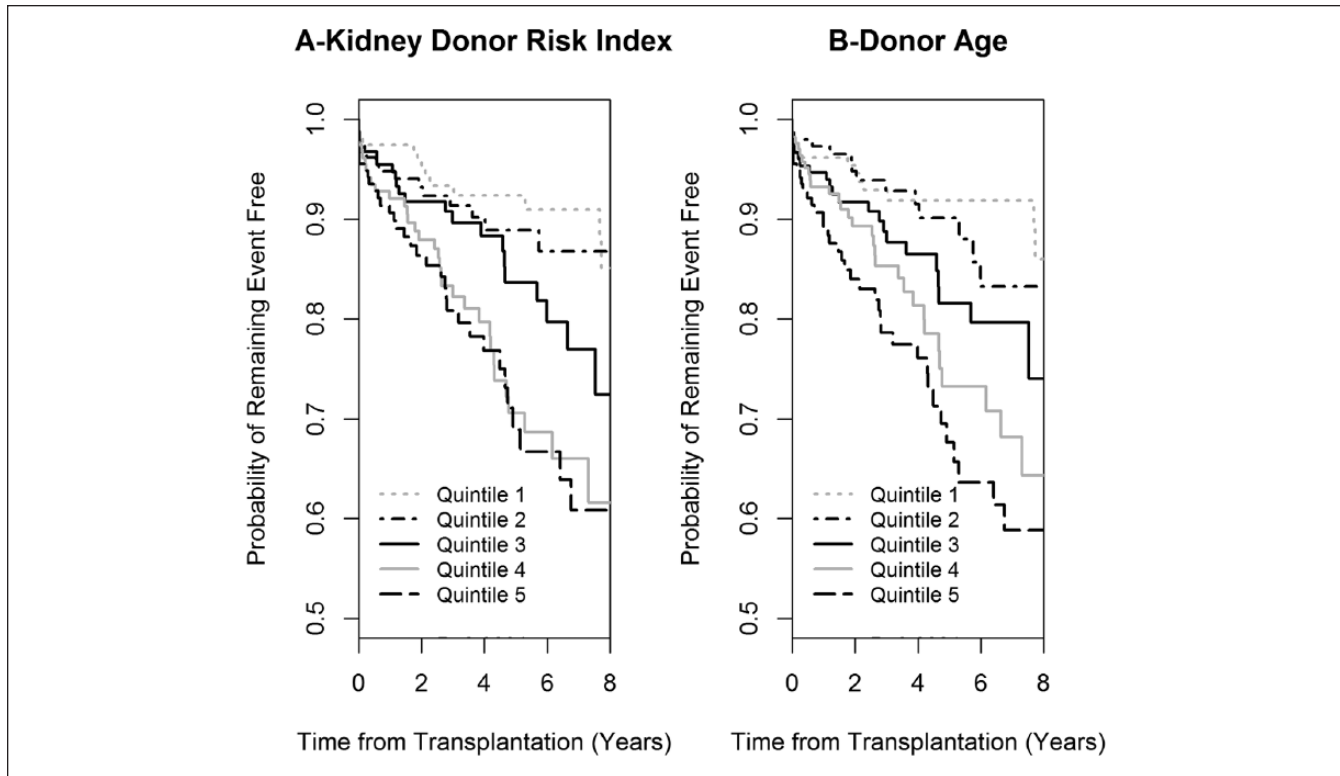
	KDRI Quintile 1 (n = 157)	KDRI Quintile 2 (n = 158)	KDRI Quintile 3 (n = 156)	KDRI Quintile 4 (n = 157)	KDRI Quintile 5 (n = 157)	P value
<b>Recipient factors</b>						
Median age, years (Q1,Q3)	47 (42, 53)	50 (39, 57)	55 (46, 61)	59 (51, 65)	64 (60, 68)	<.001
Female sex (%)	43	37	35	41	31	.183
<b>Race (%)</b>						
White	52	54	52	54	55	.786
Black	3	2	1	1	1	
South Asian	15	9	12	16	17	
East Asian	17	16	18	17	17	
Other	13	19	17	12	10	
<b>Cause of ESRD</b>						
Diabetes (%)	14	13	16	23	32	<.001
<b>Body mass index (kg/m<sup>2</sup>)</b>						
<25	54	50	55	50	37	.026
25-29.9	29	30	20	31	41	
30-34.9	13	12	18	15	16	
≥35	4	8	7	4	6	
<b>Peak PRA (%)</b>						
0	51	50	47	55	62	.306
0.1-30	33	32	37	35	24	
>30	16	18	16	10	14	
<b>Years of pretransplant dialysis</b>						
Median (Q1, Q3)	5.2 (2.9, 6.8)	5.1 (3.3, 6.8)	4.9 (3.3, 6.9)	5.4 (3.6, 7.0)	4.6 (2.8, 6.3)	.069
<b>Transplant factors</b>						
<b>Year of transplant (%)</b>						
2005-2009	48	32	38	36	30	.008
2010-2014	52	68	62	64	70	
<b>HLA mismatch</b>						
0-2	6	10	4	7	11	.310
3-4	52	43	51	49	45	
5-6	42	47	45	44	44	
Median cold ischemia time, hours (Q1, Q3)	11.1 (8.0, 14.9)	9.98 (7.6, 14.0)	10.7 (7.3, 14.0)	10.0 (7.0, 14.0)	10.2 (7.3, 13.4)	.174

Note. Missing data Canada: HLA mismatch (2.8%); PRA (19%). KDRI = Kidney Donor Risk Index; BC = British Columbia; HLA = human leukocyte antigen; PRA = panel reactive antibody; ESRD = end-stage renal disease.

may be explained by the different eras in which the KDRI was developed in the United States and in which we studied the application of KDRI in the BC population. However, there were differences that are not explained by era. Notably, the range of KDRI scores in the BC cohort was narrower than in the US KDRI derivation cohort, largely due to fewer cases of extremely high KDRI kidneys in BC (the upper end of the KDRI range was 3.06 and 5.30 in the BC and US cohorts, respectively). Also, high KDRI scores in the BC cohort appeared to be largely driven by donor age, whereas other high-risk characteristics, such as hypertension, hepatitis C, black race, and stroke as a cause of death, were less common in high KDRI donors in BC compared with the US KDRI derivation cohort. Therefore, it is not surprising that KDRI added little additional value to donor age alone in predicting recipient allograft survival in the BC cohort.

While sociodemographic differences between Canada and the United States may explain some of the noted differences in donor characteristics between the 2 cohorts, it remains surprising that there were fewer high KDRI donors in the BC cohort, particularly given that the US KDRI derivation cohort was from an older era than the BC cohort. It is unclear whether different patterns of donor acceptance between the 2 regions studied may account for some of the differences in the donor pool. However, discard rates for kidneys are less than 5% in BC (E. Ferre, Provincial Operations Director, BC Transplant, personal communication, March 3, 2017), suggesting that older age may be the most dominant high-risk characteristic in the BC cohort of donors.

The performance of KDRI in the BC cohort may also, in part, be explained by differences in recipient characteristics between the United States and Canada. The BC cohort



**Figure 3.** Allograft survival by KDRI and donor age in the Canadian cohort.

Note. Allograft survival (graft loss from all causes including death) is outlined by quintile of KDRI (panel A) and donor age (panel B) in the Canadian cohort. Canadian cohort KDRI cut-points: quintile 1 (0.62, 0.88); quintile 2 (0.89, 1.09); quintile 3 (1.10, 1.33); quintile 4 (1.34, 1.65); and quintile 5 (1.66, 3.02). Donor age cut-points: quintile 1 (<28 years); quintile 2 (28-43 years); quintile 3 (44-51 years); quintile 4 (52-60 years); and quintile 5 (>60 years). KDRI = Kidney Donor Risk Index.

included recipients that were older, but included fewer black, obese, diabetic, and sensitized recipients compared with the US cohort (see Supplementary Table 1). It is possible that donor risk factors may impact posttransplant outcomes differently in this lower risk population. In addition, health system differences (such as universal health care funding and lifelong immunosuppressive coverage) may modify the impact of certain donor risk factors on long-term recipient outcomes.

Our findings highlight the importance of analyzing the application of KDRI in different populations, particularly in regions where alternate mechanisms of facilitating longevity matching in allocation exist. In the United States, KDRI and its derivative KDPI offer an advantage over the ECD characterization as it more granularly characterizes deceased donors beyond a dichotomous grouping. The benefits of this are highlighted by the fact that the ECD characterization does not adequately distinguish donors across a wide range of KDRI scores in the United States (see Figure 2). In BC, however, this only occurred over a small range of KDRI scores, suggesting that this benefit is more muted in the Canadian context. Furthermore, donor age has been adopted in many Canadian provinces to inform decisions regarding organ

utilization and allocation. Therefore, KDRI would only be of considerable value in the Canadian context if it significantly improved the characterization of donor quality beyond donor age alone. Based on the results of our analysis, the adoption of the US-derived KDRI in BC appears to be of limited additional value beyond donor age alone. However, the discriminative ability of both donor age alone and KDRI are modest (*c* statistic, 0.63 and 0.64, respectively). Therefore, our findings support the need to better characterize donor risk factors that impact recipient outcomes in a Canadian population, which may ultimately lead to the development of a “Canadian-derived” KDRI.

Our findings are similar to other studies that have examined the applicability of KDRI outside of the United States. Peters-Sengers et al recently published an external validation of the KDRI in the Netherlands and reported similar findings to our study, with a modest discriminative ability of the KDRI (*c* statistic, 0.63).<sup>8</sup> While the authors of this study did not specifically compare the KDRI with donor age alone, they similarly concluded that the discriminative ability of the KDRI allows for limited clinical use for individualized decisions and proposed the development of an updated KDRI in the Eurotransplant region.



**Table 4.** Cox multivariate models examining the association of KDRI and donor age quintiles with the risk of allograft failure in the Canadian cohort after adjustment for differences in recipient and transplant characteristics.

	KDRI model Hazard ratio (95% CI)	Donor age model Hazard ratio (95% CI)
Quintile		
0%-20%	1.00	1.00
21%-40%	1.18 (0.57-2.44)	1.14 (0.54-2.38)
41%-60%	1.45 (0.74-2.84)	1.65 (0.84-3.23)
61%-80%	3.05 (1.60-5.80)	2.45 (1.28-4.71)
81%-100%	2.73 (1.40-5.31)	3.13 (1.62-6.07)
Age per year	1.03 (1.02-1.05)	1.03 (1.02-1.05)
Female sex	0.52 (0.34-0.80)	0.56 (0.37-0.86)
Race		
White	1.00	1.00
Black	NA	NA
South Asian	0.67 (0.38-1.18)	0.69 (0.39-1.23)
East Asian	0.45 (0.23-0.87)	0.46 (0.24-0.88)
Other	1.15 (0.67-1.96)	1.17 (0.68-1.99)
Diabetes as cause of ESRD	1.13 (0.70-1.85)	1.10 (0.68-0.79)
Body mass index (kg/m <sup>2</sup> )		
<25	1.00	1.00
25-29.9	1.08 (0.69-1.70)	1.07 (0.69-1.66)
30-34.9	1.04 (0.60-1.81)	0.99 (0.57-1.72)
≥35	1.25 (0.55-2.83)	1.27 (0.56-2.88)
Peak PRA %		
0	1.00	1.00
0.1-30	1.55 (0.94-2.56)	1.44 (0.88-2.38)
>30	7.08 (4.11-12.19)	6.78 (3.97-11.57)
Pretransplant dialysis (per year)	1.10 (1.02-1.19)	1.10 (1.02-1.19)
HLA mismatch		
0-2	1.00	1.00
3-4	1.59 (0.73-3.47)	1.72 (0.78-3.78)
5-6	1.80 (0.81-4.03)	1.99 (0.89-4.49)
Cold ischemia time hours		
≤12 hours	1.00	1.00
>12 hours	1.14 (0.52-2.54)	1.14 (0.51-2.53)

Note. KDRI = Kidney Donor Risk Index; CI = confidence interval; HLA = human leukocyte antigen; PRA = panel reactive antibody; ESRD = end-stage renal disease.

**Table 5.** Parameters of Model Fit and Complexity in Cox Proportional Hazards Models as a Marker of the Predictive Performance of KDRI and Donor Age for the Outcome of Allograft Survival After Adjustment for Recipient Factors Only (Model 1), Model 1 and US KDRI (Model 2), Model 1 and Donor Age (Model 3), and Model 1 Plus Both US KDRI and Donor Age (Model 4).

Model	Degrees of freedom (complexity)	AIC	-2 Log L (Generalized R <sup>2</sup> )
Recipient factors only	17	1404.667	1370.667
Recipient + KDRI quintiles	21	1394.423	1352.423 (0.127)
Recipient + Donor age quintiles	21	1395.512	1353.512 (0.126)
Recipient + KDRI + Donor age quintiles	25	1399.773	1349.773

Note. The table displays a summary of model goodness of fit and complexity from 4 Cox proportional hazards models examining the predictive ability of KDRI and donor age. In models 2 and 3, which included recipient factors plus KDRI alone or donor age alone, Nagelkerke's R<sup>2</sup> and the AIC were similar, suggesting that the additional predictive value of KDRI over donor age is limited. Model 4, incorporating both donor age and KDRI, was marginally inferior to the model with donor age alone due to an increase in model complexity with limited improvement in model fit. Recipient factors: Age, sex, race, cause of ESRD diabetes, BMI, peak PRA %, duration of pretransplant dialysis, HLA mismatch, and cold ischemia time. KDRI = Kidney Donor Risk Index; HLA = human leukocyte antigen; PRA = panel reactive antibody; AIC = Akaike information criterion.

While a refined version of the KDRI that is tailored to a Canadian population certainly warrants further study, to what extent a more complex scoring system will improve our decision making around organ utilization and organ allocation over donor age alone remains unclear. In an analysis of transplant recipients in Alberta, Gourishankar and colleagues examined the performance of 4 different deceased donor clinical scoring tools (including the KDRI) and found equivalent predictive ability using tools which included only 5 donor variables versus those that included up to 15 variables.<sup>9</sup> These findings question to what degree the inclusion of additional variables will actually improve the predictive ability of baseline donor characteristics on allograft survival.

In regions such as Canada where donor age is currently being utilized to facilitate longevity matching in organ allocation, a comparative evaluation of a simpler donor age-based approach versus a more complex “Canadian KDRI” score-based allocation system requires further study, specifically taking into consideration the views of patients and providers and an examination of the relative impact of these 2 strategies on organ acceptance, discard, and utilization.

This study was conducted with data from a single province, as national data in Canada do not capture all required variables to calculate the KDRI. Therefore, our findings may not be generalizable to other regions within and outside of Canada. The relatively small size of the BC cohort limited our ability to conduct analyses on the outcome of death-censored allograft survival, which may be an additional outcome of interest. Nonetheless, our results highlight the potential for variability in the performance of KDRI in different populations and suggest a need to validate the original KDRI in different regions to optimize the utility of this valuable tool.

## Conclusion

In summary, we found that while the US-derived KDRI was associated with allograft survival in a large Canadian province, it did not significantly improve upon the predictive performance of donor age alone on allograft survival. This information may be helpful in guiding policy in Canada and in other regions outside of the United States that have yet to adopt KDRI and highlights the need to validate this tool in different populations.

## Ethics Approval and Consent to Participate

This study was approved by the St Paul’s Hospital/University of British Columbia research ethics board. There was no consent required for publication.

## Consent for Publication

All authors have read and approved the final version of this manuscript.

## Availability of Data and Materials

The original data from this chart review will not be made publicly available as we did not acquire ethics approval to do so.

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