MAJOR ARTICLE

Impact of Infectious Disease Consultation on the Clinical and Economic Outcomes of Solid Organ Transplant Recipients Admitted for Infectious Complications

Bassem Hamandi,[1,2] Shahid Husain,[3] Atul Humar,[3] and Emmanuel A. Papadimitropoulos[1,4]

[1]Pharmaceutical Sciences, University of Toronto, [2]Pharmacy, and [3]Transplant Infectious Diseases, University Health Network, and [4]Eli Lilly Canada, Toronto, Ontario

Background. There has been a paucity of data on the healthcare resource utilization of infectious disease-related complications in solid organ transplant recipients. The aims of this study were to report the clinical and economic burden of infectious disease-related complications, along with the impact of infectious disease consultation.

Methods. This cohort study evaluated patients requiring admission to a tertiary-care center during 2007, 2008, and 2011. Propensity score matching was used to estimate the effects of patient demographics, comorbidities, and transplant- and infection-related factors on 28-day hospital survival, length of stay (LOS), and medical costs.

Results. Infectious disease-related complications occurred in 603 of 1414 (43%) admissions in 306 of 531 (58%) patients. Unadjusted 28-day mortality did not differ between those who received infectious disease consultations vs those who did not (2.9% vs 3.6%, $P = .820$), however, after propensity score matching, infectious disease consultation resulted in significantly greater 28-day survival estimates (hazard ratio = 0.33; log-rank $P = .026$), and reduced 30-day rehospitalization rates (16.9% vs 23.9%, $P = .036$). The median LOS and hospitalization costs were significantly increased for patients receiving an infectious disease consultation than in those managed by the attending team alone (7.0 vs 5.0 days, $P = .002$, and \$9652 vs \$6192, $P = .003$). However, the median LOS (5.5 vs 5.1 days, $P = .31$) and hospitalization costs (\$8106 vs \$6912, $P = .63$) did not differ significantly among those receiving an early infectious disease consultation (<48 hours) vs no consultation, respectively.

Conclusions. Infectious disease consultation in recipients of solid organ transplant is associated with increased LOS and hospitalization costs but decreased mortality and reduced rehospitalization rates. Early consultation with infectious disease specialists decreases healthcare resource utilization compared with delayed referrals.

Keywords. organ transplant; infectious disease; mortality; costs; utilization.

Solid organ transplant (SOT) has become an important therapeutic option for a variety of end-stage organ diseases. Well-established surgical procedures, improvements in medical management, and more refined immunosuppressant therapy have enhanced graft and patient survival rates. Unfortunately, the potential for surgical complications along with the impact of more potent immunosuppression predisposes SOT recipients to clinically important infectious syndromes that are major contributors to morbidity and mortality [1–4]. Previous literature has demonstrated that selecting appropriate initial empiric antimicrobial therapy may improve SOT patient in-hospital mortality [1, 4]. Unique infections in the immunocompromised host, such as cytomegalovirus (CMV) and invasive fungal infections, are not routinely seen by general infectious disease (ID) specialists and may be more difficult to diagnose and treat appropriately [5]. Furthermore, drug-resistant infections can be significantly more expensive to treat than

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Correspondence: Shahid Husain, MD, MS, Multi-organ Transplant and Infectious Diseases Division, University Health Network, University of Toronto, PMB 11C-1206, 585 University Ave, Toronto, ON M5G 2N2, Canada (shahid.husain@uhn.ca).

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nonresistant infections because they tend to result in increased lengths of hospitalization, readmission rates, medication costs, postdischarge care, lost workdays, and mortality [6, 7]. These challenges, along with the increased morbidity and mortality associated with infectious complications after transplant, have brought a number of ID specialists to focus on this population in an effort to improve their clinical management.

ID specialists have an increasingly important role in the management of infections in a variety of settings, but the literature regarding *Staphylococcus aureus* bacteremia is the most complete, demonstrating a significant impact on adherence to standards of care, decreased rates of relapse, better diagnosis of endocarditis, and decreased mortality [8–12]. Unfortunately, little information exists concerning the impact of ID specialist consultations on clinical outcomes and healthcare resource utilization in the SOT population. The primary objective of this study was to determine in-hospital patient survival for infectious disease-related hospitalizations in SOT recipients who receive an ID consultation compared with those who do not. Other objectives included determining the relative healthcare resource utilization when ID specialists were consulted, including length of stay (LOS) and direct medical costs associated with the management of hospitalized SOT patients with infectious disease-related complications.

METHODS

Study Design and Patients

This cohort study was conducted at the Toronto General Hospital, University Health Network, a tertiary-care hospital in Toronto, Canada, and was approved by the institution's research ethics board. The Multi-organ Transplant Program performs approximately 450 transplants annually, providing follow-up care to almost 5000 recipients of transplants including heart, lung, liver, kidney, pancreas, and small-bowel transplants. We retrospectively reviewed SOT recipients admitted during June–September 2007 and June–September 2008, and prospectively from June to September 2011. We excluded the initial admission for the transplant surgery itself. Our program had limited access to ID specialists during 2007–2008, but this changed during 2009–2010 when 2 ID specialists were consecutively appointed to be dedicated to our program. These sampling periods were chosen to (1) minimize confounding effects of variation due to seasonal infections, (2) compare periods during which our program did not have access to dedicated ID specialists, and (3) minimize the possibility of incomplete medical records given that our institution adopted electronic medical records in mid-2007.

Data Collection

Hospital visit documentation and laboratory, microbiology, and medication history were integrated into the patients' electronic medical records. Transplant-related data were obtained from a data management system (OTTR, OTTR Chronic Care Solutions, Omaha, Nebraska). Data were collected by trained abstractors using standardized data collection forms and entered into a computerized database using Access 2007 (Microsoft Corporation, Redmond, Washington). We randomly selected 30 (5%) abstracted records to assess data collection validity, and did not find any inconsistencies. Data variables collected included patient demographics, symptoms on admission, comorbidities, central venous catheter use, leukopenia, transplant-related factors, concomitant and previous immunosuppression, previous antimicrobial use, ID consultation referrals, infection-related diagnoses, and Simplified Acute Physiology Score II (SAPS II) during the first 24 hours of admission. The SAPS II is a severity of illness score and mortality estimation tool developed from a large sample of medical/surgical patients in North America and Europe [13].

Infectious Syndromes

Infectious syndromes were defined and categorized according to established consensus recommendations or Centers for Disease Control and Prevention criteria [14, 15]. Where abstractors differed on categorization, consensus agreement was reached among the principal investigators, which included a transplant pharmacist and an ID specialist. The syndrome most responsible for the majority of their hospitalization was selected.

Exposure and Outcome Assessment

Patients were grouped according to whether they received an ID specialist consultation. We classified ID consults occurring within 48 hours of admission as early interventions. The primary outcome of this study was 28-day in-hospital survival for SOT recipients experiencing infectious disease-related complications. Patient mortality included all causes of death. Other outcomes included healthcare resource use in terms of the duration of hospitalizations and direct medical costs.

Statistical Analysis

To assess the differences between those receiving an ID consultation and those not receiving one, we generated a propensity score for each patient based on a multivariable logistic regression model fitted with visit- and patient-level variables to estimate the relative odds of receiving an ID vs no ID consultation (Supplementary Appendix Figure 1) [16, 17]. The additional inclusion of patient-level variables allowed us to better account for the partially clustered nature of the data and more accurately specify the propensity score model, an approach that has been reported to be suitable for hierarchical data structures [18]. The effectiveness of bias reduction after matching was assessed by absolute standardized differences expressed as a percentage of the pooled standard deviation (SD) [19, 20].

In-hospital survival for patients managed with or without ID consultation was compared using the Kaplan–Meier product-limit method and the log-rank statistic to test the null hypothesis of no difference between survival curves. These models were fitted to both the total study population and propensity score–matched cohorts. Cox proportional hazards models were used to analyze the relationship between survival and ID consultation, in addition to covariates decided upon a priori (SAPS II and time posttransplant). The assumption of proportionality was graphically examined using log (cumulative hazard) plots and scaled Schoenfeld residuals. No important violations of the proportionality assumption were identified. We also conducted survival analyses after randomly choosing 1 admission per patient as a sensitivity analysis to account for the partially clustered nature of our dataset (Supplementary Appendix 1).

Using the propensity score–matched cohort, we compared LOS and total direct medical costs using nonparametric Mann–Whitney *U* tests. To determine whether sample loss in the matching process affected our results, we estimated the effect of ID consultation on LOS in the full cohort of patients by covariate adjustment using deciles of the propensity scores in a linear regression model (Supplementary Appendix Table 1). We conducted sensitivity analyses using a generalized linear model (GLM) with a log-link and γ distribution to analyze covariates for increasing medical costs (Supplementary Appendix Table 2*A*–*C*) [21, 22].

Values were expressed as the mean (SD) or median (interquartile range) for continuous variables depending on the distribution or as a count (percentage) for categorical variables. We compared groups using the Student *t* test, χ^2, or Wilcoxon signed-rank tests as appropriate. The criterion for statistical significance was set a priori at $\alpha = .05$, with all tests of significance being 2-tailed. All data were analyzed using StataMP 12 (StataCorp LP, College Station, Texas).

Cost Analysis

We undertook a costing analysis from an institutional economic perspective. The method used to calculate the cost of services is described in the Ontario Guide to Case Costing [23]. Direct medical costs included pharmacy, nursing, allied health, laboratory, diagnostic imaging, support services, and operating room costs. Physician fees were estimated from the Schedule of Benefits for Physician Services in Ontario [24]. All costs were calculated in 2012 Canadian dollars, using Statistics Canada's consumer price index for health and personal care [25].

RESULTS

Patient Characteristics

A total of 531 transplant recipients were admitted with 1414 hospitalizations, and were thus eligible for evaluation. Infectious disease-related complications resulted in a total of 603 (42.6%) hospitalizations from 306 (57.6%) unique patients. The median time since transplant was 4.2 years, with 85% of the hospitalizations occurring >6 months after transplant. Of the 306 patients with infectious disease-related complications, we observed 111 kidney, 81 liver, 71 lung, 33 heart, and 10 kidney–pancreas transplant recipients, with 184 (60.1%) being male, and 138 (45.1%) requiring multiple hospitalizations. Table 1 shows the baseline characteristics for both the full and propensity score–matched cohorts. The distribution of these characteristics showed substantial differences across consultation groups in the full cohort, but after propensity score matching, the differences across the consultation groups diminished considerably, demonstrated by reductions in the absolute standardized difference.

Infectious Disease Syndromes and Specialist Consultation

Overall, respiratory (27%), septic bloodstream (13%), liver and biliary tract (12%), urinary tract (12%), and CMV (10%) infectious syndromes were the most common causes of hospitalizations (Table 1).

An ID specialist consultation was requested in 272 of the 603 (45%) admissions for infectious disease-related complications. Among the 272 patients who received an ID consultation, 175 (64%) occurred within 48 hours of admission and were deemed to have received an early consultation. Patients receiving an ID consultation were more likely to have chronic renal failure, central venous access, culture-positive and polymicrobial infections, and increased SAPS II and to be receiving steroids. Logistic regression revealed that SAPS II >16 (odds ratio [OR] = 4.2; 95% confidence interval [CI], 1.8–9.7) and culture-positive infections (OR = 1.80; 95% CI, 1.2–2.8) were independently associated with ID consultation, whereas increasing age (OR = 0.98; 95% CI, .96–.99) and fever on admission (OR = 0.65; 95% CI, .42–.99) were associated with no ID consultation. The frequencies of diagnosed syndromes between the 2 consultation groups are shown in Figure 1.

In-Hospital Mortality

A total of 32 (10%) patients died in hospital, of whom 20 died within 28 days of admission; the primary causes were as follows: respiratory failure (8 patients), septic shock (6), pulmonary embolus (2), multiorgan failure (1), cardiac arrest (1), esophageal carcinoma (1), and spontaneous bacterial peritonitis (1). The proportion of patients dying in hospital did not differ between those who received an ID consultation and those who did not (2.9% vs 3.6%, $P = .820$). However, there was a significant difference in 28-day in-hospital survival across the 2 consultation groups as depicted by the Kaplan–Meier survival functions for both the propensity score–matched and full cohorts (Figure 2 and Supplementary Appendix Figure 2, respectively). In the

Table 1. Demographic, Transplant, and Selected Clinical Characteristics Among Patients Admitted for Infectious Disease-Related Complications

Characteristic	Full Cohort				Propensity Score–Matched Cohort			
	ID Consultation (n = 272)	No ID Consultation (n = 331)	Absolute Standardized Difference[a]	*P* Value	ID Consultation (n = 180)	No ID Consultation (n = 180)	Absolute Standardized Difference[a]	*P* Value
Age, y, mean (SD)	52.2 (14.3)	53.4 (14.6)	7.9	.337	51.8 (14.0)	52.3 (15.3)	3.6	.738
Male sex	171 (62.9)	201 (60.7)	4.4	.591	109 (60.6)	104 (57.8)	5.7	.593
Cohort timing								
Retrospective	165 (60.7)	218 (65.9)	10.8	.188	110 (61.1)	125 (69.4)	17.3	.097
Prospective	107 (39.3)	113 (34.1)			70 (38.9)	55 (30.6)		
Immunosuppression								
Tacrolimus	138 (50.7)	171 (51.7)	1.9	.821	89 (49.4)	89 (49.4)	0.0	.999
Cyclosporine	99 (36.4)	116 (35.1)	2.8	.731	66 (36.7)	68 (37.8)	2.3	.828
Steroid	237 (87.1)	261 (78.9)	22.1	.008	152 (84.4)	152 (84.4)	0.0	.999
Mycophenolic acid	180 (66.2)	199 (60.1)	12.6	.126	116 (64.4)	115 (63.9)	1.2	.913
Organ								
Kidney	88 (32.4)	102 (30.8)	3.3	.687	60 (33.3)	63 (35.0)	3.6	.740
Liver	66 (24.3)	117 (35.4)	24.2	.003	50 (27.8)	53 (29.4)	3.7	.727
Lung	64 (23.5)	90 (27.2)	8.4	.306	47 (26.1)	45 (25.0)	2.6	.810
Heart	49 (18.0)	15 (4.5)	43.6	.001	18 (10.0)	15 (8.3)	5.4	.585
Kidney/pancreas	5 (1.8)	7 (2.1)	2.0	.809	5 (2.8)	4 (2.2)	4.0	.737
SAPS II								
0–6	39 (14.3)	54 (16.3)	5.5	.505	28 (15.6)	31 (17.2)	4.6	.670
7–11	71 (26.1)	105 (31.7)	12.4	.131	54 (30.0)	49 (27.2)	6.1	.561
12–16	77 (28.3)	99 (29.9)	3.5	.668	53 (29.4)	51 (28.3)	2.4	.817
>16	85 (31.3)	73 (22.1)	20.9	.011	45 (25.0)	49 (27.2)	5.0	.632
Diabetes mellitus	122 (44.9)	140 (42.3)	5.1	.529	76 (42.2)	78 (43.3)	2.2	.832
Chronic renal failure	87 (32.0)	79 (23.9)	18.1	.026	46 (25.6)	55 (30.6)	11.2	.292
Dialysis dependent	27 (9.9)	31 (9.4)	1.9	.817	16 (8.9)	18 (10.0)	3.8	.719
Central venous access	122 (44.9)	89 (26.9)	38.1	.001	61 (33.9)	69 (38.3)	9.4	.381
Leukopenia	104 (38.2)	141 (42.6)	8.9	.278	75 (41.7)	67 (37.2)	9.1	.390
Fever on admission	77 (28.3)	116 (35.1)	14.5	.078	54 (30.0)	55 (30.6)	1.2	.909
Acute rejection past 30 d	31 (11.4)	33 (10.0)	4.6	.572	22 (12.2)	21 (11.7)	1.8	.871
Culture-positive infection	175 (64.3)	158 (47.7)	33.9	.001	103 (57.2)	101 (56.1)	2.3	.832
Polymicrobial infection	52 (19.1)	38 (11.5)	21.3	.009	27 (15.0)	28 (15.6)	1.5	.884
Multidrug-resistant infection	62 (22.8)	71 (21.5)	3.2	.693	34 (18.9)	39 (21.7)	6.7	.514
Infectious syndrome								
Respiratory	73 (26.8)	85 (25.7)	2.6	.748	48 (26.7)	44 (24.4)	5.0	.630
Sepsis	41 (15.1)	38 (11.5)	10.6	.194	24 (13.3)	24 (13.3)	0.0	.999
Liver and biliary tract	26 (9.6)	49 (14.8)	16.1	.052	19 (10.6)	17 (9.4)	3.4	.726
Genitourinary	25 (9.2)	46 (13.9)	14.7	.075	21 (11.7)	23 (12.8)	3.5	.748
CMV infection	34 (12.5)	19 (5.7)	23.6	.003	13 (7.2)	17 (9.4)	7.8	.447
Gastrointestinal	20 (7.4)	21 (6.3)	4.0	.625	13 (7.2)	12 (6.7)	2.2	.836
Fever of unknown origin	16 (5.9)	36 (10.6)	17.1	.039	14 (7.8)	18 (10.0)	8.1	.460
Other	37 (13.6)	38 (11.5)	6.4	.433	28 (15.6)	25 (13.9)	5.0	.657

Proportions are reported as No. (%). Continuous variables are reported as mean (SD).

Abbreviations: CMV, cytomegalovirus; ID, infectious disease; SAPS II, Simplified Acute Physiology Score II; SD, standard deviation.

[a] Absolute standard difference in means or percentages divided by an evenly weighted pooled SD, or the difference between groups in number of SD [20].

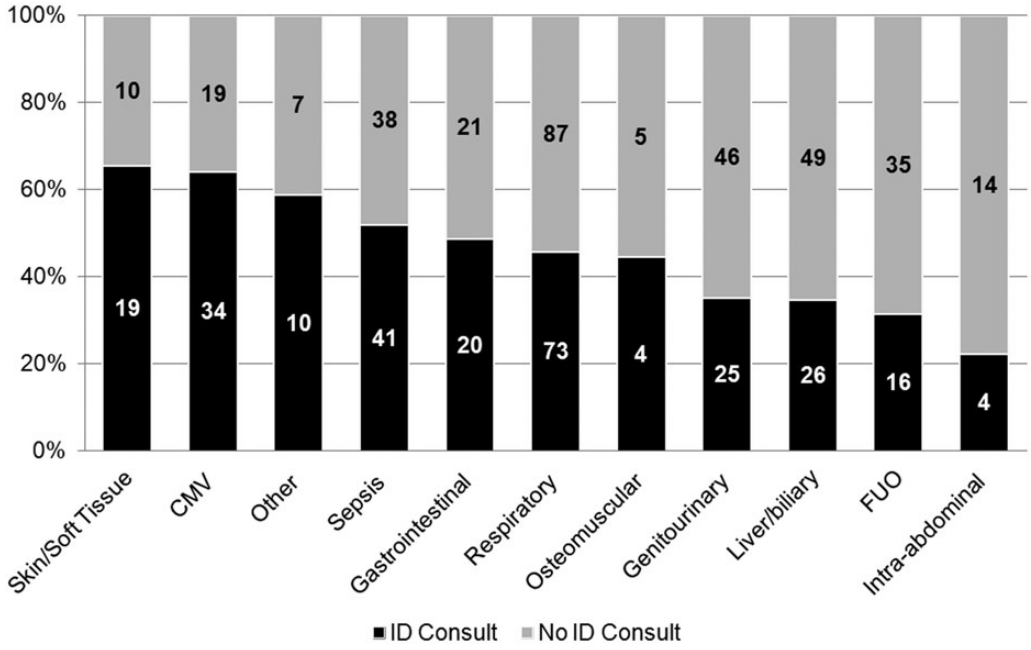

Figure 1. Number of cases by infectious syndrome for those receiving and not receiving an infectious disease (ID) specialist consultation. Number of patients shown on bar and proportion of total shown on the y-axis. ID consultation was more likely to be requested for those admitted for skin/soft tissue ($P = .024$) or cytomegalovirus infection ($P = .004$), but less likely for those admitted for fever of unknown origin ($P = .039$) and intra-abdominal infections ($P = .048$). All comparisons by χ^2 test. Abbreviations: CMV, cytomegalovirus; FUO, fever of unknown origin; ID, infectious disease.

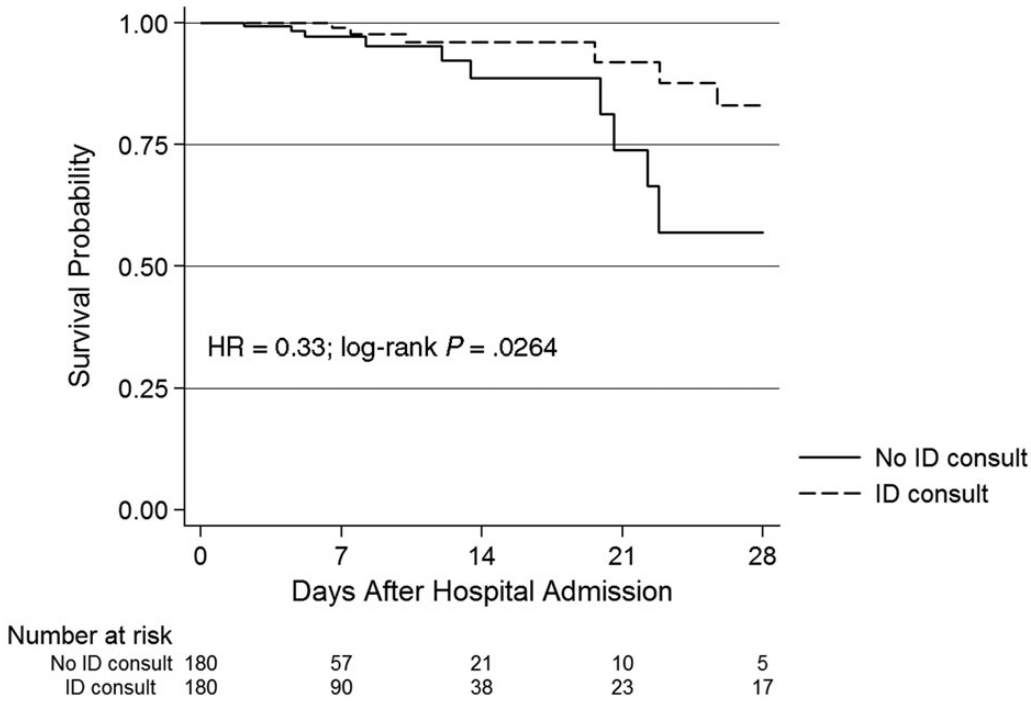

Figure 2. Kaplan–Meier curve illustrating the effect of infectious disease (ID) consultation (dashed line) vs no ID consultation (solid line) on 28-day hospital mortality for the propensity score–matched cohort. Hazard ratios (HRs) reported are for those receiving an ID specialist consultation relative to those not receiving one. A relative HR <1 indicates a reduced hazard of death among those receiving an ID specialist consultation. Abbreviations: HR, hazard ratio; ID, infectious disease.

Table 2. Cox Proportional Hazards Models for the Relation Between Infectious Disease Specialist Consultation and 28-Day Hospital Mortality

Model	HR	95% CI	*P* Value
Full cohort, unadjusted	0.34	.14–.83	.018
Full cohort, adjusted for SAPS II and time posttransplant	0.29	.12–.70	.007
Propensity score–matched cohort	0.33	.12–.89	.029

HRs reported are for those receiving an infectious disease specialist consultation relative to those not receiving one. A relative HR <1 indicates a reduced hazard of death among those receiving an infectious disease specialist consultation.

Abbreviations: CI, confidence interval; HR, hazard ratio; SAPS II, Simplified Acute Physiology Score II.

propensity score–matched cohort, maximum follow-up times were 106 and 61 days for the ID vs non-ID consultation groups, respectively. Restricted (to the longest follow-up time) mean in-hospital survival times were 75.7 and 42.6 days for the ID vs non-ID consultation groups, respectively. The Cox proportional hazards model confirmed a significant hazard reduction among those receiving an ID consultation (hazard ratio = 0.33; 95% CI, .12–.89). Cox proportional hazards models for the full cohort, both unadjusted and adjusted, also displayed similar hazard reductions (Table 2). Sensitivity analyses suggest these results are likely robust with respect to the partially clustered nature of our dataset (Supplementary Appendix 1).

Length of Stay, Cost of Hospitalization, and Hospital Readmission

Overall, the mean (SD) LOS was 10.8 (18.2) days, with mean (SD) medical costs of $21 365 ($53 266). Table 3 displays the results of the healthcare resource utilization among the 2 consultation groups. The median LOS was significantly longer for patients receiving an ID consultation, contributing to a significant difference in median hospitalization costs. In the propensity score–matched cohort, mean in-hospital costs were $19 619 for the ID vs $13 923 for the non-ID consultation group, resulting in an excess cost of $5696, 33.1 life-days gained, and a calculated cost-effectiveness ratio of $62 811 per life-year gained. GLM regression estimated the increased cost of hospitalization to be 1.4 times that of not receiving an ID consultation ($P = .079$; Supplementary Appendix Table 2*B*). We also found that patients receiving an ID consultation were less likely to be readmitted within 30 days of their hospital discharge compared with those not referred to an ID specialist (16.9% vs 23.9%, $P = .036$).

Sensitivity analysis around the timing of consultations revealed that early ID specialist referral was associated with a reduction in median LOS (6.9 days vs 9.8 days, $P = .001$) and median hospitalization cost ($9070 vs $13 033, $P = .003$) compared with late referral in the full cohort of patients. Using the propensity score–matched cohort, the median LOS and hospitalization costs did not differ significantly between those who received an early vs no ID consultation (Table 4). Furthermore, an early consultation led to mean cost savings of $432 compared with no ID consultation.

DISCUSSION

Infectious disease-related complications represent a significant burden in SOT recipients, but this large single-center study demonstrated that formal consultation with an ID specialist was associated with a reduction in 28-day mortality. Although increased healthcare resource utilization was associated with those receiving ID consultation, this increase was mitigated when referrals occurred within 48 hours of admission, and any ID consultation was associated with lower readmission rates.

The impact of ID specialists has been demonstrated in several clinical settings, but to our knowledge, this is the first study to specifically address this issue in SOT recipients. Using a national Medicare claims database, Schmitt et al reported that ID specialist intervention was associated with a reduction in both 30-day mortality (OR = 0.87) and readmissions (OR = 0.96) compared with no ID intervention [26]. Additionally, early consultation within 2 days of admission was associated with

Table 3. Length of Stay and Total Costs of Hospitalization Among Patients Admitted for Infectious Disease-Related Complications With and Without an Infectious Disease Specialist Consultation

		Propensity Score–Matched Cohort		
Length of Stay/Cost	Overall (n = 603)	ID Consultation (n = 180)	No ID Consultation (n = 180)	*P* Value
Length of stay, d	5.5 (3.3–10.2)	7.0 (4.0–11.8)	5.0 (3.0–8.8)	.002
		(n = 179)	(n = 176)	
Hospitalization costs, $CDN	7432 (4414–15 299)	9652 (5367–17 706)	6192 (4053–13 143)	.003

Data are presented as median (interquartile range). Five admissions were excluded from the cost analysis as a result of missing data.

Abbreviation: ID, infectious disease.

Table 4. Length of Stay and Total Costs of Hospitalization Among Patients in the Propensity Score–Matched Cohort Receiving an Early and Late Versus No Infectious Disease Specialist Consultation

Length of Stay/Cost	Early ID Consultation (n = 119)	No ID Consultation (n = 119)	*P* Value	Late ID Consultation (n = 61)	No ID Consultation (n = 61)	*P* Value
Length of stay, d	5.5 (3.8–10.2)	5.1 (2.9–10.2)	.315	8.2 (4.9–16.2)	4.7 (3.3–6.8)	<.001
	(n = 117)	(n = 117)		(n = 61)	(n = 58)	
Hospitalization costs, $CDN	8106 (5230–14 861)	6912 (4204–15 173)	.631	12 148 (6283–23 332)	5549 (3956–10 544)	<.001

Data are presented as median (interquartile range). Consults by ID specialists occurring within 48 hours of admission were classified as early interventions. Five admissions were excluded from the cost analysis as a result of missing data.

Abbreviation: ID, infectious disease.

significantly shorter lengths of stay and decreased overall charges and payments [26].

Previous literature has suggested that the risk of nosocomial and opportunistic infections in SOT recipients peaks during the first 6 months, but more recently it has been demonstrated that the etiology and related mortality after 6 months is only slightly different and still poses a significant burden [27]. Admitting physicians may overlook the need to be more vigilant in diagnosing late infections. Because we did not use an incidence cohort, the majority of hospitalizations occurred >6 months posttransplant; however, despite having a median time of 4.2 years posttransplant, our cohort of patients was admitted with a variety of infectious syndromes that are often seen in the early period after surgery. It may also be more difficult to diagnose infection in SOT recipients vs nonimmunosuppressed individuals, as patients may not present with typical signs and symptoms of infection such as fever [2]. Furthermore, fever may be a marker of noninfectious processes, such as allograft rejection, which may complicate accurate diagnoses. Only one-third of those diagnosed with an infection actually presented with a febrile episode, slightly less than previously reported [28]. We previously reported that one-quarter of patients receiving inadequate empiric antimicrobial therapy did not survive their hospital stay [1]. This is especially problematic in the context of polymicrobial and multidrug-resistant isolates, which in this study amounted to 27% and 40% of all culture-positive infections. Despite the late time frame of these infections, they are clinically burdensome and these findings underscore the need for careful and specialized evaluation for infection in this population.

Although ID consultation was associated with improved patient survival, we also described an associated increase in resource utilization. Some have suggested that specialists contribute unnecessarily to the total cost of care without justified improvements in clinical or healthcare resource outcomes [29, 30]. Classen et al reported that patients receiving ID consultation had a longer LOS and higher antibiotic costs compared with matched controls [30]. Our results were similar, however, with the salient finding that ID consultation resulted in a significant mortality benefit. Additionally, the cost of care was reduced when ID consultation occurred early following admission, perhaps reflecting the benefits of earlier diagnosis and appropriate treatment. Moreover, ID consultation may help in the transition of care, as we found patients that were less likely to be readmitted within 30 days of their hospital discharge had they received an ID consultation.

Despite a membership of approximately 250 transplant centers in the United Network for Organ Sharing, only a handful of these centers actually have a dedicated transplant ID specialist. Having a dedicated transplant ID specialist may be beneficial to SOT programs across the nation given the unique infectious syndromes and risk of mortality if not treated in a timely and appropriate fashion [1]. Implementation of a hospital policy of routine ID specialist consultation may lead to more detailed patient evaluation from an infectious diagnosis perspective and improved clinical outcomes.

Limitations of this study include the observational nature of the dataset and the potential for selection bias. For instance, if we are unable to observe that patients who see specialists are more severely ill, then the positive effects of specialists on health outcomes may be understated. We attempted to overcome this bias through propensity score matching on severity of illness, age, comorbidities, and other variables. We also utilized various sensitivity analyses to confirm our estimates. With a limited cohort of patients, we did not include interaction terms in the regression analyses, which may have revealed situations where ID consultation may have had a different effect, such as in specific organ groups or infectious syndromes. Despite not capturing informal or "curbside" consultations, our results continued to show a benefit for those receiving formal consultations. Although representing a minority of patients, admissions to other hospitals were not recorded, which may have underestimated the incidence of infection, and overestimated cost estimates as these patients were managed in a community setting rather than a more specialized center. Given that this study was conducted during summer months in a single center, the results reported are reflective of this sampling period and

institutional-specific practices. However, excluding winter months may provide a more conservative estimate of both baseline and the effect of ID consultation on patient mortality, given that seasonal respiratory infections may be more difficult to diagnose and ID specialists may be more proficient at providing appropriate treatment.

In summary, this cohort study suggests that infectious disease-related complications continue to pose a clinical and economic burden on the healthcare system several years after the initial transplant period. In addition, there is an association between an ID specialist consultation and improved patient outcomes both during and after hospitalization. The healthcare costs associated with specialist care can be significantly reduced when referrals are made early in the course of patient care. In this era of cost containment, the role of a specialist needs to be carefully weighed against not only the associated incremental costs, but the clinical and future economic benefits of specialized care. Future studies may focus on the cost-effectiveness of such strategies, which, based on our results, may increase current direct costs, but may improve patient outcomes and may be beneficial in preventing future hospitalizations.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online (http://cid.oxfordjournals.org). Supplementary materials consist of data provided by the author that are published to benefit the reader. The posted materials are not copyedited. The contents of all supplementary data are the sole responsibility of the authors. Questions or messages regarding errors should be addressed to the author.

Notes

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Author contributions. B. H., E. A. P., and S. H. participated in research design. B. H. and S. H. participated in the performance of the research. B. H., E. A. P., and S. H. participated in data analysis. B. H., E. A. P., A. H., and S. H. participated in the writing of the paper.

Potential conflicts of interest. All authors: No reported conflicts.

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