Patterns of emergency department utilization by patients on chronic dialysis: A population-based study

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Abstract

Importance

Patients on dialysis are often elderly and frail, with multiple comorbid conditions, and are heavy users of Emergency Department (ED) services. However, objective data on the frequency and pattern of ED utilization by dialysis patients are sparse. Such data could identify periods of highest risk for ED visits and inform health systems interventions to mitigate these risks and improve outcomes

Objective

To describe the pattern and frequency of presentation to ER by dialysis patients

Design

Retrospective cohort study using administrative data collected over ten years (2000–2009) in the Province of Manitoba, Canada.

Setting

Patients presenting to any of 9 ED's in Winnipeg and Brandon Manitoba. These departments serve >90% of the population of Manitoba, Canada (population 1.2 million).

Participants

All patients presenting to an ED in any of 9 emergency departments in Manitoba, Canada.

Exposure

Dialysis status

Main outcomes

Presentation to the ED

Results

Over 2.1 million ED visits by more than 1.2 million non-dialysis patients and 17,782 ED visits by 3257 dialysis patients were included. Dialysis patients presented 8.5 times more frequently to the ED than the general population (age and sex adjusted, p<0.001). For dialysis patients, ED utilization was significantly higher following the long interdialytic interval (33.6% higher Mondays and 19.5% higher Tuesdays vs. other days of the week, p<0.001) and was 10-fold higher in the 7 days before and after the initiation of dialysis.

Conclusion and relevance

The heavy use of ED services by dialysis patients spikes upward following the long interdialytic interval and also in the week before and after dialysis initiation. The relative risks associated with these vulnerable periods were much higher than those reported for clinical patient characteristics. We propose that intrinsic gaps in the structure of care delivery (e.g. 3 times a week dialysis, imperfect surveillance and clinical monitoring of patients with low GFR) may be the fundamental drivers of this periodicity. Strategies to mitigate this excess health risk are needed.

Introduction

Emergency Department (ED) utilization in North America continues to rise at a rate exceeding population growth [1]. This increase has had a major impact on ED wait times, quality of care, and expenditures worldwide. A small portion of ED users are responsible for a disproportionate utilization of these services compared to the rest of the population [2]. These "frequent users" include individuals of lower socioeconomic status [3, 4], those whose first point of medical contact is the ED [5], and populations with a specific medical condition [3, 6], including patients with kidney failure on dialysis

Dialysis patients tend to be elderly and frail, have multiple comorbid conditions, and frequently require non-dialysis health care services [1–8]. In particular, it is widely assumed that dialysis patients as a population impose a disproportionate burden on emergency departments, contributing to ED congestion and wait times. Although some data exist to support this assertion, with the exception of one large registry report, most studies examining rates of ED utilization among dialysis patients have been limited in scope and methodology.

Importantly, no population-based study has examined the temporal patterns of ED utilization by dialysis patients. A more thorough understanding of the frequency and pattern of ED visits could help health systems appropriately align ED resources with the needs of dialysis patients and facilitate design of pre-emptive health system interventions to reduce ED utilization, improve patient outcomes, and enhance system efficiencies.

In an attempt to fill some of these knowledge gaps, we performed a population based retrospective cohort study linking two large regional databases in order to compare rates of ED presentations in patients both with and without kidney failure on dialysis. We sought to compare temporal and secular trends of ED presentations in these populations, and identify periods of high risk for ED presentation.

Methods

The study protocol was approved by the Winnipeg Regional Health Authority (WRHA) Research Review Board and the Health Research Ethics Board of the University of Manitoba.

Study design

We assembled a population-based retrospective cohort of kidney failure and non-kidney failure patients by linking the Manitoba Renal Program (MRP) provincial database, a registry of all Manitoba kidney failure patients, and the Emergency Admission, Discharge, and Transfer (ADT) Database, an administrative registry of all patients presenting to any ED in the Winnipeg Regional Health Authority (WRHA). Linkage was achieved via utilization of unique Personal Health Identifier Number (PHIN).

Study population

The study population consisted of the entire population within the WRHA, from the period of Jan 1, 2000 to Dec 31, 2009. The WRHA is responsible for the health care of over 700,000 Winnipeg residents and the tertiary care of nearly 500,000 additional residents of Manitoba [9], representing the vast majority of the province's population.

Data sources

The MRP registry has tracked both incident and prevalent dialysis patients in Manitoba since 1996. The registry excludes patients with acute kidney injury who required temporary dialysis. For the purposes of the present study, we linked data from Jan 1, 2000 to Dec 31, 2009. The registry is complete for all prevalent kidney failure patients in Manitoba and provides the basis for billing and reporting of provincial dialysis information to the Canadian Organ Replacement Registry (CORR), the body responsible for the collection of medical data of patients with kidney failure in Canada [10]. Data elements captured included the patient's PHIN, date of initial dialysis treatment, and modality. All changes to vital status and dialysis modality are updated weekly at interprofessional rounds and are reported in the MRP and CORR registries [11].

The ADT system has tracked all ED visits in the WRHA from its inception in 1999 until Dec 31, 2009, with the purpose of providing real-time data entry and patient registration uniformly across the entire region. We linked data from Jan 1, 2000 to Dec 31, 2009. The database is known to have captured 100% of all ED presentations in the WRHA over this period. Data elements recorded include the patient's PHIN, general demographics, address, time and date of presentation, hospital of presentation, mode of arrival, and Canadian Triage and Acuity Scale (CTAS) score [12]. Data are entered in real time by skilled personnel upon patient presentation to the ED triage nurse.

Data was linked across databases at the individual level via the patient's PHIN and patients with non-valid or corrupt PHINs were excluded. All linkages were done on a secure server. Prior to exporting the file for analysis, each patient was given a unique study number and the PHINs were purged from the data, ensuring anonymity of the exported file. The resulting linked data file described ED visits in over 1.2 million unique individuals over the study period.

Variable definitions

Dialysis (kidney failure) status. Dialysis status was assessed separately for each ED visit for each patient using the MRP registry. Patients not appearing in the registry were classified

as non-dialysis patients for all ED visits. Patients were classified as a dialysis patient if the date of the ED visit for that patient occurred after the date of initial dialysis, as recorded in the MRP registry. Patients who had ED visits before and after initiation of dialysis were classified as non-dialysis patients for ED visits occurring before and as dialysis patients for visits occurring after dialysis start.

Dialysis modality. The vast majority of patients on chronic dialysis in Manitoba are treated with in-centre conventional hemodialysis (CHD, 75%) or peritoneal dialysis (PD, 20%), with a small number undergoing home hemodialysis (HHD, 5%). These proportions are similar to other Canadian provinces. For the purposes of the present analyses, we combined CHD and HHD into one group (HD). We classified kidney transplant patients as non-dialysis patients. Over time, patients undergo modality switches such as changing from transplant to dialysis, or HD to PD (and vice versa). Because the MRP registry records the start and end dates of each modality transition, we attributed each ED visit to the concurrent treatment modality.

Demographic data. Demographic data were taken from the ADT system. As this data is also in the MRP registry for patients with kidney failure, the data were compared and reconciled in the small number of cases where disagreement existed. Patient age was calculated for each ED visit based on date of birth and date of ED admission.

Data analysis. Normally distributed continuous variables of interest were summarized as mean (SD). Dichotomous variables and outcomes were summarized as percentages. T tests and ANOVA were used to compare normally distributed measures. The Mann-Whitney U test and the Kruskall-Wallis test were used for non-Gaussian distributions. The χ^2 test was used to compare dichotomous variables.

Secular trends in rates of ED visits. For each year of follow-up, a crude yearly ED visit rate for patients on chronic dialysis was calculated as the number of ED visits by dialysis patients in that year divided by the number of dialysis patients registered in the MRP database at the end of that year. Patients who were on dialysis for less than 6 months of the year in question were classified as non-dialysis patients for that year. Because patients on chronic dialysis were older and had a greater proportion of men than the general Manitoba population, we adjusted the crude rates using direct age and gender standardization referenced to the 2006 adult population of Manitoba. Yearly ED visit rates for non-dialysis patients were calculated as the number of ED visits by non-dialysis patients divided by the estimated adult population of Manitoba in that year. The adult population in Manitoba was estimated for each year using linear interpolation of population data from the 2001, 2006, and 2011 censuses.

Clustering of ED visits in relation to day of the week. HD patients typically dialyze three times a week on a Monday/Wednesday/Friday or a Tuesday/Thursday/Saturday schedule, and thus experience two short and one long interdialytic interval (i.e. the Friday to Monday interval or Saturday to Tuesday interval, respectively). To address the question of whether ED visits might be clustered on days following the long interdialytic intervals in HD patients, we calculated the rate of ED visits per patient year occurring on each day of the week, stratified by HD, PD, and non-dialysis status. Rates were compared across days of the week and across strata using Poisson regression. The hypothesis that the day of the week effect was more pronounced in HD than in other categories was tested using a formal interaction term (weekday x kidney failure status).

Clustering of ED visits in relation to dialysis start date. To address the question of whether ED visits clustered shortly before or shortly after the initiation of chronic dialytic therapy, we calculated the timing in weeks of each ED visit in relation to the dialysis initiation date for each patient (e.g. visit occurred 21–28 days before; 21–28 days after initiation of dialysis). We then calculated the total number of ED visits for each week preceding and each week following initiation of dialysis. We investigated ED utilization up to 52 weeks prior to the

Table 1. Dialysis patient visits to the emergency department by year.

Year	General Population (reference)	Dialysis Cohort					
	Crude	All		HD		PD	
	(annual visits/100 patients)	(annual visits/100 patients)		(annual visits/100 patients)		(annual visits/100 patients)	
		Crude	Age/Sex adjusted	Crude	Age/Sex adjusted	Crude	Age/Sex adjusted
2000	17.3	140	148	134	144	159	215
2001	18.4	163	179	159	175	177	239
2002	18.0	159	152	163	157	143	170
2003	18.0	155	163	155	166	158	158
2004	18.0	149	146	148	148	151	164
2005	18.6	157	179	167	187	125	135
2006	18.3	149	159	157	167	123	197
2007	17.7	155	168	171	188	101	129
2008	17.9	141	165	157	184	86.0	98.1
2009	19.2	138	149	155	165	76.7	106
10 year average	**18.1**	**150**	**153**	**157**	**161**	**124**	**124**

https://doi.org/10.1371/journal.pone.0195323.t001

initiation of dialysis and 52 weeks after the initiation of dialysis in both HD and PD patients. The weekly frequencies were expressed as rate per patient-year of follow-up.

Results

Over the study period, the linked dataset included more than 2.1 million ED visits by more than 1.2 million non-dialysis patients and 17,782 ED visits by 3257 dialysis patients. In total, 301 patients had invalid or missing PHINs and were excluded from the study.

As demonstrated in Table 1 and Fig 1, the crude rates show a more than eight-fold greater rate of ED presentations by dialysis patients compared to the non-dialysis patients in Manitoba (150 vs. 18 visits per 100 patients per year, $p<0.001$) over the study period. Age and sex adjusted rates were similar to unadjusted rates. Rates were fairly stable over the ten-year study period, with negligible variation year to year from 2000 to 2009. There was a slightly higher average rate of ED presentation in patients on HD compared to patients on PD (157 vs. 124 visits per patient year, $p<0.001$) over the study period.

Temporal trends in ED utilization

In the general population, rates of ED visits were approximately 7% higher on Mondays and 5% higher on Tuesdays compared to the other days of the week. This "post-weekend" effect
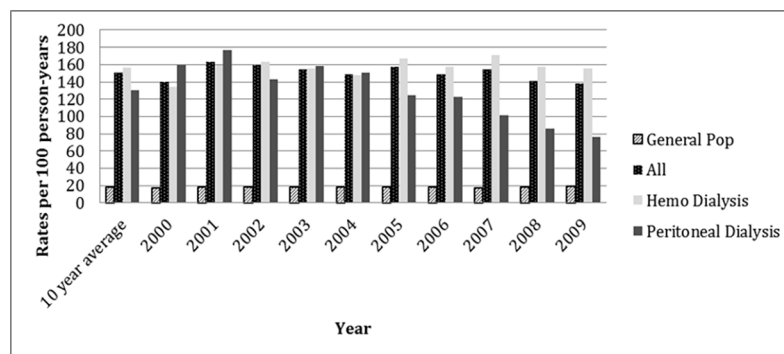

Fig 1. Crude rates of ED visits in dialysis patients vs. the general population.

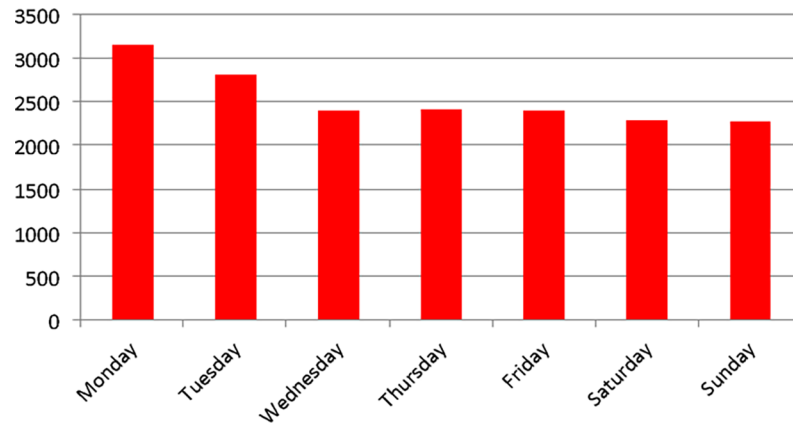https://doi.org/10.1371/journal.pone.0195323.g001

Fig 2. Number of total ED visits by dialysis patients as a function of time and weekday.

was much more pronounced in dialysis patients, where rates were 30% higher on Mondays and 15% higher on Tuesdays (Fig 2).

We also observed a consistent daily trend based on the time of day. In the general population (Fig 3), ED visits showed a relatively bimodal distribution, with a prominent spike in late morning to early afternoon (10:00–15:00) and a slighter peak in the early evening (18:00–20:00). These periods account for approximately 40% of all ED presentations. We also recognized a prominent lull in ED utilization daily in the early morning (1:00–7:00). In contrast, data for the dialysis population (Fig 3) showed generally less distinct diurnal patterns. Of note, a higher proportion of dialysis patients visited the ED in the early mornings of Monday and Tuesday in contrast to this same time in the general population (13.6% vs. 10.4%).

Relationship of ED presentation to timing of dialysis initiation

Among dialysis patients, ED utilization rates differed considerably in the period surrounding dialysis initiation (i.e. time of first dialysis; Fig 4). Several weeks prior to the start of dialysis, rates of ED presentation for incident dialysis patients were found to be higher than that of the general population and of prevalent kidney failure patients. In fact, in the 7 days prior to dialysis initiation, the rate of ED presentation was nine fold higher than the average for prevalent dialysis patients, and nearly 20 fold higher than the general population (14.4 per patient year, $p < 0.001$). In addition, in the 7 days after dialysis initiation there was a four-fold higher rate of ED presentations when compared to the background rate in the average prevalent dialysis
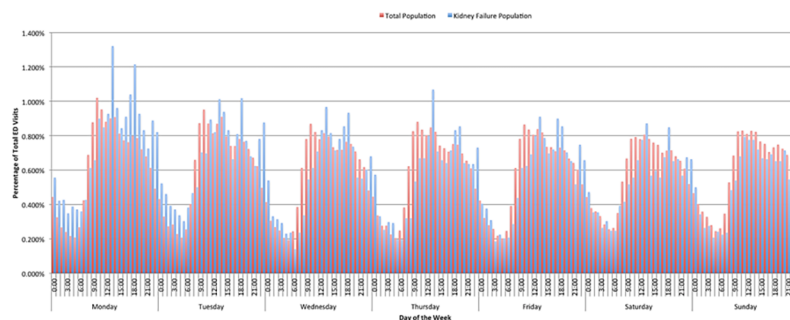

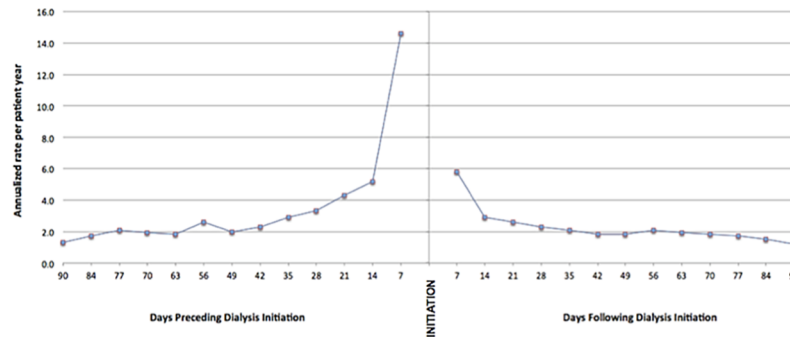**Fig 3. Frequency of ED visits as a function of dialysis initiation.**

Fig 4. Frequency of ED visits as a function of dialysis initiation.

https://doi.org/10.1371/journal.pone.0195323.g004

patient (5.8 per patient year, p<0.001). When comparing modality type, patients initiating on HD were twice as likely to present to the ED as patients starting on PD.

Discussion

In this large population-based study, we found that patients with kidney failure on dialysis experienced more than eight-fold higher rates of ED presentation when compared to an age and sex matched cohort from the general population. Importantly, these rates were not homogeneous, but spiked during defined periods of vulnerability; specifically, on Mondays and Tuesdays following a long interdialytic interval, and in the weeks surrounding the initiation of dialysis.

Current literature has long suggested that patients on dialysis use the health care system more frequently than the general population. This utilization includes resources such as specialized clinics, secondary care services [13, 14], and the ICU [8,14,15,16,17]. Several studies have explored "frequent users" of the ED [2,3,18,19,20], but until recently, the identification of kidney failure as a risk factor for ED use has only been established in studies within smaller single-centre populations [2,6,21]. A recently published population based study examined risk factors for ED use in a US Medicare ESRD cohort [22]. The authors found that ED patients presented 6-fold more often to ER than the general population, consistent with the 8-fold rate found in our Canadian population. Both studies thus validate and generalize the observations of smaller studies. Each of these large studies also contributes complementary information about risk. The US cohort contained significant patient level data on comorbidities and hospital admissions. The majority of ED presentations were attributable to dialysis related issues, such as high potassium, volume overload, and bacteremia. The authors were able to identify a large number of risk factors for ED presentation and admission, including sociodemographic factors (younger age, female sex, black race, institutionalization, insurance type) and comorbid medical conditions such as diabetes. While most of these factors had modest impact on risk (i.e. increased or decreased the OR by 3–4%), the presence of catheter hemodialysis access (vs fistula) was associated with a 22% higher odds of ED presentation, identifying this as a potential target for intervention. In contrast, our study focused on the periodicity of ED visits, and showed that specific epochs (after the long interdialytic interval and around initiation of dialysis) were associated with a sharp increase in risk of ED presentation. The effect of this periodicity was marked (30%-900% higher risk), and greater than for most reported sociodemographic and comorbid disease factors.

Importantly these vulnerable periods identify targets for potential health system interventions. Our observation of higher ED risk after the long interdialytic interval is novel and deeply

concerning in the context of published data from the United States Renal Data Systems (USRDS) showing a higher mortality rate for dialysis patients on Mondays/Tuesdays compared to the other days of the week [23]. The cause of this "post weekend" effect is thought lie in how in-centre dialysis treatments are structured. In-centre hemodialysis patients typically dialyze three times a week: either Monday-Wednesday-Friday (Mo-We-Fr) or Tuesday-Thursday-Saturday (Tu-Th-Sa). The between-dialysis (interdialytic) interval is 48 hours, except for the Fr to Mo and Sa to Tu intervals, which are 72 hours. It is plausible that the longer 72 hour interdialytic interval may lead to progressive fluid accumulation, more severe electrolyte derangements (e.g. hyperkalemia), and greater cardiovascular instability, resulting in higher need for emergent care or death on the last day (Mo or Tu) of the interval. Whether this higher risk for adversity following the long interdialytic interval applies to all dialysis patients, or is restricted to a subset, is a question of critical importance and will need to be addressed in future research. Importantly, while strategies exist to eliminate the long dialytic interval, such as short daily hemodialysis and home hemodialysis, these strategies have implications in terms of patient care burden (higher with home dialysis) and cost to payers (higher with short daily dialysis). The cost-benefit from patient, societal, and payer perspectives will need to be better understood and balanced before clear recommendations can be made.

The observation of more frequent ED visits around the time of dialysis initiation is also novel, and highlights a period of heightened vulnerability for patients with progressive kidney disease. Some of this spike may be attributable to patients presenting in extremis with undiagnosed CKD who require urgent dialysis (so called "crash starts"). Such patients are often first diagnosed in the ED and plausibly contribute to the excess ED visits observed at or around the time of initiation. However, even patients who were known to have started dialysis electively exhibited a higher rate of ED visits around the time of initiation. For example, the subcohort of patients starting peritoneal dialysis exhibited a similar, albeit attenuated, spike in ED visits around the time of initiation.

It is plausible that patients with advanced CKD approaching the need for dialysis may be at higher risk of ED presentation. Advanced CKD patients are often elderly, have a high prevalence of frailty and mild to moderate cognitive impairment, and multiple comorbid diseases, all of which may be adversely influenced by progressive decline in GFR, leading to higher frequency of ED visits for both medical (e.g. fluid overload/hyperkalemia) reasons, as well as accelerated functional decline (e.g. "failure to thrive"). Conversely, the initiation of dialysis carries new potential risks and complications, including hemodynamic instability, hemodialysis access related complications, and inability to cope functionally with the new burden of dialysis treatment, all of which could contribute to increased visits in the immediate post-initiation period. We hypothesize that population-based programs of CKD surveillance will be needed to decrease the incidence of crash starts due to undiagnosed CKD. In addition, home telemonitoring of nephrology clinic patients with advanced CKD may prevent ED presentations and hospital admissions, as has been shown for heart failure patients [24–29]. Similar research in CKD patients is urgently needed.

Our findings have some direct clinical, health policy, and research implications. First, our data provide health care professionals and policy makers accurate estimates of the impact of dialysis patients on ED utilization at a population level. These data can be used to plan additional ED capacity based on growth of the dialysis population [24].

Second, the excess of ED presentations after the long interdialytic interval, in the context of an identical pattern for death reported by others, highlights the need to carefully examine alternatives to standard, thrice weekly hemodialysis regimens. Further research is needed to address which patients are at greatest risk and to identify the most feasible and cost-effective strategies decrease this risk (e.g. short daily dialysis, home dialysis)

Finally, the spike in ED presentations in the few weeks bracketing the initiation of dialysis needs to be better understood, and strategies to mitigate this risk developed and tested.

The major strength of this study is its population-wide, comprehensive data capture. We analyzed large regional databases that tracked over 1.2 million people attending multiple treatment centers serving nearly the entire population of a Canadian Province. This allowed us to generate population based rates and trends of ED utilization for both dialysis and non-dialysis patients over a decade, and to identify periods of risk for ED visits. To the extent that the population of Manitoba is broadly similar to the larger, multi-ethnic and multi-racial Canadian population, and as the causes and kidney failure are similar to other jurisdictions in North America, results of this study should be applicable to other regions in North America. Our study also has some limitations, many of them implicit in the use of administrative data. The datasets we used were extensive and population based, but limited with respect to individual patient level comorbidity data. Additional research will be required to address patient level risk factors for, and outcomes of, ED presentations.

Conclusion

The heavy use of ED services by dialysis patients spikes upward following the long interdialytic interval and also in the week before and after dialysis initiation. Further research on strategies to mitigate the excess health risk during these periods of heightened vulnerability is needed. Specifically, research on interventions to better manage or eliminate the risk associated with long interdialytic interval and to better identify and monitor patients around the initiation of dialysis should be prioritized

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References

1. Niska R, Bhuiya F, Xu J. National hospital ambulatory medical care survey: 2007 emergency department summary. *Natl Health Stat Report*. 2010; 26:1–31.

2. Ondler C, Hegde GG, Carlson JN. Resource utilization and health care charges associated with the most frequent ED users. *Am J Emerg Med*. 2014; 32(10):1215–1219. https://doi.org/10.1016/j.ajem.2014.07.013 PMID: 25154348

3. Pines JM, Asplin BR, Kaji AH, et al. Frequent users of emergency department services: Gaps in knowledge and a proposed research agenda. *Acad Emerg Med*. 2011; 18(6):e64–9. https://doi.org/10.1111/j.1553-2712.2011.01086.x PMID: 21676051

4. Gordon JA, Chudnofsky CR, Hayward RA. Where health and welfare meet: Social deprivation among patients in the emergency department. *J Urban Health*. 2001; 78(1):104–111. https://doi.org/10.1093/jurban/78.1.104 PMID: 11368190

5. Breton M, Brousselle A, Boivin A, et al. Evaluation of the implementation of centralized waiting lists for patients without a family physician and their effects across the province of Quebec. *Implement Sci*. 2014; 9:117-014-0117-9.

6. Miller JB, Brauer E, Rao H, et al. The most frequent ED patients carry insurance and a significant burden of disease. *Am J Emerg Med*. 2013; 31(1):16–19. https://doi.org/10.1016/j.ajem.2012.05.001 PMID: 22795986

7. U.S. Renal Data System. USRDS 2008 annual data report. In: *Atlas of chronic kidney and end-stage renal disease in the united states*. Bethesda, MD: National Institute of Health, National Institute of Diabetes and Digestive and Kidney Diseases; 2008.

8. Strijack B, Mojica J, Sood M, et al. Outcomes of chronic dialysis patients admitted to the intensive care unit. *J Am Soc Nephrol*. 2009; 20(11):2441–2447. https://doi.org/10.1681/ASN.2009040366 PMID: 19729437

9. Winnipeg Regional Health Authority. About us. http://www.wrha.mb.ca/about/aboutus.php. Updated 2015. Accessed 06/23, 2015.

10. Canadian Institute for Health Information. CORR report: Dialysis and renal transplantation. 2006.

11. Sood MM, Komenda P, Sood AR, et al. Adverse outcomes among aboriginal patients receiving peritoneal dialysis. *CMAJ*. 2010; 182(13):1433–1439. https://doi.org/10.1503/cmaj.100105 PMID: 20660579

12. Doupe M, Kozyrskyj A, Soodeen R, Derksen S, Burchill C, Huq S. An initial analysis of emergency departments and urgent care in Winnipeg. 2008; 1(07/02).

13. Erickson KF, Winkelmayer WC, Chertow GM, Bhattacharya J. Physician visits and 30-day hospital readmissions in patients receiving hemodialysis. *J Am Soc Nephrol*. 2014; 25(9):2079–2087. https://doi.org/10.1681/ASN.2013080879 PMID: 24812168

14. Hutchison CA, Crowe AV, Stevens PE, Harrison DA, Lipkin GW. Case mix, outcome and activity for patients admitted to intensive care units requiring chronic renal dialysis: A secondary analysis of the ICNARC case mix programme database. *Crit Care*. 2007; 11(2):R50. https://doi.org/10.1186/cc5785 PMID: 17451605

15. Sood MM, Miller L, Komenda P, et al. Long-term outcomes of end-stage renal disease patients admitted to the ICU. *Nephrol Dial Transplant*. 2011; 26(9):2965–2970. https://doi.org/10.1093/ndt/gfq835 PMID: 21324978

16. Ostermann M, Chang R, Riyadh ICU Program Users Group. Renal failure in the intensive care unit: Acute kidney injury compared to end-stage renal failure. *Crit Care*. 2008; 12(5):432. https://doi.org/10.1186/cc7085 PMID: 18983713

17. Clermont G, Acker CG, Angus DC, Sirio CA, Pinsky MR, Johnson JP. Renal failure in the ICU: Comparison of the impact of acute renal failure and end-stage renal disease on ICU outcomes. *Kidney Int*. 2002; 62(3):986–996. https://doi.org/10.1046/j.1523-1755.2002.00509.x PMID: 12164882

18. Doupe MB, Palatnick W, Day S, et al. Frequent users of emergency departments: Developing standard definitions and defining prominent risk factors. *Ann Emerg Med*. 2012; 60(1):24–32. https://doi.org/10.1016/j.annemergmed.2011.11.036 PMID: 22305330

19. Castillo EM, Brennan JJ, Killeen JP, Chan TC. Identifying frequent users of emergency department resources. *J Emerg Med*. 2014; 47(3):343–347. https://doi.org/10.1016/j.jemermed.2014.03.014 PMID: 24813059

20. Sun BC, Burstin HR, Brennan TA. Predictors and outcomes of frequent emergency department users. *Acad Emerg Med*. 2003; 10(4):320–328. PMID: 12670845

21. Mandelberg JH, Kuhn RE, Kohn MA. Epidemiologic analysis of an urban, public emergency department's frequent users. *Acad Emerg Med*. 2000; 7(6):637–646. PMID: 10905642

22. Lovasik BP, Zhang R, Hockenberry JM, Schrager JD, Pastan SO, Mohan S, Patzer RE. Emergency department use and hospital admissions among patients with end-stage renal disease in the United States. JAMA Intern Med 2016; 176:1563–1565. https://doi.org/10.1001/jamainternmed.2016.4975 PMID: 27548699

23. Foley RN, Gilbertson DT, Murray T, Collins AJ. Long interdialytic interval and mortality among patients receiving hemodialysis. *N Engl J Med*. 2011; 365(12):1099–1107. https://doi.org/10.1056/NEJMoa1103313 PMID: 21992122

24. Antonicelli R, Testarmata P, Spazzafumo L, Gagliardi C, Bilo G, Valentini M, et al. Impact of telemonitoring at home on the management of elderly patients with congestive heart failure. J Telemed Telecare. 2008; 14(6):300–5. https://doi.org/10.1258/jtt.2008.071213 PMID: 18776075

25. Dendale P, De Keulenaer G, Troisfontaines P, Weytjens C, Mullens W, Elegeert I, et al. Effect of a tele-monitoring-facilitated collaboration between general practitioner and heart failure clinic on mortality and rehospitalization rates in severe heart failure: the TEMA-HF 1 (TElemonitoring in the MAnagement of Heart Failure) study. Eur J Heart Fail. 2012 Mar; 14(3):333–40. https://doi.org/10.1093/eurjhf/hfr144 PMID: 22045925

26. Giordano A, Scalvini S, Zanelli E, Corra U, Longobardi GL, Ricci VA, et al. Multicenter randomised trial on home-based telemanagement to prevent hospital readmission of patients with chronic heart failure. Int J Cardiol. 2009 Jan 9; 131(2):192–9. https://doi.org/10.1016/j.ijcard.2007.10.027 PMID: 18222552

27. Leventhal ME, Denhaerynck K, Brunner-La Rocca HP, Burnand B, Conca-Zeller A, Bernasconi AT, et al. Swiss Interdisciplinary Management Programme for Heart Failure (SWIM-HF): a randomised controlled trial study of an outpatient inter-professional management programme for heart failure patients in Switzerland. Swiss Med Wkly. 2011 Mar 8; 141:w13171. https://doi.org/10.4414/smw.2011.13171 PMID: 21384285

28. Kasper EK, Gerstenblith G, Hefter G, Van Anden E, Brinker JA, Thiemann DR, et al. A randomized trial of the efficacy of multidisciplinary care in heart failure outpatients at high risk of hospital readmission. J Am Coll Cardiol. 2002 Feb 6; 39(3):471–80. PMID: 11823086

29. Kitsiou S, Pare G, Jaana M. Effects of home telemonitoring interventions on patients with chronic heart failure: an overview of systematic reviews. J Med Internet Res. 2015 Mar 12; 17(3):e63. https://doi.org/10.2196/jmir.4174 PMID: 25768664