The Impact of the COVID-19 Pandemic on Home Dialysis Modality Use in Canada

by

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Abstract

Background: The majority (~75%) of individuals with kidney failure in Canada receive facility-based hemodialysis, which involves travelling to treatment sessions, often located in a hospital setting, for 4-hour periods, 3 times a week. Both hemodialysis and peritoneal dialysis can be performed by individuals in their own home, yet a minority perform home dialysis. During the COVID-19 pandemic, nephrology societies recommended that individuals receiving facility-based hemodialysis transition to home modalities where possible. The pandemic's effect on transition to home dialysis use and ability to remain on home dialysis in Canada are unknown.

Objectives: To compare the proportion of people with end-stage kidney disease transitioning from facility-based hemodialysis to home dialysis modalities (either peritoneal dialysis or home hemodialysis) in Canada before and during the first 18 months of the COVID-19 pandemic. We also compared differences in initiations on facility-based hemodialysis, home dialysis failure (transition to facility-based hemodialysis) rates, reasons for failure on home dialysis, and risk factors for failure between these two time periods.

Methods: Using administrative data from the Canadian Organ Replacement Registry (CORR), we performed an interrupted time-series analysis comparing monthly trends in transition to and failures on home dialysis during the pre-pandemic period (Jan. 1, 2016 – Dec. 31, 2019) to the pandemic period (Apr. 1, 2020 – Sept. 30, 2021). A transition period was defined as Jan. 1, 2020 – Mar. 31, 2020. All individuals who spent any time on hemodialysis during the study period were included in the study cohort. Transitions to home dialysis were defined as moving from facility-based hemodialysis to a home modality for >30 days. Home dialysis failures were defined as moving from a home modality to facility-based hemodialysis for >30 days. Logistic regression models examined predictors of home dialysis failures between time periods.

Results: In total 31,596 and 22,607 unique individuals were prevalent on facility-based hemodialysis at some point in the pre-pandemic period and during the pandemic period, respectively. There was an increase in transitions from facility-based hemodialysis to home dialysis over the course of the pandemic relative to the pre-pandemic rate of transitions (trend change = 0.0000595, p=0.0271). Home dialysis failures within our cohort increased (trend change = 0.000357, p=0.0450) but facility-based initiations did not change during the pandemic as compared to pre-pandemic. In our cohort, more home dialysis failures due to peritonitis (9.2% vs 7.3%; p = 0.0423) and resource-related reasons (5.8% vs 2.7%; p <0.0001) and fewer failures due to dialysis recipient/family burnout (4.3% vs 5.9%; p=0.0307), occurred during the pandemic period.

Conclusion: The observed increase in transitions from facility-based hemodialysis to home dialysis suggests that recommendations from nephrology societies to facilitate these transitions to mitigate COVID-19 related risks where possible were implemented by kidney programs across the country. Study methodology did not allow us to definitively identify whether the increase in home dialysis failures was attributable to excess transitions from facility-based hemodialysis or other pandemic-related factors. Observed differences in reasons for home modality failure between study time periods suggest pandemic-related factors may have magnified failure risk factors in this population.

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Introduction

Chronic kidney disease is a condition that affects nearly 700 million people worldwide.[1] According to international consensus reached in 2005, chronic kidney disease (CKD) is defined as having kidney damage and/or a diminished estimated glomerular filtration rate (eGFR), under 60 mL/min/1.73 m^2 for 3 or more months.[2] CKD exists on a continuum, at the most advanced end of which is end-stage kidney disease, characterized by eGFR < 15 mL/min/1.73 m^2 and requiring kidney replacement therapy in forms such as hemodialysis, peritoneal dialysis or kidney transplantation to sustain life.[3] As kidney transplantation is not always possible or immediately feasible given limited organ availability, dialysis therapies are used for at least some period of time in the care of most individuals with end-stage kidney disease. Dialysis therapies filter toxins from the body and remove water that an individual's failing kidneys are no longer fully capable of removing.

In the last 50 years, dialysis has developed from being a life-support treatment for a select few to a routine therapy for many.[4-6] The majority (~75%) of individuals on dialysis in Canada receive facility-based hemodialysis, which generally involves travelling to treatment sessions, often located in a hospital setting, for 4 hour periods, 3 times a week. Peritoneal dialysis and home hemodialysis are two alternative options to facility-based hemodialysis. A February 2020 review reported that the Canadian individuals on peritoneal dialysis, which makes use of the body's peritoneal membrane to filter wastes, constituted roughly 20% of the overall population on kidney replacement therapy, while those using home hemodialysis accounted for 4-5%.[7] Use of home modalities is cost-effective,[8-11] safety and efficacy are on par with facility-based hemodialysis,[9,12,13] and quality of life is typically better. However, a minority of individuals choose and remain on home modalities and it is unclear whether the pool of individuals receiving home dialysis modalities can be expanded from the current population, which tends to have better functional status and fewer comorbidities than the population receiving facility-based hemodialysis.[9,14-16]

The COVID-19 pandemic in Canada presented many challenges for individuals with end-stage kidney disease who receive life sustaining facility-based hemodialysis treatment. Due to close proximity of individuals on dialysis and their frequent interactions with multiple different healthcare providers in the hemodialysis unit, facility-based hemodialysis sessions posed high levels of risk of COVID-19 transmission to an already immunocompromised end-stage kidney disease community. Moreover, direct reductions in the proportion of patients receiving a transplant during the COVID-19 pandemic due to periodic internal hospital resource reallocations, organ procurement and shipping challenges, and recommendations to cancel transplant surgeries led to an increased need for facility-based hemodialysis. In view of the uniquely high risks of infection and mortality posed to individuals on facility-based hemodialysis by COVID and its secondary effects, the Canadian Society of Nephrology (CSN) released recommendations to preferentially offer all prevalent and incident individuals requiring dialysis the opportunity to transition to home dialysis modalities.[17,18,19] However, it is unknown if these recommendations were acted upon and if rates of transition from facility-based hemodialysis to home dialysis modalities increased in Canada during the COVID-19 pandemic. The purpose of this time-series analysis was to compare the proportion of individuals receiving facility-based hemodialysis who transitioned to home dialysis modalities during the COVID-19 pandemic to time periods prior to the COVID-19 pandemic in Canada. In addition, to help healthcare providers potentially expand criteria, education, and resources to increase eligibility for and transition to home dialysis and lead to higher penetrance of home modality use in individuals with end-stage kidney disease, we subsequently compared failure rates for (withdrawal from) home dialysis in this population during these two time periods. Moreover, we assessed the effect of key demographic and clinical characteristics on the risk of home dialysis failure during the COVID-19 pandemic.

Review of the Literature

Elevated risk from COVID-19 among individuals with end-stage kidney disease: First pandemic pressure

According to data from the Canadian Institute for Health Information, the first cases of COVID-19 emerged in Canada on January 31, 2020 in British Columbia and Ontario.[20] The severity of COVID-19 infection rates varied widely in the first wave, which took place from approximately January 31 to June 30, 2020.[20] The summer (July 1 to August 31, 2020) had consistently low case counts and was followed by a second wave beginning around October 1, 2020 and ending on January 31, 2021, a third wave from about February 14 to July 1, 2021, a fourth wave from July 1 to December 1, 2021, and the beginning of a fifth wave that lasted from December 1, 2021 to March 15, 2022.[20] In tandem with the onset of the third wave, the vaccine rollout period began around February 1, 2021, and this drastically reduced relative risk of hospitalization for SARS CoV-2 infection in people receiving dialysis.[21]

Health authorities needed to act quickly to implement changes to facility-based hemodialysis care when the pandemic began. For people with end-stage kidney disease that do not have a kidney transplant, dialysis is needed to sustain life and is unavoidable, so remaining home and forgoing treatment was not an option during the pandemic. People receiving hemodialysis are typically required to travel to a hemodialysis unit three times a week, usually located in a health facility, where nurses and health care aides provide care to multiple individuals on dialysis per shift in unavoidable proximity, with individual hemodialysis stations typically being less than the pandemic-recommended 2 metres apart. Some individuals on dialysis communally travel to and from sessions, and all encounter more contacts in the waiting room prior to and following their hemodialysis appointments.[22] Other risks included frequent comorbid conditions of individuals on dialysis and kidney failure-associated immunocompromise which significantly increased their risk of acquiring COVID-19 and worsened their COVID-19 prognoses.[23] A study of COVID-19 infections among individuals on dialysis within Ontario from March to August, 2020, found that 1.5% of the population receiving long-term dialysis contracted COVID-19 in this time frame, which was 500% the rate of the general population in Ontario during the same time period.[24] Other studies in Qatar and the United States found similar results, with all additionally noting decreased infection rates among people on home modalities compared to those receiving facility-based hemodialysis.[24-27] Studies in China, Italy, the United Kingdom and United States found that people receiving dialysis who contracted COVID-19 experienced higher mortality and more severe outcomes than the general population. [28-33] Among people receiving dialysis, those who contract COVID-19 have an approximate 20% chance of dying as a result of the disease.[34-36] By contrast, individuals undergoing home dialysis in France had 0.6 times the odds of infection compared to their counterparts undergoing facility-based HD (95% CI 0.4-0.8), while people receiving facility-based HD in Italy had roughly 3 times the odds of contracting COVID-19 relative to those on home modalities.[35,36] Even after vaccination, people receiving dialysis experienced a diminished immunologic response to vaccines compared to the general population.[21,37]

Notably, people receiving dialysis that were included in France's end stage kidney disease registry and who had at least one COVID-19 vaccine dose between March 11, 2020 and April 29, 2021 showed about a three-fold reduction of hospitalization risk compared to those who did not receive a vaccine dose.[21] The same study found that each 10% increase in COVID-19 vaccination coverage in any age category of the general population translated into a decrease in incidence of severe infections in people receiving dialysis of the same age category by 50% (IRR = 0.50, 95% CI: 0.40 to 0.61). This showed that COVID-19 vaccine exposure was independently associated with reduced hospitalization rates in people receiving dialysis when compared with the general population of the same age.[21]

While these data were unavailable at the start of the pandemic when care providers had to initially make transition decisions, Canadian dialysis providers pre-emptively anticipated the adverse effects of unit COVID-19 outbreaks on individuals receiving facility-based hemodialysis, doctors, nursing staff and overall healthcare systems. A formal recommendation to transition from facility-based hemodialysis to home modalities where possible was part of the strategy to address this.[17,22,38,39]

Within these deliberations, ensuring individuals with kidney failure received dialysis treatments one way or another remained an immovable concern as dialysis is required to sustain life in this population.

Reductions in individuals receiving kidney transplants: Second pandemic pressure

In 2019, a total of 1,789 kidney transplant procedures for individuals with end-stage kidney disease were completed in Canada, an increase of 4.8% from the prior year (n=1706), and in keeping with a consistent trend towards increased transplantation rates over the prior 10 years.[40,41] Compared to 2019, organ transplants in 2020 decreased as a whole by 14%, and kidney transplantation decreased by 22.6%.[42] Observed decreases were attributable to the pandemic's pressure on hospital resources, the severity of protocols to protect organ donors and recipients from COVID-19, and a sharp decrease in deceased donor transplants (i.e.; reduced fatal car accidents due to decreased travel).[18,19] The record of when transplant surgeries were formally halted/permitted to resume and what occurred indeed are likely different between regions, given the lack of documentation regarding specific institutional resource limits over time. In any case, the CIHI timeline of COVID-19 pandemic intervention data charts the dates on which all formal delays and resumption of medical procedures occurred (Table 1 in Appendix).[20]

When initial data confirmed assumptions that COVID-19 risks of severe infection and mortality were heightened in the end-stage kidney disease population, some practitioners wondered whether kidney transplantation was associated with a survival advantage from COVID-19 compared to those on dialysis.[43] Contradicting this sentiment, a study of the European Renal Association COVID-19 Database (specifically made to collect data on kidney transplant and individuals on dialysis with COVID-19) found that individuals who contracted COVID-19 in the first three months of the pandemic and who were in their first year post-transplant were at increased risk of COVID-19 related mortality compared to people receiving dialysis who were on the waiting list for transplantation.[44] Once analyses were adjusted for age, sex, and frailty, however, in-hospital mortality no longer significantly differed between people with a kidney transplant and people receiving dialysis.[44] A study from Brazil found that, compared to people receiving dialysis who contracted COVID-19, a higher percentage of people with a kidney transplant infected with COVID-19 required hospitalization (51% vs 68%, $p<0.001$), intensive care (30% vs 37%, $p = 0.023$), and invasive mechanical ventilation (22% vs 28%, $p=0.035$).[45] Moreover, relative to people receiving dialysis who contracted COVID-19, 30-day fatality was higher among the transplant group according to Kaplan–Meier analysis with propensity score matching (78% vs 83%, $p =0.0014$). Thus overall, several difficulties surrounded kidney transplant timing during the COVID-19 pandemic. Transplantation results in a period of high immunosuppression, with greater predisposition to succumbing to COVID-19 if infected. Meanwhile, people who are transplant candidates but remain on dialysis are subject to the ever-present associated greater mortality with this kidney replacement therapy as compared to transplantation.[46]

Ultimately in balancing these competing risks, transplantation was resumed during the second wave of the pandemic, albeit with variation in how this occurred and the degree to which transplants were treated as urgent surgeries and prioritized across provincial programs and in different centres. Still, programs variably had repeated interruptions in kidney transplantation, depending on provincial circumstances and COVID-19 prevalence.[47] Generally, programs also developed provincial/local guidelines for reinitiating transplants based on a balance of risk mitigation and medical urgency. Importantly, the overall decrease in transplant rates led to increased demand for facility-based hemodialysis leading to capacity issues in many hemodialysis units across Canada.[38] This made following pandemic restrictions difficult within hemodialysis centres and introduced an additional pressure to transition an increased number of individuals to home modalities where possible.

Benefits of home dialysis

Home dialysis modalities include peritoneal dialysis (PD) and home hemodialysis (HHD), with variations in treatment schedules for each modality. Peritoneal dialysis involves filling the peritoneal cavity with a clear glucose-containing fluid called dialysate that collects waste and removes water over time and is then drained through a catheter in the abdomen, in what is called a PD exchange.[48] Contrary to facility-based hemodialysis, people choosing PD typically dialyze seven days a week. Modalities fall into two general categories. Continuous ambulatory PD (CAPD), which is often the first method to be taught and involves manually setting up the 30-minute PD exchanges four to five times a day. While the fluid dwells in the abdomen for 4-5 hours per PD exchange, the individual is able to do usual daily activities and is not required to be at home. Automated PD (APD), is a broad term for all forms of PD using a mechanical device to assist in the delivery and drainage of the dialysate that is carried out overnight for about nine hours.[48,49] PD training is provided by PD nurses in-hospital and takes 3-5 days to complete. Beyond training, PD nurses are available by phone in the PD unit for any questions and help with trouble shooting problems related to PD treatment and there are typically support lines of communication for issues with PD machines once people return to their home after training.[49] Like facility-based hemodialysis, HHD involves filtration of toxins by taking a small amount of blood and cleaning it outside the body by the use of an external dialysis filter (instead of using the peritoneal membrane as a naturally-occurring filter), however the treatment schedules can be nocturnal HHD (overnight while sleeping), short daily HHD (four to six days a week for three to five hours), and conventional HHD (three or four days a week for four hours).[50] HHD training is provided by HHD nurses at the hospital but it is more time and resource-intensive than PD training, as it takes six to ten weeks to complete. HHD unit staff are available by phone to answer questions and trouble shoot issues when required once people return to their home after training.[50] Naturally, home dialysis generally removes the requirement for frequent travel to facility-based appointments, with PD and HHD clinic review visits generally scheduled every 3 to 6 months rather than three times per week for facility-based hemodialysis.

The first reported implementation of home dialysis modalities were in 1962 and 1964 for peritoneal dialysis and HHD respectively, with the development of continuous ambulatory peritoneal dialysis (CAPD) in 1978 later offering a simpler alternative to the then highly-complex HHD machines.[4-6] Home hemodialysis ultimately declined in use but more recently has been experiencing renewed interest, with approximately 5% of Canadians receiving dialysis using it today.[7] Conversely, PD has maintained popularity as the home dialysis modality of choice, now constituting about a 20% share of Canadian dialysis.[4,7] PD offers greater flexibility, because when properly trained, individuals are able to modify their PD prescription to their daily activities if needed, perform dialysis while travelling without the need for facility support, and generally have increased autonomy and independence.[51] It also permits individuals to follow a more liberal diet than that which is required when on facility-based hemodialysis. [52] The challenge with literature comparing quality of life across dialysis modalities is the persistent confounding by the typically healthier home dialysis population, as they often have better functional status and fewer comorbidities. Notably, a study comparing quality of life in individuals on PD to that among facility-based hemodialysis individuals found better health-related quality of life after adjusting for clinical and socioeconomic characteristics.[53]

Further complicating comparisons, the quality of life benefit for each modality has been poorly defined across studies with varying degrees of effect and, in some cases, directionality of differences.[9,14-16] Although a 2020 systematic review of differences between facility-based hemodialysis and PD and HHD found no consistent statistically significant differences in global quality of life for up to 24 months after starting dialysis, there were significant differences in specific QoL domains between the individual home modalities and facility-based hemodialysis.[54] Between facility-based hemodialysis and HHD, these included improvements in "burden of kidney disease" and "general health" with HHD, with both domains surpassing a minimally clinically important difference threshold compared with facility-based hemodialysis after 6 months.[54] In fact, there are over 20 years of mounting evidence suggesting that nocturnal HHD schedules, where individuals dialyze overnight, are associated with superior health-related quality of life compared to facility-based hemodialysis, very likely due to the increased duration of dialysis intrinsic to nocturnal HHD. [55-59] Taken together, the potential benefit to quality of life and the innate flexibility afforded by home modalities, particularly for individuals living at long distances from hospital settings, make them potentially more attractive to some individuals who may not fit current eligibility criteria for home dialysis. In fact, years of study of the optimal dialysis modalities for people with end-stage kidney disease, have demonstrated that people tend to use more than one form of kidney replacement therapy over the course of their journey with end-stage kidney disease. Some programs outside of Canada have adopted a PD-first policy which has shown promise in terms of survival and cost optimization.[60]

Howell et al.'s 2019 systematic review of economic evaluations of dialysis modalities found that among 16 included studies, almost all suggested that home dialysis options – whether PD, HHD, or a combination of the two – are less costly while offering similar or better health outcomes compared to facility-based HD.[9] A notable limitation of this review is that most of the included studies only reported average cost-effectiveness ratios which are less useful for decision-making regarding movement between modalities than incremental cost-effectiveness ratios, as the former conceals the relative costs and benefits of the different interventions.[9,61] A population-based study within Ontario, Canada found that at 5-years post dialysis-initiation, which is the median survival time on hemodialysis, mean 30-day costs for people receiving PD and HHD were 50% and 64% lower respectively, than for people receiving facility-based hemodialysis. With adjustment for a summed quantitative measure of comorbidity for each individual, consisting of clinical similarity, chronicity, likelihood of requiring specialty care, and disability, mean 5-year cumulative costs were similar between individuals receiving PD and home HD ($304,178 and $349,338) and higher for those who started in facility-based hemodialysis ($410,981).[11] Furthermore, past studies have failed to outline the cost effectiveness of more realistic, complex pathways of care which involve multiple transitions.[9,60]

Barriers to home dialysis uptake

Several interrelated barriers surround home dialysis uptake. From an individual's perspective, fears of making mistakes, getting infections, not receiving adequate treatment and supervision, or having a catastrophic event occur at home when self-administering dialysis commonly arise.[62-64] Some individuals are reluctant to medicalize part of their home with the designated sterile space required for home dialysis, especially if they have minimal living space to begin with.[63] For many individuals in remote northern communities in Manitoba, home environment limitations, including absences of safe running water, crowding, and poor temperature regulation preclude home dialysis options.[65]

Impaired cognitive ability and physical function, common in end-stage kidney disease, can limit individuals' ability to perform home dialysis and may impact whether options for this modality are even discussed. [65-67] While populations on home dialysis have historically been younger, less frail, and healthier than those on facility-based HD, assisted home dialysis, in which nurses or caregivers are formally trained and assist in home-based modalities, have been emerging as a way to broaden the eligible population for home dialysis.[67] Local assisted PD sites, where individuals find sufficient storage space for dialysis supplies, adequate running water, and a nurse to help with select parts of treatment as needed have started showing value in Australia, New Zealand, and British Columbia as a method to minimize the unique challenges of dialysis in rural and remote areas and the costs associated with facility-based hemodialysis.[65,68]

Physicians' attitudes towards home dialysis may influence individuals' beliefs. Some nephrologists have had little experience with home modalities during their training or are not well educated about them, so may not propose home options to individuals needing dialysis or have well-developed educational programs for those potentially capable of home dialysis.[69-71] Notably, a study of UK nephrologist attitudes found that their notions of the ideal proportions of individuals treated with PD and HHD were positively correlated with the proportions of the individuals who they were treating with these modalities ($R^2 = 0.15$, $p = 0.02$ and $R^2 = 0.16$, $p = 0.001$ respectively).[72] More broadly, a 2014 national Canadian survey of HHD practice patterns identified wide variation in the approaches of different kidney care programs to most aspects of HHD delivery in Canada, including recruitment of individuals on dialysis, human resources, water access, training, home requirements, follow-up of individuals, allowance of self-administration of certain medications, and the approach to non-adherent individuals.[73] Thus, it is difficult to predict the COVID-19 pandemic's effect on transition rates to home modalities across different regions.

The personal and systemic benefits of home dialysis may make it worthwhile to offer it more uniformly as an option, even beyond the unique necessity and challenges of the pandemic. Several systematic reviews of modality cost analyses in the last decade have found that home dialysis is associated with lower costs and better survival than facility-based dialysis, with home dialysis having higher start-up costs in the short term which are ultimately offset by cost savings.[8,9] Moreover, avoiding dialysis facilities means avoiding the well-established associated risks of contracting communicable diseases therein.[74,75]

Home dialysis failure rates and reasons

Home dialysis technique failures and their corresponding risk factors and stated reasons established prior to the pandemic must be considered when assessing modality effectiveness. Technique failures on home dialysis are defined as permanent unplanned transitions from home dialysis to facility-based hemodialysis (generally >30 days, although up to >60 days depending on definition).[52]

Most of the literature on home dialysis technique failures focuses on identifying risk factors associated with technique failure while remarkably few examine individual-level reasons for failures as detailed in medical records.[76] From expert opinion and synthesis on reasons for HHD failure,[76] Paterson et al.'s cohort study of 167 Canadian individuals on HHD,[77] Shah et al.'s study of transitions from HHD among 94 individuals from an Albertan HHD centre,[78] Chaudhary's review on causes of PD dropout,[79] and Workeneh et al.'s single-centre study of technique failure among 128 individuals starting on PD,[80] home dialysis technique failures seem to be multifactorial and can be modality-related, system-related or related to the individuals on dialysis (social and medical). (see Table 4 in Appendix for summary).

Modality-related reasons for PD failure include peritonitis, catheter dysfunction, inadequate filtration of the blood (ultrafiltration failure and volume overload), and hernia, peritoneal leak, or other surgical complications. [79-81] Reasons for HHD failure include dialysis access issues, cannulation difficulties, change in access site/type, malfunctioning dialysis equipment, change in water quality, plumbing issues, inadequate dialysis monitoring, and an individual's use of a new psychoactive medication (ie: opioids) prohibiting self-management.[76]

At the system level, studies have found an association between low number of PD individuals attached to a centre (ie: small facility size) and high technique failure rates and low survival.[82-84,85,86] It has been repeatedly posited in the literature that a self-perpetuating cycle may develop where low numbers of people on PD may translate into little training or expertise among practitioners, which then affects their ability to problem solve when facing possible technique failure with resultant transfer to facility-based hemodialysis more readily.[79] For HHD, studies seem to show an opposite effect, with a smaller center size (ie: fewer attached individuals on dialysis) being associated with lower mortality.[87]

Social reasons for PD dropout include inadequate education at treatment initiation, geography and distance from care teams' bases of operation, and possibly burnout/fatigue from having to self-care and undergo dialysis, which is known to be physically draining.[79] Social reasons for HHD dropout similarly include burnout of the individual on dialysis/their caregiver,[76] marital dissolution and loss of residence, eviction, loss of a support system, and non-adherence to dialysis treatment due to cognitive issues.[77]

Relocation is shared as a socially-related cause for failure between individuals on HHD and PD, and accounts for a significant proportion of technique failures for HHD (25% in Paterson et al.'s study).[79,88] It is unclear from the literature whether, and if so, how much relocations are intentional moves to be closer to hemodialysis facilities or unrelated to migration towards hemodialysis facilities. Absence or loss of support systems has also been shown to exacerbate the aforementioned factors for individuals on PD and HHD.[88,89] Issues with physical space at residences and having insufficient family and social support are also disproportionately reported reasons for home dialysis failure among individuals in the lowest income quintile.[90]

Medical reasons for technique failure largely differ between PD and HHD. For PD, reasons include peritonitis, abdominal surgeries/hernia, malnutrition, and/or excess protein loss.[79] Potential medical causes for HHD technique failure include bacteremia or other infections, hypotension (a potential side-effect of hemodialysis), and other major surgical procedures.[76] Strokes or severe illnesses that limit manual dexterity affect both individuals on PD and HHD, as it directly inhibits their ability to self-manage for treatments.[76,79] Catheter-site infection risk has been shown to be similarly high risk between home and facility-based dialysis modalities; however, this may reflect the generally healthier population on home modalities, who tend to be younger and have fewer comorbidities.[91] Thus, modality-related reasons for home dialysis attrition may be found to differ if the population using the modality becomes more reflective of the overall dialysis population and there are insufficient accompanying adaptations to training and community supports.

Risk factors for technique failure are moderately consistent across studies, with diabetes and age being associated with greater failure risk for HHD; with Medicaid enrolment in the United States and male sex being associated with greater failure risk for PD; and obesity, black race in the US, and smoking being associated with greater failure risks for both PD and HHD.[81,85,86,92] Frailty, a multidimensional cluster, defined by Fried as having three of a list of commonly co-occurring factors - unintentional weight loss, exhaustion, slow gait speed, muscle weakness, and low levels of physical activity- has been associated with a more than 2-fold higher risk of technique failure or death in individuals undergoing both forms of home dialysis.[52,91,93]

Education level has been shown in two separate retrospective studies to have associations of ambivalent direction with PD technique failure rates.[94,95] This could suggest that this outcome is dependent on education levels in different jurisdictions, which adds impetus for conducting such analyses separately across Canadian jurisdictions, as numbers allow. Among the few studies examining

HHD technique failure, it is apparent that none have examined education level as a risk factor. At least for peritoneal dialysis, technique failures are often entangled with the same structural inequities in the social determinants of health which predispose people experiencing lower socioeconomic status, structural racism, and marginalization to kidney failure. Alternatively, the varying association of education level with PD technique failure rates could indicate variation in the educational level that PD is taught at in different jurisdictions.

Of further note, in a recent Canadian cohort study, death while on HHD was a small contributor to program exit (<5%), and tended to occur later in therapy (after 32 months) relative to other reasons for exit.[88,96] A cohort study of nocturnal HHD found that this modality was associated with excellent adverse event-free survival, with adverse events defined as a composite of death and technique failure.[96] It must be highlighted that this study was carried out among a dialysis population with a mean age of 45.7 which underrepresents the typically older population (ie: the mean age of prevalent individuals on dialysis is 64 with 55% of individuals in 2019 aged 65 or older).[7,41]

During the pandemic, additional factors such as difficulty with securing dialysis supplies due to stressed supply chains, getting remote advice on access and technical issues, and having less perceived support for emergencies may have impacted technique failure.[97] In-person access to home dialysis units for assistance may have been constricted by individuals requiring dialysis and programmatic hesitancy due to concerns of COVID transmission. In addition, individuals on dialysis have increased prevalence of mental health issues that may have been further exacerbated by social isolation during the pandemic, with potential increases in home dialysis failures as a result.[97]

Two nationally representative matched cohort studies comparing individuals on HHD and PD - one in the United States and the other Canadian - found that HHD was associated with less technique failure than PD, although the Canadian study found that the beneficial association of HHD only manifested after the first year of dialysis.[85,98] Although candidates are carefully selected and trained for home-based therapies and cared for and supported by multidisciplinary teams, 30-55% of individuals on home dialysis sustain technique failure within 2 years.[99-102] Failure is often traumatic and associated with high early mortality, with approximately 60% survival one year after transition from continuous ambulatory PD.[89,102,103] Moreover, rates of death, transfer to facility-based HD, and the composite end-point of either death or transfer to HD have decreased in recent decades, primarily thanks to reductions in infection-related transfers.[89,104] Notably, while infection-related failure has been found to be independently associated with premature mortality, the association between social-related failure and premature mortality can likely be explained by the greater comorbid burden in the individuals who experience social-related failure.[105,106]

Scan of changes to home dialysis uptake pre- and post-pandemic

As of 2008, Canada was one of nine countries out of 36 major countries that had more than 20% prevalence of home dialysis usage among individuals on dialysis.[107] Still, Canadian kidney health teams and administrators are increasingly working to make the option available to more individuals. For example, a series of targeted interventions in the Ontario Renal Network involving regular meetings between physicians and administrative leadership, specific bundled payments for each home modality, standardised data reporting and accountability for achievement of home modality targets yielded an increase from 21.9% home modality usage in 2012 to 26.2% in 2019.[108] In this population, the age gap between home dialysis and facility-based populations closed, but failure rates did not increase.[108] This lends support to the hypothesis that there is room for expansion of eligibility given sufficient focused efforts.

The general challenges of home-based therapy remained during the pandemic. Regardless of the increased pressure to transition individuals to home dialysis modalities, timely dialysis access placement, sufficient training and sustained support still needed to be available.[109] A valuable study of the incidence and outcomes of peritoneal dialysis in British Columbia during the first 10 weeks of the COVID-19 pandemic found that while overall dialysis initiation was lower than expected based on the prior 10-year trend (41.3/million population versus 45.7/million population), the incidence rate of PD was higher than expected (18.2/million population versus 16.3 million population, 95% CI: 14.0-19.0).[110] Importantly, there were no signs of higher rates of early peritonitis among individuals initiating PD compared to prior years, although the authors note that their findings did not capture other catheter-related complications.[110] In a study of individuals from the United States Renal Data System in the first half of 2020, Wetmore et al. (2021) exclusively focused on dialysis-naïve individuals .[111] Notably, the authors found that facility-based hemodialysis initiation among all Americans requiring dialysis decreased relatively more than PD initiation. Since people who typically initiate PD are often healthier and have higher health literacy than their peers initiating HD, the larger decrease in people starting facility-based hemodialysis could have been attributable to this population's relative challenges in starting dialysis during the pandemic. A more recent study from the United States, including 2021 data found that home dialysis prevalence continued falling further below forecasts in the year of 2021 based on pre-pandemic trends.[112] Taken together, the current data on home dialysis usage indicate there may have been a significant shift in home dialysis uptake during the pandemic in Canada, with little knowledge about what changed in individuals' experience on home modalities.

Understanding the efficacy of facility-based hemodialysis to home dialysis transitions and the reasons for home dialysis failures during the COVID-19 pandemic, particularly among hesitant populations and those in challenging logistical and social environments will help care providers update their concept of eligibility for home dialysis, gain an understanding of current barriers faced, and plan for adjustments to education around home dialysis options to facilitate increased use of these modalities.

Research Questions

Through interrupted time series analysis of administrative data from the Canadian Organ Replacement Register (CORR) (research question 1)[113] and secondary analyses (research questions 2-5), we aimed to answer the following questions:

Research Question 1

Did the proportion of transitions from facility-based hemodialysis to home dialysis (either peritoneal dialysis or home hemodialysis) change during the first 18 months of the pandemic (April 01, 2020 - September 30, 2021) compared to historical trends drawn from data from February 01, 2016 through December 31, 2019?

Hypothesis 1

The proportion of individuals transitioning from facility-based hemodialysis to home dialysis increased during the first 18 months of the COVID-19 pandemic (April 01, 2020 - September 30, 2021) relative to secular trends established from February 01, 2016 through December 31, 2019.

Research Question 2

Did rates of facility-based hemodialysis initiation change during the first 20 months of the pandemic (April 01, 2020 - December 31, 2021) compared to historical trends established from January 01, 2016 to December 31, 2019?

Hypothesis 2

The number of facility-based hemodialysis initiations among dialysis naïeve individuals decreased during the first 20 months of the pandemic (April 01, 2020 - December 31, 2021) compared to historical trends established from January 01, 2016 to December 31, 2019.

Research Question 3

In the cohort that transitioned from facility-based hemodialysis to home dialysis, did the proportion of home hemodialysis failures change during the first 18 months of the pandemic (April 01, 2020 -

September 30, 2021) as compared to historical trends established from February 01, 2016 to December 31, 2019?

Hypothesis 3

A higher proportion of home dialysis failures occurred in this cohort in the first 18 months of the pandemic (April 01, 2020 - September 30, 2021) compared to historical trends established from February 01, 2016 to December 31, 2019.

Exploratory Research Questions

Research Question 4

In the cohort that transitioned from facility-based hemodialysis to home dialysis, did reasons for home dialysis failures change when comparing the 18 months preceding the washout period (July 1, 2018 – December 31, 2019) to the 18 months following the onset of the pandemic (April 01, 2020 - September 30, 2021)?

Hypothesis 4

The reasons for home dialysis failure (ie: number of failures for each given reason divided by the number of total failures in the given period) will differ between the two time periods.

Research Question 5

What risk factors (sex, age, demographic characteristics, distance from a dialysis facility, comorbidities) were associated with home dialysis failure in the cohort that transitioned from facility-based hemodialysis to home dialysis, when comparing the pre-pandemic period (February 01, 2016 – December 31, 2019) to the pandemic period (April 01, 2020 - September 30, 2021)?

Hypothesis 5

Failures in the given population will be associated with age, time on dialysis, diabetes, distance from a dialysis centre, and lower income quintile in both time periods.

Methods

Study design

Using administrative data from the Canadian Organ Replacement Registry (CORR) housed at the Canadian Institute for Health Information (CIHI), we performed a retrospective interrupted time-series analysis comparing monthly trends in clinical outcomes during the pre-pandemic period (Jan. 1, 2016-Dec. 31, 2019) and the pandemic period (Apr. 1, 2020 – Dec. 31, 2021), while treating the time when pandemic-related changes were rapidly implemented (Jan 1, 2020-Mar 31, 2020) as a transition period. CORR is a national longitudinal database that captures comprehensive individual-level data in individuals receiving kidney replacement therapy from provincial programs and participating dialysis centers across Canada (excluding Quebec). [114] Among quasi-experimental studies, interrupted time-series (ITS) studies are considered the most robust, as they are able to differentiate the effect of the intervention from the change that would have occurred temporally apart from the intervention.[115,116,117] This study accomplished this by comparing shifts in levels (e.g; immediate absolute change in proportions of home dialysis transitions) and trends (i.e.; slope) from before and after the distinct study periods. ITS studies show the nuances in slope and level changes for outcomes of interest, like the length of the onset period of a change, whether the effect persists between and within time periods or not, and both immediate and long-term intervention or exposure effects.[117]

Study sample and data collection

The study population included all adult (≥ 18 years old) individuals registered in CORR who were receiving hemodialysis as of December 31, 2015 (prevalent) and any newly registered maintenance dialysis individuals who were on hemodialysis at least once from January 1, 2016 to December 31, 2021. Individuals residing in Quebec were excluded due to provincial data privacy laws restricting use of deidentified data without first-person consent. In 2019, 23,125 individuals were receiving maintenance dialysis. [118]

Cohort creation

Individuals were excluded if they died, withdrew from treatment, or had a transplant within the first 90 days of their entry into the CORR database (Figure 1). This was further intended to incidentally exclude individuals with acute kidney injury or those who had recovered kidney function within the first 90 days.[119] An individual's initial modality could be home dialysis (PD or HHD) or facility-based hemodialysis and was defined as the first modality they received for at least 30 days. A combination of consecutive facility-based hemodialysis arrangements (i.e; moving from an acute care hospital to a chronic care hospital for hemodialysis) that themselves did not amount to 30 days but, together, did amount to 30 days were considered valid as one facility-based hemodialysis period. The same was true for home dialysis arrangements. Transfers of less than 30 days from a facility-based modality to a home modality or vice versa were not considered transitions or failures. In such cases, the individuals were considered as having never left their original modality.

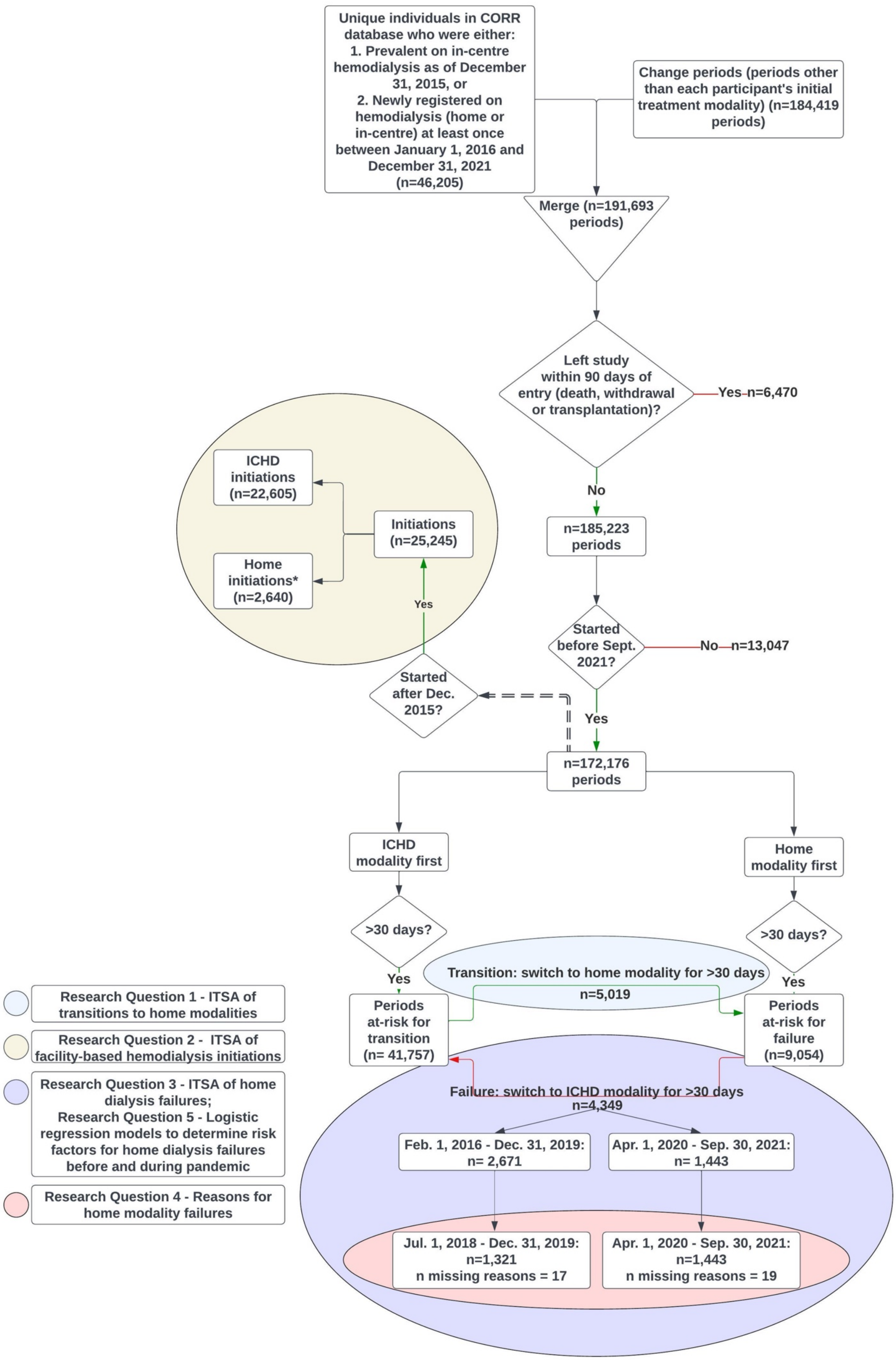

Unique individuals in CORR database who were either:
1. Prevalent on in-centre hemodialysis as of December 31, 2015, or
2. Newly registered on hemodialysis (home or in-centre) at least once between January 1, 2016 and December 31, 2021
(n=46,205)
Change periods (periods other than each participant's initial treatment modality) (n=184,419 periods)
Merge (n=191,693 periods)
Left study within 90 days of entry (death, withdrawal or transplantation)?
Yes n=6,470
No
n=185,223 periods
Started before Sept. 2021?
No n=13,047
Yes
n=172,176 periods
Started after Dec. 2015?
Yes
Initiations (n=25,245)
ICHD initiations (n=22,605)
Home initiations* (n=2,640)
ICHD modality first
Home modality first
>30 days?
>30 days?
Yes
Yes
Transition: switch to home modality for >30 days
n=5,019
Periods at-risk for transition (n= 41,757)
Periods at-risk for failure (n=9,054)
Failure: switch to ICHD modality for >30 days
n=4,349
Feb. 1, 2016 - Dec. 31, 2019: n= 2,671
Apr. 1, 2020 - Sep. 30, 2021: n= 1,443
Jul. 1, 2018 - Dec. 31, 2019: n=1,321 n missing reasons = 17
Apr. 1, 2020 - Sep. 30, 2021: n=1,443 n missing reasons = 19
Research Question 1 - ITSA of transitions to home modalities
Research Question 2 - ITSA of facility-based hemodialysis initiations
Research Question 3 - ITSA of home dialysis failures;
Research Question 5 - Logistic regression models to determine risk factors for home dialysis failures before and during pandemic
Research Question 4 - Reasons for home modality failures

Figure 1. Study outline and cohort selection.
Figure shows derivation of the 3 main cohorts (facility-based hemodialysis initiations, transitions to home modality, and home dialysis failures) and their pre- and post-pandemic sub-cohorts (only those for home dialysis failures pictured). To be "at risk" for home dialysis failure (to have a period considered part of the home modality cohort) the participant must have been on a home modality for 30 consecutive days or more. A failure is then defined as a transfer of 30 or more uninterrupted days to a facility-based modality (i.e.: no switches back to a home modality in the interim). Thus, if the individual switched to a facility-based modality for only two weeks and then went back on home dialysis, it is considered as though they never left/failed. Within this model, individuals may have had multiple periods in the cohort at-risk for failure and multiple periods in the cohort at-risk for transition, depending on their treatment pathway. Research questions 1,3,4, and 5 work with 30+ day "at-risk periods" as the functional units of analysis while research question 2 looks at individuals. FBHD, facility-based hemodialysis; ITSA, interrupted time series analysis.
*Home initiations exclude PD initiations in which the individuals never spent time on a hemodialysis modality (home or facility-based) during the study period.

Primary Outcome – Change in proportion of transitions from facility-based hemodialysis to home dialysis in post-pandemic period as compared to pre-pandemic period:

If an individual spent 30 consecutive days or more on facility-based hemodialysis, their time was included in the facility-based hemodialysis cohort as a "period" until interrupted by a transplant, death, the end of the study period (Sep. 30, 2021) or time on a home modality of 30 days or more. Individuals could have multiple periods in the facility-based hemodialysis cohort, as, for example one may have started for more than 30 days on facility-based hemodialysis (first period at risk for transition), left for home-based dialysis for more than 30 days (transition), and went back to facility-based hemodialysis for more than 30 days (second period at risk for transition). The end of each period was considered to be a transition unless the individual had a transplant, died, or the period ended on Sep. 30, 2021, which was the artificial endpoint of the study based on available data. Transitions were only considered from February 1, 2016 onwards, as this permitted 30 days of being in the study - this being the earliest possible date after which a transition could occur in the overall study period. Transitions were no longer considered after September 30, 2021, as any individuals starting between this date and the end of the study on December 31, 2021 would not be able to meet the 90 day minimum inclusion criterion. In total, there were 41,757 periods of varying lengths in the facility-based hemodialysis cohort, which were deemed at risk for transition to a home modality. The proportion of transitions was defined as the number of transitions within a month divided by the number of individuals receiving facility-based hemodialysis at the start of the month.[110]

Secondary Outcomes

1. *Change in number of facility-based hemodialysis initiations during post-pandemic period as compared to pre-pandemic period (Outcome 2)*

The dialysis modality on which each individual completed their first 30 consecutive dialysis days was identified as their starting dialysis modality. This was counted as either a home dialysis initiation or a facility-based hemodialysis initiation. Initiations of individuals who initiated on facility-based PD initiations (1,011 of 46,205 unique individuals) were not considered in either group and excluded from analyses. Since the raw study sample was limited to people who were prevalent on facility-based hemodialysis as of December 31, 2015 and people who were on hemodialysis (home or facility-based) at least once between January 1, 2016 and September 30, 2021, the true total of PD initiations could not be determined. For example, people who were on PD as of December 31, 2015 and who never had hemodialysis treatment are not included in the cohort.

2. *Change in home dialysis failure rates during post-pandemic period as compared to pre-pandemic period (Outcome 3)*

All periods in which individuals spent a minimum of 30 consecutive days on a home modality were included in the home dialysis cohort. The end of each period on home dialysis was considered a failure unless the individual had a transplant, died, or the period ended on Sep. 30, 2021. Failures were only considered from Feb. 1, 2016 onwards, as this permitted 30 days of being in the study - this being the earliest possible date after which a failure could occur for the overall study period. Failures were no longer considered after September 30, 2021, as any individuals starting dialysis between this date and the end of the study on December 31, 2021 would not be able to meet the 90 day minimum inclusion criteria which would allow the opportunity for exclusion due to transplant, withdrawal, or death. In total, there were 9,054 periods of varying lengths in the home dialysis cohort that were at risk for failure. Since the population excludes individuals who were solely on PD during the entire study period, the monthly denominator for failures is not the total number of prevalent home dialysis individuals per month. Rather, the monthly denominator for the proportion of failures is composed of all individuals from the overall study cohort who were on a home modality that month.

3. *Change in reasons for home dialysis failures during post-pandemic period as compared to pre-pandemic period (Outcome 4)*

Reasons for failures consisted of CORR's listed options including individuals on dialysis and/or families being unable to cope with their current treatment, geographical or resource access challenges, and various reasons related to treatment complications (See Table 3 in Appendix).[114] The same cohort used in research question 3 was used for question 4, except the "pre-pandemic" sub-group was restricted to include only the periods with failures from July 1, 2018 to December 31, 2019. All failures were divided into failures occurring 18 months before the onset of the pandemic (July 1, 2018 to December 31, 2019; n = 1,321 with 17 missing their reason for failure), and failures occurring in the 18 months after the onset of the pandemic and washout period (Apr. 1, 2020 – Sep. 30, 2021; n=1,443 with 19 missing their reason for failure).

4. *Change in risk factors associated with home dialysis failures during post-pandemic period as compared to pre-pandemic period (Outcome 5)*

The same cohort used in research question 3 was used in research question 5. Periods whose endpoint was death or which ended on the artificial endpoint of September 30, 2021 were designated a label "0" and were considered as "No failure" period in the logistic regression models.

Sample size

Since all of the data available to us were used for the outcomes of interest, sample size determination was not conducted. Despite our large sample for each of the 3 main research questions, our study did not meet the general recommendation of having a minimum of 100 observations at each data point (ie: 100 transitions each month) of the time series, which is supposed to permit a reasonable degree of variability for each estimate.[117] This presented problems for conducting stratified analyses by province, so these planned secondary analyses were abandoned.

Data management

Data pertaining to individuals' kidney replacement therapy modalities (a dialysis modality or a kidney transplant), dates of kidney replacement therapy initiation, dialysis modality at initiation, distances from residences to dialysis facilities, demographic information, baseline comorbidities, modality transfer records, and major reasons for changing modalities were drawn from the CORR database. The CORR database registers and keeps records of individuals with organ replacement therapy needs – kidney-related or otherwise - across Canada. CORR uses unique identifiers and our data contained no identifiable personal health information. All data were stored in a Secure Access Environment (SAE) within CIHI servers and were remotely accessed through their portal by individuals who were granted access by CIHI. No line level data was exported from the SAE. All aggregate results were vetted by CIHI prior to export from the SAE. Cells containing <5 observations were suppressed and marked with "Supp." to avoid any potential identification and in accordance with CIHI policy.

Variables and measures

Outcome definitions for research questions 1-4 are described in the cohort creation section above. Transitions from facility-based hemodialysis to home dialysis, hemodialysis initiations and home dialysis failures were aggregated individually over each month of the study period, with values expressed as cumulative incidence measures for each outcome. For home dialysis transitions and failures, these cumulative incidences were then divided by the population on facility-based hemodialysis and home dialysis (albeit with incomplete PD numbers), respectively to give the proportions of transitions and failures for each month.

For logistic regression modelling in research question 5, all included raw variables as provided by CIHI are presented in Table 2 in the Appendix. Demographic covariates of home dialysis failure included age [classified as a categorical outcome and grouped in 5-year categories (27=<30, 32=30-34,37=35-39…77=75+)], sex, body mass index, race/ethnic origin (white or not), and province (Northwest Territories merged with Alberta, Atlantic provinces grouped together). Social covariates included distance from an individual's residence to the nearest dialysis facility (5 km categories (2 = 0-4, 7=5-9…22=20+) and socioeconomic status quintile. Quintiles denoting socioeconomic status were received pre-generated in the CORR database, having been derived using the Postal Code Conversion File Plus (PCFF+) product developed by Statistics Canada.[120] This tool serves as a bridge between specific postal codes and demographic information collected at the level of the smallest geographic units used in census data known as "dissemination areas" which typically consist of 400-700 persons. The PCCF+ utilizes multiple sources of information, including data from the census, administrative boundaries, and other geospatial datasets to assign postal codes to geographic areas. It includes a wide range of demographic and socioeconomic variables associated with each postal code, including population characteristics, income levels, educational attainment, and employment status.[120]

Under the assumption that multiple comorbid conditions have generally been a contraindication to home modality usage clinical covariates included the following factors as collected when individuals began kidney replacement therapy: angina, myocardial infarct, malignancy, pulmonary edema, prior cerebrovascular accident, peripheral vascular disease, type 1 and 2 diabetes, chronic obstructive lung disease, hypertension (as measured by hypertensive medication usage), current smoking, prior coronary artery bypass grafts/angioplasty, and other serious illness that could shorten life by 5 years. The date of first kidney replacement therapy was also included to calculate dialysis vintage at the time of first failure, as increased end-stage kidney disease vintage is associated with a greater risk of death and the composite of death and technique failure from PD.[121]

Statistical analysis

All analyses were performed from using SAS software, version 9.4 (SAS Institute Inc). Baseline characteristics for the study populations are presented as mean +/- standard deviation or median, interquartile range for continuous data depending on data distribution. Categorical outcomes are presented as proportions. Comparison of baseline characteristics between the pre- and post pandemic cohorts was completed using the unpaired student's t-test and Wilcoxon rank-sum test for normally and non-normally distributed data, respectively. Categorical data was assessed with the chi-squared test.

After visualizing the data in linear regression plots of transition to home dialysis proportions and home dialysis failure proportions over time, simple linear regression models using the least squares method were specified with autoregressive errors applied as necessary. Initiations on facility-based hemodialysis were expressed as a count so a generalized linear model with a natural log link and Poisson distribution was used. For transitions to home dialysis, facility-based hemodialysis starts and home dialysis failures, a full regression model was specified for each outcome first, including the baseline trend and all level and trend changes as recommended by Wagner et. al. Segments included the pre-intervention period (January 1, 2016 – February 28 2020), the first COVID-19 pandemic wave in Canada (approximated as April 1, 2020 – June 30, 2020), the low-case summer of 2020 (July 1, 2020 – September 30, 2020), the second-wave (approximated as October 1, 2020 – March 31, 2021), the third wave (approximated as April 1, 2021 – June 30, 2021), and the fourth wave (approximated as July 1, 2021 – September 30, 2021). [20]

For transitions to home dialysis and failures from home dialysis to facility-based hemodialysis, autocorrelation function plots were used to assess the presence of any autocorrelation or seasonality. Autocorrelation function plots show the correlation of a given time point within a time series with its own past values at different lags – signs of autocorrelation. Significant correlations at lags of 10-12 were considered suggestive of seasonality. Heteroskedasticity was assessed using residual plots in case alteration to the models would help achieve better fit. The Durbin-Watson statistic was used to test for remaining autocorrelation in each regression model's output. A Durbin-Watson score can range in value from 0 to 4. A value of 2.00 indicates no autocorrelation, while a value below 2 indicates positive autocorrelation and a value above 2 indicates negative autocorrelation.[117]

For initiations on facility-based hemodialysis, overdispersion – a feature of the data where variance exceeds the mean and causes biased parameter estimation and underestimated standard error – was assessed by using the negative binomial distribution and testing whether the negative binomial dispersion parameter was zero. The Poisson regression is a specific, more restrictive, form of a negative binomial regression and a negative binomial regression can handle overdispersion. A dispersion parameter of zero in a negative binomial distribution indicates that the negative binomial model is equivalent to the Poisson distribution, and there is no overdispersion.[122]

From here, non-significant variables were removed using stepwise elimination at a predetermined significance level of $alpha < 0.05$. Yule-Walker estimates of model performance were used whenever an autoregressive lag parameter was specified.

The two-sample z-test for proportions was used to compare changes in the proportion of reasons for home dialysis failures in the 18 month period preceding the pandemic (July 1, 2018 – December 31, 2019) to the those in the first 18 months of the pandemic (April 1, 2020 – September 30, 2021), where a proportion was simply the count of a given reason divided by the total number of failures in the period. One-sided z-tests were used as appropriate for each given reason.

Two multivariable logistic regression models were used to separately evaluate the risk factors associated with home dialysis failure before and after the pandemic. The first model captured failures occurring from January 01, 2016 to December 31, 2019 while the second model captured failures occurring from April 01, 2020 to December 31, 2021. Categorical variables were inspected using cross tabulations. The categories in the "distance to dialysis facility" variable between 22 km and 149 km had very small cell counts, so they were collapsed to create a "22-149 km" category. For continuous variables, linearity was assessed using plots of the log odds of the outcome versus predictors (using design variables made by the differences between the quartiles of each predictor). After inspection, univariate analyses were run on all the demographic, social, and clinical comorbidity covariates. Covariates that were significant at an *alpha* of 0.10 were included in the multivariate modelling; otherwise, they were excluded. Backward selection was finally used to assess the most parsimonious multivariate model.[116,117,123] The Hosmer-Lemeshow test was used to assess model fit, and receiver operating characteristic curves were used to measure the discriminatory ability of different iterations of each model, with the best models striking the best balance between having a high area under the curve and the lowest Akaike Information Criterion. Variables whose addition to the model only slightly increased the area under the curve at the cost of increasing the Akaike Information Criterion and which were nonsignificant were not included.

Sensitivity analyses

1. Transitions to home dialysis for the month of March 2020 were high at a magnitude out of keeping with surrounding observations. This time point was treated as an outlier and not included in the primary analysis. It is possible that this upswing may have represented a real level change associated with the onset of the pandemic. A sensitivity analysis including this timepoint was performed.
2. Transitions to HHD and PD were analysed separately to distinguish whether the change in overall home dialysis transitions could be attributed to changes in one specific home modality.
3. We assessed if shortening the definition of a 'period' to $\geq$21 days significantly affected home modality transition and failure rates.
4. We restricted the pre-pandemic period to an 18 month period from July 1, 2018 to December for analysis of home modality failures to match the time periods assessed in pre-and post-pandemic periods. We did this because the year-over-year increase in the prevalent home

dialysis population of our cohort did not resemble the trend seen in CIHI's data until 2018, likely due to a lag in the time it took for patients who were on facility-based hemodialysis to transition to home dialysis before having the opportunity to fail (see Table 5 in Appendix and Figure 1 in Appendix). For this reason, the analysis where the pre-pandemic time period was restricted to begin after July 1, 2018 was conducted.

5. Failures from HHD and PD were analysed separately to distinguish whether the change in overall failures could be attributed to changes in one specific home modality.
6. Following the same logic for restricting the examination of failures to 18 months prior to the pandemic as discussed above, univariate regression models were attempted with the restricted time period of July 1, 2018 to December 31, 2019.

Ethical considerations

Approval for this study was obtained from the University of Manitoba Health Research Ethics Board on May 30, 2022 and renewed on May 15, 2023. Following the University of Manitoba Health Research Ethics Board and CIHI privacy policies, informed consent was not obtained from members of the study population as consent for entry into the CORR Registry was obtained within the HD Unit. Data privacy measures are discussed in the data analysis section above.

Results

Baseline characteristics

The main study cohort included 31,596 individuals prevalent on facility-based hemodialysis during the pre-pandemic period (Jan. 1, 2016 – Dec. 31, 2019) and 22,607 individuals who were prevalent on facility-based hemodialysis during the pandemic period (Apr. 1, 2020 – Sep. 30, 2021 (Table 1). Notably, the age distribution was significantly different between the periods, with the pandemic period having a higher proportion of individuals aged 30-74 and lower proportion of those aged 75 and over compared to the pre-pandemic period. A greater proportion of those prevalent on facility-based hemodialysis were non-Caucasian in the pandemic period compared to the pre-pandemic period. Prevalent individuals in the pandemic period had higher body mass index (28.4 ± 6.7 versus 28.2 ± 6.7 pre-pandemic, $p < 0.0037$). For prevalent individuals on dialysis, the distance to the nearest dialysis facility differed significantly between the pre-pandemic and pandemic periods, mainly in that the proportions living 0-4 km away decreased from 34.9% to 32.2%, respectively, and that the proportions of individuals living between 20-149 km away increased from 21.1% in the pre-pandemic period to 22.3% in the post-pandemic period. Socioeconomic quintile distribution changed as well, with the proportion of individuals in the second lowest quintile decreasing from 19.0% pre-pandemic to 17.8% during the pandemic and the proportion of individuals in the highest quintile increasing from 17.3% pre-pandemic to 18.7% during the pandemic. Individuals who were prevalent in the pandemic period tended to have fewer comorbidities but had a higher proportion of type II diabetes (15.9% in the pandemic period versus 15.0% in the pre-pandemic period, $p=0.0068$) and were more likely to be on antihypertensive medication (84.4% in the pandemic period versus 82.0% in the pre-pandemic period, $p<0.0001$).

A total of 15,586 individuals initiated facility-based hemodialysis in the pre-pandemic period while 6,015 individuals initiated facility-based hemodialysis in the pandemic period (Table 2).

A total of 5,505 unique individuals were prevalent on a home dialysis modality at some point in the pre-pandemic period while 3,677 unique individuals were prevalent on home dialysis at some point in the pandemic period. Demographic characteristics and differences between study periods were similar to findings in the prevalent facility-based hemodialysis cohort (Table 3).

Table 1. Characteristics of prevalent individuals receiving facility-based hemodialysis between Jan. 1, 2016 and Sep. 30, 2021

Characteristics	Jan. 2016 – Dec. 31, 2019 (n=31,596)	Apr. 1, 2020 – Sep. 30, 2021 (n=22,607)	*P* Value
Age range (years)			<0.0001
<30	741 (2.4)	583 (2.6)	
30-34	595 (1.9)	471 (2.1)	
35-39	780 (2.5)	569 (2.5)	
40-44	1,112 (3.5)	812 (3.6)	
45-49	1,625 (5.2)	1,236 (5.5)	
50-54	2,291 (7.3)	1,714 (7.6)	
55-59	3,034 (9.7)	2,325 (10.4)	
60-64	3,627 (11.6)	2,673 (11.9)	
65-69	4,346 (13.8)	3,124 (13.9)	
70-74	4,199 (13.4)	3,212 (14.3)	
75+	9,042 (28.8)	5,729 (25.5)	
Sex n (%)			0.2577
Female	12,549 (39.7)	9,088 (40.2)	
Male	19,047 (60.3)	13,519 (59.8)	
Race n (%)			<0.0001
Caucasian	19,696 (62.3)	13,121 (58.0)	
Non-Caucasian	11,900 (37.7)	9,486 (42.0)	
Body Mass Index (kg/m^2)	28.2 ± 6.7	28.4 ± 6.7	0.0037
Dialysis Vintage (days)	1,365 {714 - 2,395}	1,067 {467-2,018}	<0.0001
Province			0.1056
BC	4,661 (14.8)	3,423 (15.1)	
Alberta/Northwest Territories	3,452 (10.9)	2,608 (11.5)	
Saskatchewan	1,300 (4.1)	910 (4.0)	
Manitoba	2,263 (7.2)	1,659 (7.3)	
Ontario	16,803 (53.2)	11,804 (52.2)	
Atlantic Provinces	3,117 (9.9)	2,203 (9.7)	
Distance to facility (km)			<0.0001
0-4	10,911 (34.9)	7,207 (32.2)	
5-9	7,076 (22.6)	5,082 (22.7)	
10-14	3,013 (9.6)	2,248 (10.1)	
15-19	1,768 (5.7)	1,302 (5.8)	
20-149	6,599 (21.1)	4,995 (22.3)	
150+	1,892 (6.1)	1,525 (6.8)	
Socioeconomic quintile			<0.0001
First (lowest)	11,912 (40.1)	8,429 (39.9)	
Second	5,659 (19.0)	3,760 (17.8)	
Third	3,857 (13.0)	2,782 (13.2)	
Fourth	3,135 (10.5)	2,193 (10.4)	
Fifth (highest)	5,155 (17.3)	3,958 (18.7)	
Comorbidities			
Myocardial Infarct	4,936 (16.5)	3,118 (14.4)	<0.0001
Pulmonary Edema	6,822 (23.0)	4,453 (20.8)	<0.0001
Type 1 Diabetes	244 (0.8)	175 (0.8)	0.9928
Type 2 Diabetes	4,553 (15.0)	3,451 (15.9)	0.0068
Cerebrovascular Disease	3,664 (12.2)	2,451 (11.3)	0.0017
Peripheral Vascular Disease	4,289 (14.3)	2,711 (12.5)	<0.0001
Malignancy	3,872 (13.1)	2,615 (12.2)	0.002
Lung Disease	3,283 (11.0)	2,148 (9.9)	<0.0001
HTN medication	24,776 (82.0)	18,315 (84.4)	<0.0001
Current smoker	4,813 (16.5)	3,492 (16.5)	0.8899
Coronary Artery Bypass Graft	4,503 (15.0)	3,045 (14.0)	0.0022
OSI-5	4,074 (16.8)	2,900 (16.9)	0.7837

Data shown as n (%), mean +/- SD and median{IQR}. HTN, hypertension; OSI-5 Other serious illness that could shorten life by 5 years

Table 2. Characteristics of incident individuals receiving facility-based hemodialysis Jan. 1, 2016 to Dec. 31, 2021

Characteristics	Jan. 1, 2016 – Dec. 31, 2019 (n=15,586)	Apr. 1, 2020 – Dec. 31, 2021 (n=6,015)	*P* Value
Age range (years)			0.6487
<30	435 (2.8)	184 (3.1)	
30-34	315 (2.0)	116 (1.9)	
35-39	397 (2.6)	144 (2.4)	
40-44	540 (3.5)	202 (3.4)	
45-49	807 (5.2)	315 (5.3)	
50-54	1,061 (6.8)	416 (7.0)	
55-59	1,527 (9.9)	573 (9.6)	
60-64	1,842 (11.9)	716 (12.0)	
65-69	2,189 (14.1)	821 (13.7)	
70-74	2,171 (14.0)	908 (15.2)	
75+	4,225 (27.2)	1,586 (26.5)	
Sex n (%)			0.8600
Female	6,056 (38.9)	2,345 (39.0)	
Male	9,530 (61.1)	3,670 (61.0)	
Race n (%)			<0.0001
Caucasian	9,273 (62.4)	3,507 (58.3)	
Non-Caucasian	5,863 (37.6)	2,508 (41.7)	
Body Mass Index (kg/m^2)	28.3 ± 6.7	28.4 ± 6.7	0.4260
Province			0.1205
BC	2,474 (15.9)	1,006 (16.7)	
Alberta/Northwest Territories	1,714 (11.0)	677 (11.3)	
Saskatchewan	660 (4.2)	279 (4.6)	
Manitoba	1,120 (7.2)	453 (7.5)	
Ontario	8,159 (52.4)	3,087 (51.3)	
Atlantic Provinces	1,459 (9.4)	513 (8.5)	
Distance to facility (km)			>0.999
0-4	4,489 (29.1)	1,703 (28.7)	
5-9	3,308 (21.4)	1,268 (21.3)	
10-14	1,566 (10.2)	577 (9.7)	
15-19	888 (5.8)	340 (5.7)	
20-149	3,884 (25.2)	1,571 (26.4)	
150+	1,300 (8.4)	483 (8.1)	
Socioeconomic quintile			0.0073
First (lowest)	5,874 (40.6)	2,294 (41.2)	
Second	2,561 (17.7)	871 (15.7)	
Third	1,740 (12.0)	727 (13.1)	
Fourth	1,454 (10.1)	568 (10.2)	
Fifth (highest)	2,836 (19.6)	1,106 (19.9)	
Comorbidities			
Myocardial Infarct	2,588 (17.0)	838 (14.4)	<0.0001
Pulmonary Edema	3,651 (24.3)	1,151 (20.1)	<0.0001
Type 1 Diabetes	134 (0.9)	64 (1.1)	0.1367
Type 2 Diabetes	2,629 (17.3)	1,025 (17.7)	0.5182
Cerebrovascular Disease	1,908 (12.5)	628 (10.8)	0.0006
Peripheral Vascular Disease	2,252 (14.8)	741 (12.7)	0.0002
Malignancy	2,118 (14.0)	782 (13.5)	0.4021
Lung Disease	1,867 (12.2)	664 (11.4)	0.0874
HTN medication	12,576 (82.8)	4,975 (85.6)	<0.0001
Current smoker	2,572 (17.3)	953 (16.6)	0.2689
Coronary Artery Bypass Graft	2,567 (16.8)	879 (15.1)	0.0027
OSI-5	2,081 (17.7)	927 (20.9)	<0.0001

Data shown as n (%), mean +/- SD and median{IQR}. HTN, hypertension; OSI-5 Other serious illness that could shorten life by 5 years

Table 3. Characteristics of prevalent individuals on home dialysis between Jan. 1, 2016 and Sep. 30, 2021

Characteristics	Jan. 2016 – Dec. 31, 2019 (n=5,505)	Apr. 1, 2020 – Sep. 30, 2021 (n=3,677)	*P* Value
Age range (years)			0.6349
<30	225 (4.1)	180 (4.9)	
30-34	198 (3.6)	123 (3.4)	
35-39	234 (4.3)	159 (4.3)	
40-44	365 (6.6)	228 (6.2)	
45-49	480 (8.7)	305 (8.3)	
50-54	550 (10.0)	366 (10.0)	
55-59	661 (12.0)	420 (11.5)	
60-64	719 (13.1)	474 (12.9)	
65-69	707 (12.9)	465 (12.7)	
70-74	618 (11.3)	408 (11.1)	
75+	734 (13.4)	535 (14.6)	
Sex			0.2206
Female	1,976 (35.9)	1,366 (37.1)	
Male	3,529 (64.1)	2,311 (62.9)	
Race			0.0033
Caucasian	3,576 (65.0)	2,278 (62.0)	
Non-Caucasian	1,929 (35.0)	1,399 (38.0)	
BMI (mean ± SD)	28.5 ± 6.7	28.3 ± 6.6	0.3188
Dialysis Vintage (median, IQR)	823 {407-1428}	756 {403 - 1,296}	<0.0001
Province			0.1469
BC	940 (17.1)	591 (16.1)	
Alberta/Northwest Territories	777 (14.1)	566 (15.4)	
Saskatchewan	236 (4.3)	156 (4.2)	
Manitoba	346 (6.3)	263 (7.2)	
Ontario	2,927 (53.2)	1,898 (51.6)	
Atlantic Provinces	279 (5.1)	203 (5.5)	
Distance to facility			0.8411
0-4	1,114 (20.4)	751 (20.6)	
5-9	1,098 (20.1)	720 (19.8)	
10-14	655 (12.0)	406 (11.1)	
15-19	376 (6.9)	262 (7.2)	
20-149	1,655 (30.3)	1,124 (30.8)	
150+	566 (10.4)	381 (10.5)	
Socioeconomic quintile			0.8565
First (lowest)	2,106 (40.1)	1,364 (39.7)	
Second	1,025 (19.5)	660 (19.2)	
Third	690 (13.2)	480 (14.0)	
Fourth	530 (10.1)	342 (9.9)	
Fifth (highest)	895 (17.1)	592 (17.2)	
Comorbidities			
MI	683 (12.9)	420 (11.8)	0.1255
Pulmonary Edema	812 (15.5)	522 (14.9)	0.4356
Type 1 DM	37 (0.7)	28 (0.8)	0.6337
Type 2 DM	619 (11.7)	404 (11.4)	0.6283
CVA	420 (7.9)	273 (7.7)	0.6774
PVD	544 (10.3)	310 (8.7)	0.0127
Malignancy	590 (11.2)	387 (10.9)	0.6305
Lung Disease	357 (6.8)	223 (6.3)	0.3598
HTN medication	4,358 (82.6)	3,034 (85.7)	<0.0001
Current smoker	796 (15.4)	553 (15.8)	0.6161
CABG	620 (11.7)	409 (11.5)	0.738
OSI-5	573 (13.7)	405 (14.4)	0.4062

Data shown as n (%), mean +/- SD and median{IQR}. HTN, hypertension; OSI-5 Other serious illness that could shorten life by 5 years

Transitions from facility-based hemodialysis to home dialysis

The proportion of individuals transitioning from facility-based hemodialysis to home dialysis increased over the course of the COVID-19 pandemic period, as demonstrated by a significant increase in the trend change of 0.00006 after the pandemic onset in the most parsimonious segmented regression model (p=0.0271; Table 4, Figure 2). This trend change was relative to an essentially flat monthly rate of transitions of 1.5299×10^{-6} in the pre-pandemic period (p=0.8014). There was no significant immediate change in transitions at the onset of the pandemic, as demonstrated by the non-significant level change of -0.000379 after the pandemic onset in the most parsimonious model (p=0.25332).

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model of transitions. Residuals plotted to assess for heteroskedasticity in the final and most parsimonious models demonstrated homoscedastic errors. The final model of transitions had second order autocorrelation (meaning values that were two time periods apart – for example January 2021 and March 2021 - had significant correlation); accordingly, a lag term of 2 was applied. The final model of transitions had an R-square of 0.1619, Akaike Information Criterion of -784.3388, Mean Absolute Percentage Error of 10.3645 and normal residuals (Shapiro-Wilk p = 0.8713, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p>0.250, Anderson-Darling p > 0.250). The Durbin-Watson statistic was 1.9857, indicating very little likelihood of autocorrelation.

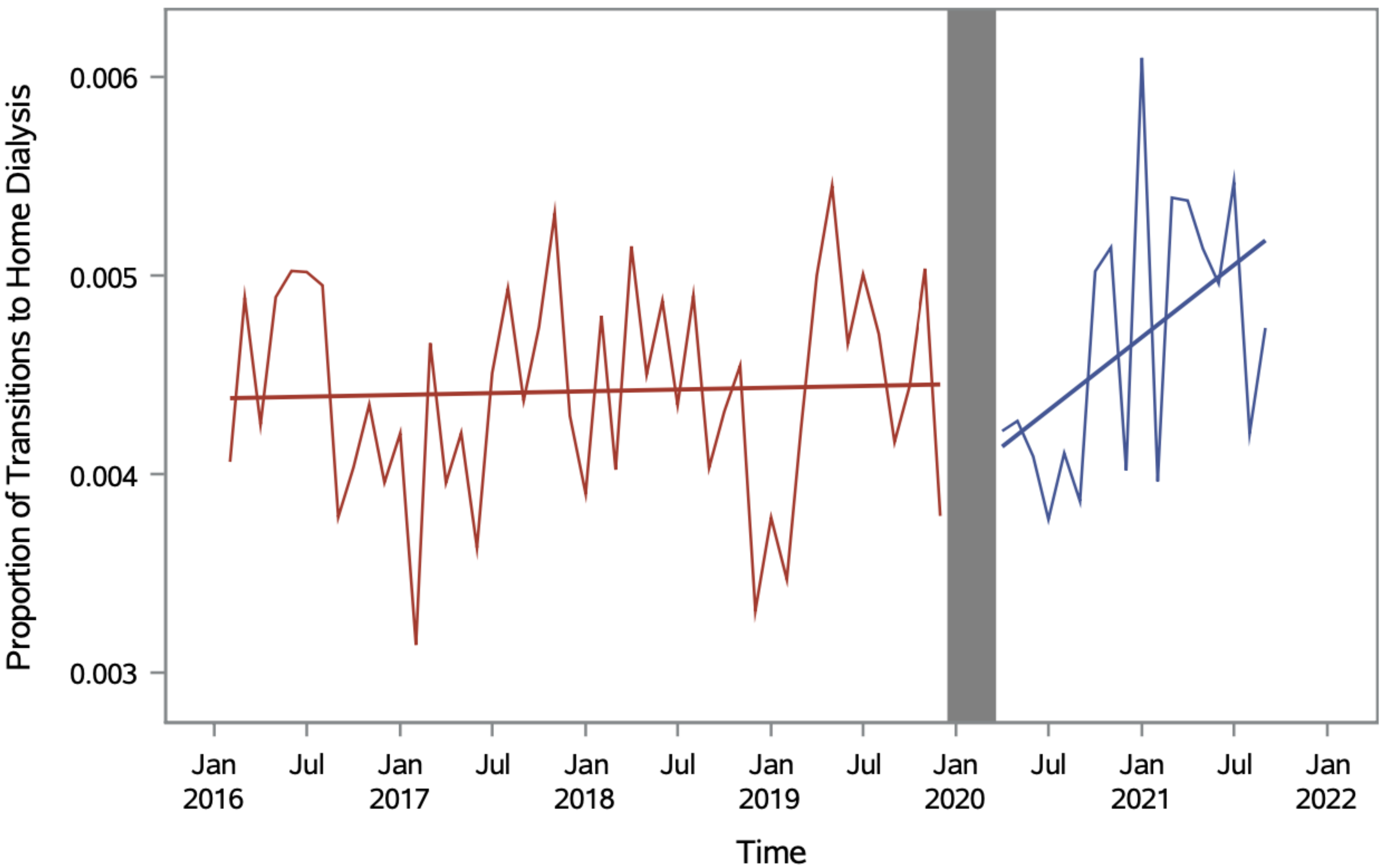


Figure 2. Transitions from facility-based hemodialysis to home dialysis in Canada over time as a proportion of monthly prevalent individuals on facility-based hemodialysis.

Table 4. Parameter estimates, standard errors and P-values from the full and most parsimonious segmented regression models predicting transition from facility-based hemodialysis to home dialysis modalities in Canada over time

	Coefficient	SE	95% CI	*P*-value
Full segmented regression model				
Intercept β_0	0.004388	0.000203	0.003990, 0.004786	<0.0001
Baseline trend β_1	1.2321×10^{-6}	7.3126×10^{-6}	-0.000013, 0.000016	0.8669
Level change after pandemic (wave 1) onset β_2	-0.000224	0.000780	-0.001753, 0.001305	0.7754
Trend change after pandemic (wave 1) onset β_3	-0.000020	0.000346	-0.000698, 0.000658	0.9531
Level change after low-case summer 2020 β_4	-0.000331	0.000862	-0.002021, 0.001359	0.7023
Trend change after low-case summer 2020 β_5	0.0000565	0.000486	-0.000896, 0.001009	0.9078
Level change after wave 2 onset β_6	0.001043	0.000656	-0.000243, 0.002329	0.1180
Trend change after wave 2 onset β_7	-0.000056	0.000375	-0.000791, 0.000679	0.8809
Level change after wave 3 onset β_8	0.000841	0.000825	-0.000776, 0.002458	0.3130
Trend change after wave 3 onset β_9	-0.000228	0.000375	-0.000963, 0.000507	0.5454
Level change after wave 4 onset β_{10}	0.000553	0.000866	-0.001144, 0.002250	0.5259
Trend change after wave 4 onset β_{11}	-0.000139	0.000488	-0.001095, 0.000817	0.7774
Most parsimonious segmented regression model				
Intercept β_0	0.004380	0.000167	0.004053, 0.004707	<0.0001
Baseline trend β_1	1.5299×10^{-6}	6.0549×10^{-6}	-0.000010, 0.000013	0.8014
Level change after pandemic (wave 1) onset β_2	-0.000379	0.000329	-0.001024, 0.000266	0.2532
Trend change after pandemic (wave 1) onset β_3	0.0000595	0.0000263	0.000008, 0.000111	0.0271

SE, standard error; CI, confidence interval

Facility-based hemodialysis initiations

There were increasing facility-based hemodialysis initiations in the pre-pandemic period such that with every increasing month, there was an average increase of 0.27% (Incidence rate ratio [IRR], 1.0027; 95% CI, 1.0015 to 1.0039; p <0.0001). There was no significant immediate change at the onset of the pandemic (IRR, 0.9685; 95% CI, 0.9100 to 1.0308; p=0.3136) or any change to the pre-pandemic trend during the pandemic (IRR, 0.9961; 95% CI, 0.9910 to 1.0012; p=0.1246) (Figure 3, Table 5).

When the negative binomial regression was conducted, the negative binomial dispersion parameter was zero, indicating that the negative binomial model was equivalent to the Poisson distribution, and there was no overdispersion.[122]

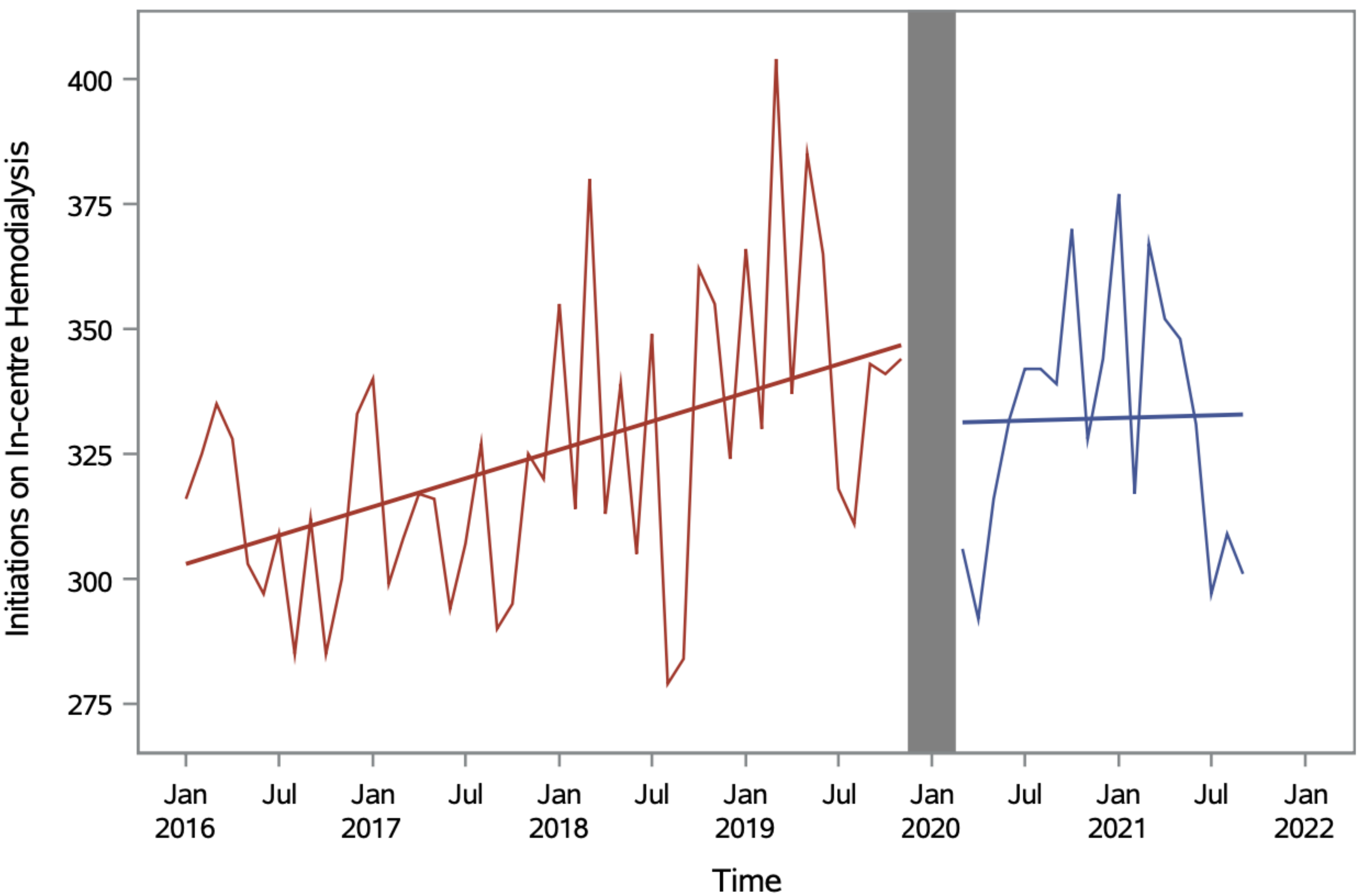


Figure 3. Absolute number of individuals initiating facility-based hemodialysis in Canada over time.

Table 5. Parameter estimates, standard errors and P-values from the full and most parsimonious segmented regression models predicting initiations on facility-based hemodialysis in Canada over time

	Coefficient	SE	Wald 95% CI	*P*-value	IRR	95% CI
Full segmented regression model						
Intercept β_0	5.7199	0.0160	5.6885, 5.7513	<0.0001	.	.
Baseline trend β_1	0.0025	0.0005	0.0015, 0.0035	<0.0001	.	.
Level change after pandemic (wave 1) onset β_2	-0.2289	0.0892	-0.4038, -0.0540	0.0103	.	.
Trend change after pandemic (wave 1) onset β_3	0.0614	0.0400	-0.0170, 0.1398	0.1248	.	.
Level change after low-case summer 2020 β_4	0.0309	0.0967	-0.1587, 0.2205	0.7494	.	.
Trend change after low-case summer 2020 β_5	-0.0683	0.0554	-0.1768, 0.0402	0.2175	.	.
Level change after wave 2 onset β_6	0.0362	0.0701	-0.1013, 0.1737	0.6062	.	.
Trend change after wave 2 onset β_7	0.0032	0.00404	-0.0759, 0.0823	0.9373	.	.
Level change after wave 3 onset β_8	0.0442	0.0904	-0.1330, 0.2213	0.6251	.	.
Trend change after wave 3 onset β_9	-0.0293	0.0402	-0.1082, 0.0495	0.4659	.	.
Level change after wave 4 onset β_{10}	-0.1105	0.1012	-0.3088, 0.0877	0.2746	.	.
Trend change after wave 4 onset β_{11}	0.0372	0.0558	0.0721, 0.1465	0.5050	.	.
Scale	1.0000	0.0000	1.0000, 1.0000		.	.
Most parsimonious segmented regression model						
Intercept β_0	5.7163	0.0165	5.6839, 5.7487	<0.0001	.	.
Baseline trend β_1	0.0027	0.0006	0.0016, 0.0038	<0.0001	1.0027	1.0015, 1.0039
Level change after pandemic (wave 1) onset β_2	-0.0320	0.0318	-0.0944, 0.0303	0.3136	0.9685	0.9100, 1.0308
Trend change after pandemic (wave 1) onset β_3	-0.0039	0.0026	-0.0089, 0.0011	0.1246	0.9961	0.9910, 1.0012
Scale	1.0000	0.0000	1.0000, 1.0000		.	.

SE, standard error; CI, confidence interval; IRR, Incidence rate ratio

Home dialysis failures

When the pre-pandemic period was defined as January 1, 2016-December 31, 2019, the rate of home dialysis failures in the pre-pandemic period increased significantly over time as demonstrated by the baseline trend of 0.000162 (p=0.0002). There was no immediate change in failures when the pandemic started as demonstrated by the level change of -0.004285 (p=0.0543) and there was an increase in the rate of monthly proportions of failures over the course of the pandemic period as demonstrated by the trend change of 0.000357 (p=0.0450). See Table 6, Figure 4.

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model of failures. Residuals plotted to assess for heteroskedasticity in the final and most parsimonious models demonstrated homoscedastic errors. The final model of failures had no autocorrelation. The final model of failures had an R-square of 0.4377, Akaike Information Criterion of 538.26332, Mean Absolute Percentage Error of 11.417 and normal residuals (Shapiro-Wilk p = 0.1977, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p=0.1965, Anderson-Darling p > 0.1945). The Durbin-Watson statistic was 1.7107 indicating some remaining positive autocorrelation.

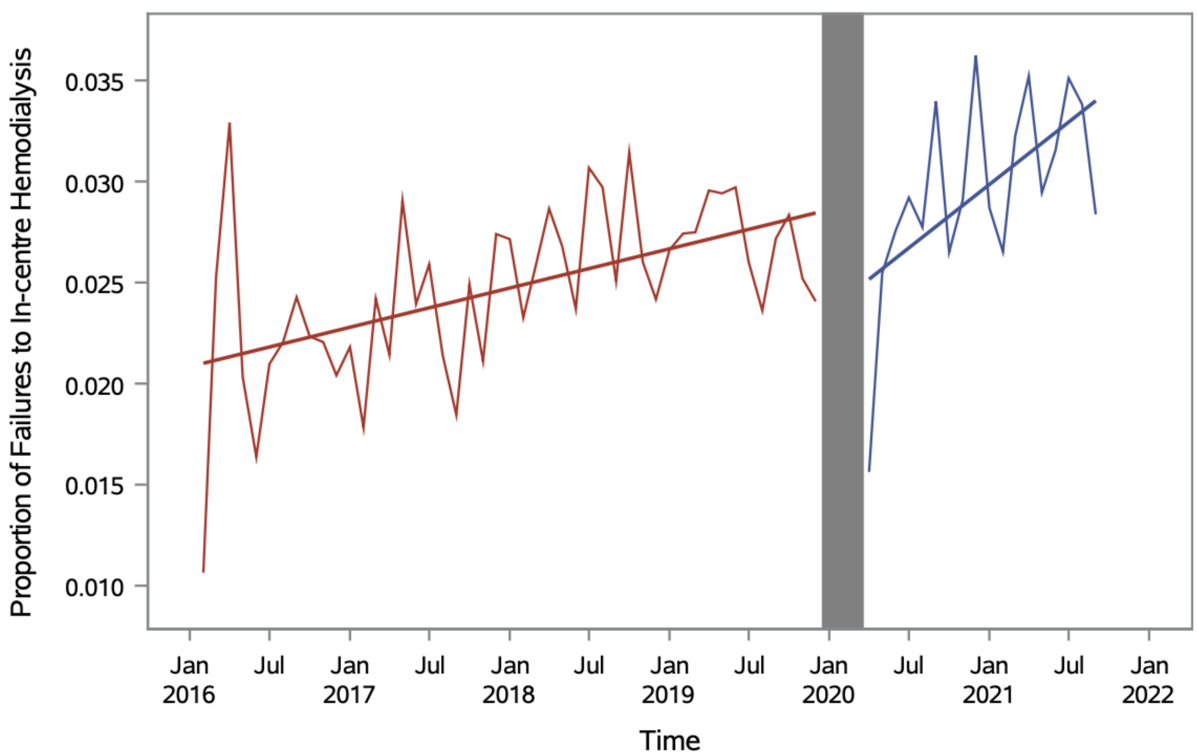


Figure 4. Home dialysis failures in Canada over time as a proportion of monthly prevalent individuals on home dialysis

Table 6. Parameter estimates, standard errors and P-values from the full and most parsimonious segmented regression models predicting failure from home dialysis modalities to facility-based hemodialysis in Canada over time

	Coefficient	SE	95% CI	*P*-value
Full segmented regression model				
Intercept β_0	0.0208	0.001069	0.018705, 0.022895	<0.0001
Baseline trend β_1	0.000162	0.0000388	0.000086, 0.000238	0.0001
Level change after pandemic (wave 1) onset β_2	-0.0180	0.005623	-0.029021, -0.006979	0.0023
Trend change after pandemic (wave 1) onset β_3	0.005812	0.002550	0.000814, 0.010810	0.0267
Level change after low-case summer 2020 β_4	-0.003338	0.006416	-0.015913, 0.009237	0.6050
Trend change after low-case summer 2020 β_5	-0.003588	0.003605	-0.010654, 0.003478	0.3242
Level change after wave 2 onset β_6	-0.004174	0.004701	-0.013388, 0.005040	0.3785
Trend change after wave 2 onset β_7	-0.001996	0.002691	-0.007270, 0.003278	0.4614
Level change after wave 3 onset β_8	0.004894	0.006094	-0.007050, 0.016838	0.4255
Trend change after wave 3 onset β_9	-0.002229	0.002691	-0.007503, 0.003045	0.4111
Level change after wave 4 onset β_{10}	0.008939	0.006416	-0.003636, 0.021514	0.1694
Trend change after wave 4 onset β_{11}	-0.001528	0.003605	-0.008594, 0.005538	0.6734
Most parsimonious segmented regression model				
Intercept β_0	0.0208	0.001108	0.018628, 0.022972	<0.0001
Baseline trend β_1	0.000162	0.0000402	0.000083, 0.000241	0.0002
Level change after pandemic (wave 1) onset β_2	-0.004285	0.002184	-0.008566, -0.000004	0.0543
Trend change after pandemic (wave 1) onset β_3	0.000357	0.000175	0.000014, 0.000700	0.0450

SE, standard error; CI, confidence interval

Reasons for home dialysis failures

A higher proportion of failures due to peritonitis occurred in the PD population during the pandemic (9.2%) compared to the 18 months preceding the washout period (7.3%); p = 0.0423 (Figure 5, Table 8 in Appendix.) Across both home dialysis modalities, a lower proportion of failures due to individuals on dialysis and/or their families being unable to cope with their treatment occurred during the pandemic period (4.3%) compared to the pre-pandemic period (5.9%); p=0.0307). Finally, a higher proportion of failures due to resource/geographical reasons occurred during the pandemic period (5.8%) compared to the pre-pandemic period (2.7%); p <0.0001.

No significant differences to proportions of failures from inadequate dialysis (5.7% during the pandemic vs 5.3% pre pandemic; p=0.3077), transfer to originally intended treatment (8.8% during the pandemic vs 8.1%; p=0.2760), leaving the country (p-0.2510) or "other" reasons (54.2% during the pandemic vs 56.1% pre-pandemic; p=0.1441) were noted between time periods.

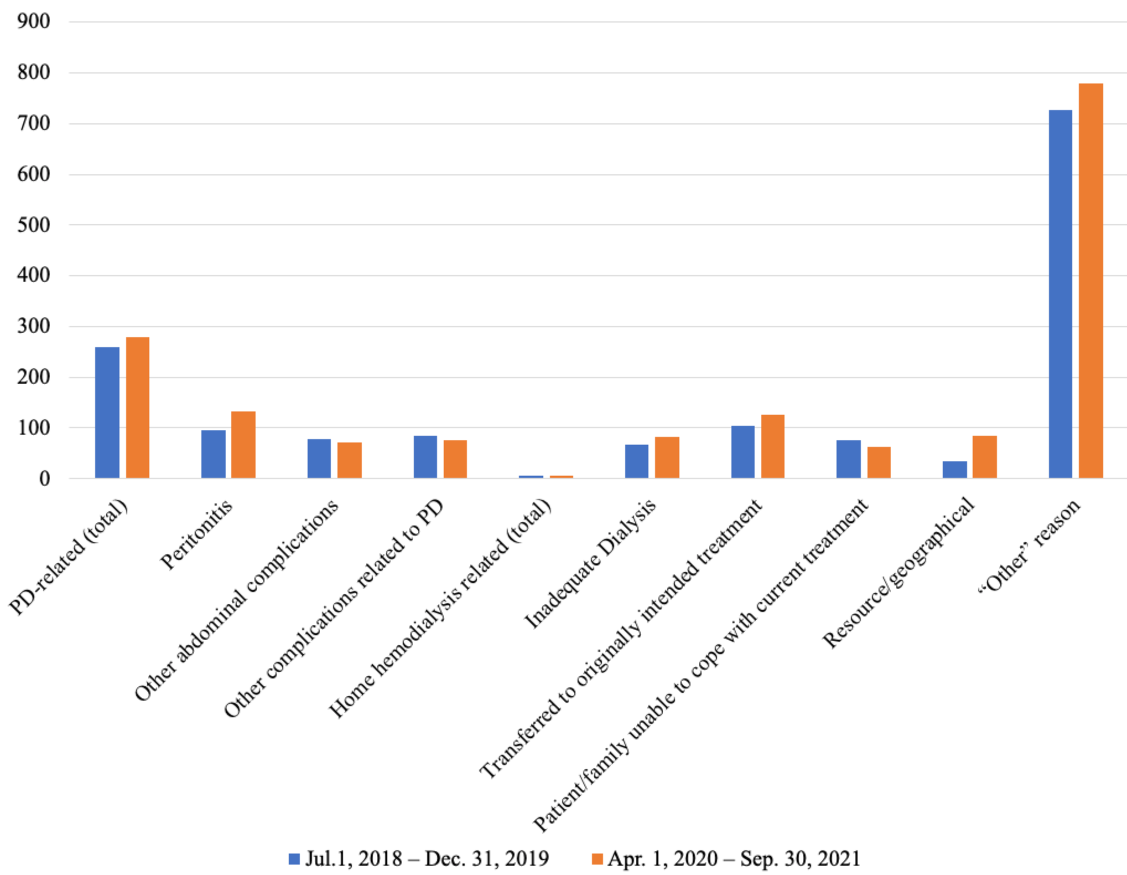


Figure 5. Failures count stratified by reason before and after pandemic onset (presented as counts)

Risk factors for home dialysis failures

Data visualization revealed that individuals in Ontario and BC both had disproportionately high representation of individuals in the “75+” age category compared to the rest of the Canadian provinces represented in this analysis. However there was no significant interaction effect between province and age group when assessed in univariate analysis.

For home dialysis failures occurring between January 1, 2016 and December 31, 2019, univariate analyses demonstrated that province, time on dialysis in years, history of myocardial infarct and pulmonary edema as reported at the time of dialysis initiation were statistically significant as independent risk factors at an *alpha* of 0.05. Socioeconomic status quintile, prior cerebrovascular accident, and distance from a facility as reported at the time of dialysis initiation were marginally significant at an *alpha* of 0.10 and were also included in preliminary multivariate models. Backward selection yielded a final model which included province, myocardial infarct (OR, 0.775; 95% CI, 0.661, 0.909), and the time on dialysis (with each one-year increase; OR, 0.909; 95% CI, 0.895, 0.922) (Table 7).

The Hosmer-Lemeshow test yielded a p-value of <0.0001 (indicating poor fit). The final model had an area-under-the-curve of 0.6707 in its receiver-operating-characteristic curve (Figure 6).

Table 7. Parameter estimates, standard errors and P-values from the full and most parsimonious logistic regression models predicting home dialysis failures from Jan. 1, 2016 - Dec. 31, 2019

	Estimate	Standard error	Wald Chi-square	*P*-value	Odds Ratio	95% CI
Full model with all variables significant at alpha <0.10 in univariate analyses						
Intercept	0.2927	0.0681	18.4906	<0.0001	.	.
Province (reference=Ontario)						
Alberta/Northwest Territories	-0.2588	0.0850	9.2688	0.0023	0.772	0.654, 0.912
Atlantic Provinces	-0.1615	0.1360	1.4105	0.2350	0.851	0.652, 1.111
British Columbia	-0.1296	0.0734	3.1167	0.0775	0.878	0.761, 1.014
Manitoba	-0.5755	0.1216	22.3885	<0.0001	0.562	0.443, 0.714
Saskatchewan	-0.4236	0.1466	8.3500	0.0039	0.655	0.491, 0.873

Distance to nearest dialysis facility (km; reference= 0-4 km)						
5-9	-0.0712	0.0833	0.7314	0.3924	0.931	0.791, 1.096
10-14	-0.1093	0.0969	1.2725	0.2593	0.896	0.741, 1.084
15-19	-0.1488	0.1176	1.6017	0.2057	0.862	0.684, 1.085
20+	-0.2578	0.0725	12.6524	0.0004	0.773	0.670, 0.891
Myocardial Infarct	-0.2163	0.0847	6.5228	0.0106	0.806	0.682, 0.951
Pulmonary Edema	-0.1417	0.0783	3.2715	0.0705	0.868	0.744, 1.012
Cerebrovascular Accident	0.0640	0.1002	0.4080	0.5230	1.066	0.876, 1.298
Dialysis Vintage (yr)	-0.0949	0.00774	150.3379	<0.0001	0.909	0.896, 0.923
Most parsimonious model						
Intercept	0.1569	0.0445	12.4259	0.0004	.	.
Province (reference=Ontario)						
Alberta/Northwest Territories	-0.2818	0.0839	11.2826	0.0008	0.754	0.640, 0.889
Atlantic Provinces	-0.2341	0.1327	3.1091	0.0779	0.791	0.610, 1.026
British Columbia	-0.1488	0.0731	4.1467	0.0417	0.862	0.747, 0.994
Manitoba	-0.6089	0.1203	25.5966	<0.0001	0.544	0.430, 0.689
Saskatchewan	-0.4726	0.1454	10.5624	0.0012	0.623	0.469, 0.829
Myocardial Infarct	-0.2548	0.0812	9.8408	0.0017	0.775	0.661, 0.909
Dialysis Vintage (yr)	-0.0958	0.00769	154.9818	<0.0001	0.909	0.895, 0.922

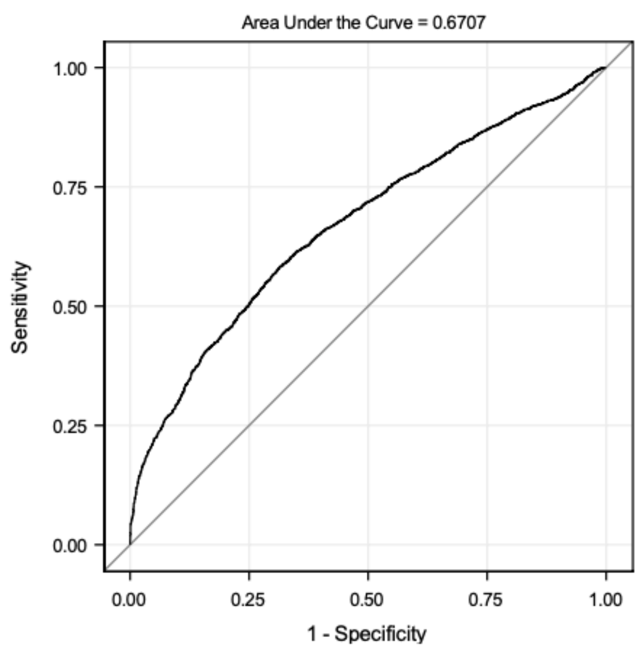


Figure 6. Receiver operating characteristic curve for the final model of failures from home dialysis to ICHD from Jan. 1, 2016 - Dec. 31, 2019

For home dialysis failures occurring between April 1, 2020 and December 31, 2021, univariate analyses demonstrated that only pulmonary edema, and time on dialysis in years were statistically significant at an *alpha* of 0.05. Backward selection yielded a final model where pulmonary edema and the time on dialysis were included (Table 8). The Hosmer-Lemeshow test yielded a p-value of 0.0963 (indicating poor fit). Multicollinearity was presumed to be present, as parameter estimates and odds ratio estimates significantly changed in magnitude and direction when the order that predictors were specified in the model was altered. The final model had an area-under-the-curve of 0.6441 in its receiver-operating-characteristic curve, presented in Figure 7.

Table 8. Parameter estimates, standard errors and P-values from the full and most parsimonious logistic regression models predicting failures from home modalities to ICHD from Apr. 1 – 2020 - Dec. 31, 2021

	Estimate	Standard error	Wald Chi-square	*P*-value	Odds Ratio estimate	95% CI
Most parsimonious model						
Intercept	-0.3086	0.0466	43.8503	<0.0001	.	.
Pulmonary Edema	-0.2312	0.0924	6.2577	0.0124	0.794	0.662, 0.951
Dialysis Vintage (yr)	-0.1001	0.0109	84.0840	<0.0001	0.905	0.886, 0.924

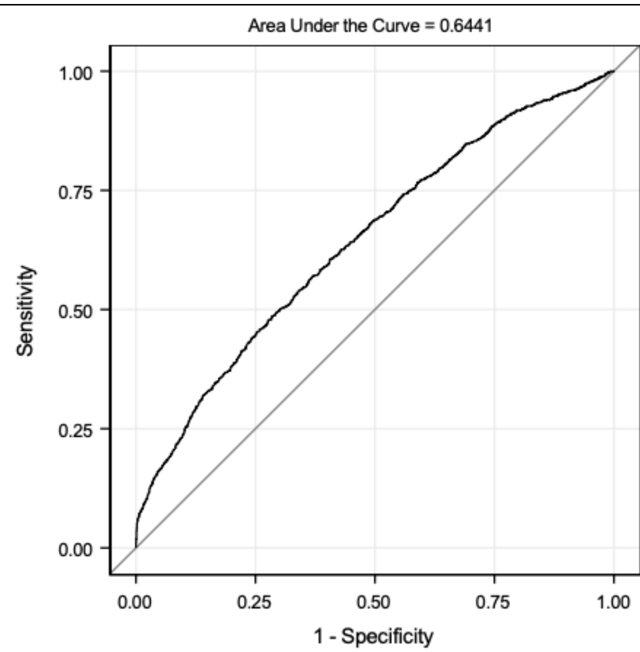


Figure 7. Receiver operating characteristic curve for the final model of failures from home dialysis to ICHD from Jan. 1, 2016 - Dec. 31, 2019

Sensitivity analyses

1. Transitions from facility-based hemodialysis to home dialysis with inclusion of March 2020 in pandemic period

The inclusion of March 2020 in a sensitivity analysis proved it to be a highly influential observation, as trend change after the onset of the pandemic of 0.0000360 became nonsignificant with inclusion of the time point (p=0.1583; Table 9, Figure 8). The baseline trend from the pre-pandemic period of 1.5299×10^{-6} remained nonsignificant (p=0.8082), as did the immediate level change of -0.000126 (p=0.7054). Autocorrelation plots indicated normal residuals and no seasonality.

Table 9. Parameter estimates, standard errors and P-values from segmented regression model predicting transition from facility-based hemodialysis to home dialysis modalities in Canada over time with the inclusion of March 2020 in the pandemic period

	Coefficient	SE	95% CI	*P*-value
Most parsimonious segmented regression model with inclusion of March 2020 (highly influential)				
Intercept β_0	0.004380	0.000173	0.004041, 0.004719	<0.0001
Baseline trend β_1	1.5299×10^{-6}	6.2767×10^{-6}	-0.000011, 0.000014	0.8082
Level change after pandemic (wave 1) onset β_2	-0.000126	0.000331	-0.000775, 0.000523	0.7054
Trend change after pandemic (wave 1) onset β_3	0.0000360	0.0000252	-0.000013, 0.000085	0.1583

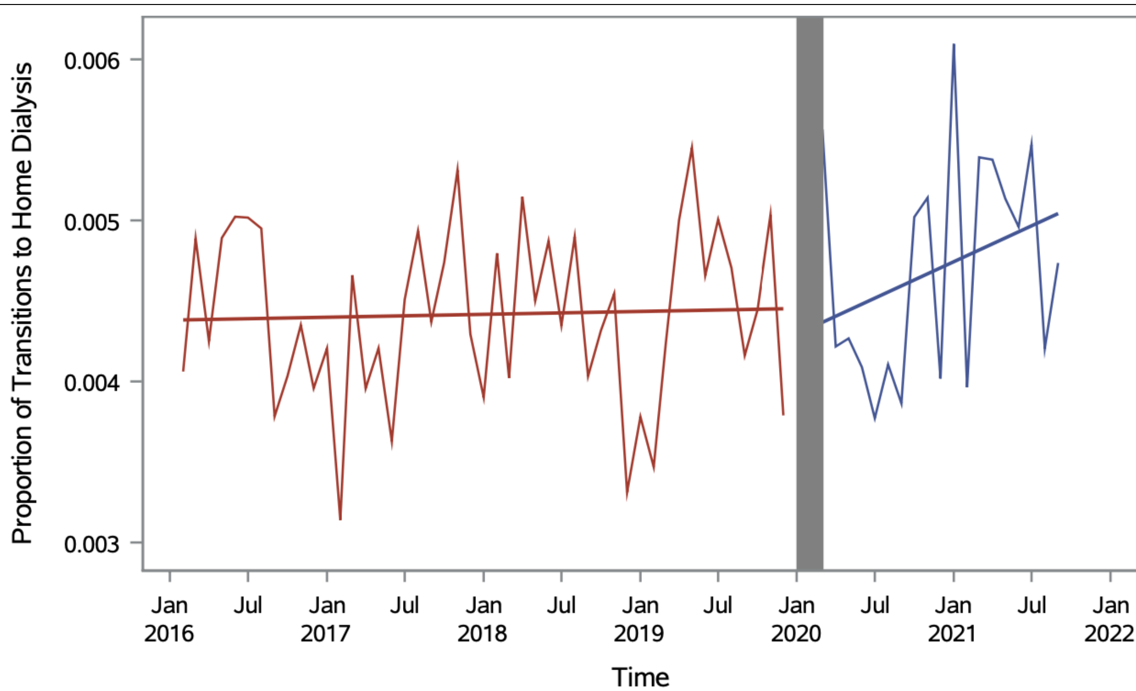


Figure 8. Transitions from facility-based hemodialysis to home dialysis in Canada over time as a proportion of monthly prevalent individuals on facility-based dialysis (sensitivity analysis with inclusion of March 2020)

2a. Transitions from facility-based hemodialysis to PD

The monthly proportions of individuals transitioning from facility-based hemodialysis to peritoneal dialysis did not immediately change at the onset of the pandemic (level change = -0.000356, p=0.1854), nor over the course of the COVID-19 pandemic period (trend change = 0.000028, p=0.1911) relative to an unchanging pre-pandemic monthly rate of transitions of 1.7257×10^{-6} in the pre-pandemic period (p=0.7258; Table 10, Figure 9).

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model of transitions from ICHD to PD. No heteroskedasticity of residuals was observed. The final model had an R-square of 0.0356, Akaike Information Criterion of -811.91086, Mean Absolute Percentage Error of 13.642 and normal residuals (Shapiro-Wilk p = 0.9931, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p>0.250, Anderson-Darling p > 0.250). The Durbin-Watson statistic was 2.0694, indicating very little likelihood of autocorrelation.

Table 10. Parameter estimates, standard errors and P-values from the most parsimonious segmented regression model predicting transition from facility-based hemodialysis to peritoneal dialysis in Canada over time

	Coefficient	SE	95% CI	*P*-value
Intercept β_0	0.002686	0.000135	0.002421, 0.002951	<0.0001
Baseline trend β_1	1.7257×10^{-6}	4.8978×10^{-6}	-0.000008, 0.000011	0.7258
Level change after pandemic (wave 1) onset β_2	-0.000356	0.000266	-0.000877, 0.000165	0.1854
Trend change after pandemic (wave 1) onset β_3	0.0000281	0.0000213	-0.000014, 0.000070	0.1911

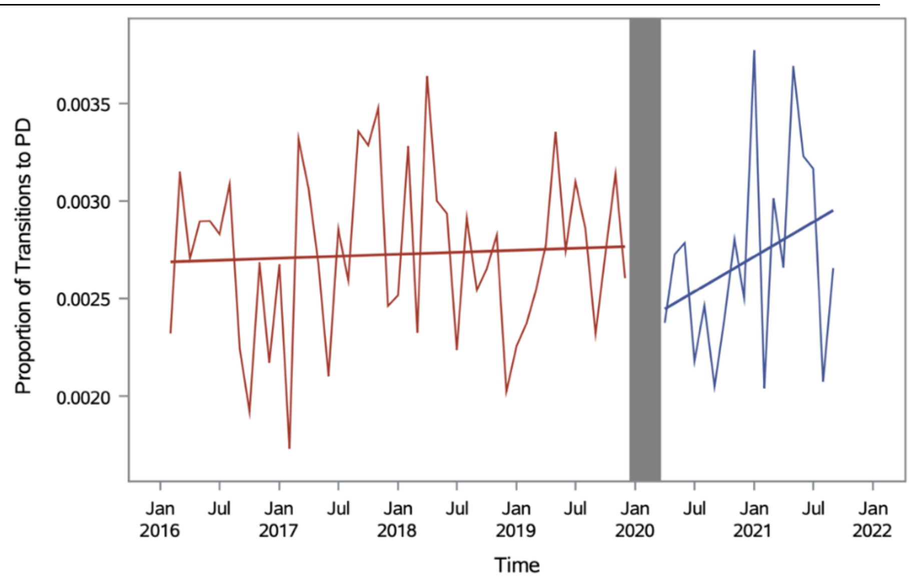


Figure 9. Transitions from facility-based hemodialysis to peritoneal dialysis in Canada over time as a proportion of monthly prevalent individuals on facility-based hemodialysis

2b. Transitions from facility-based hemodialysis to HHD

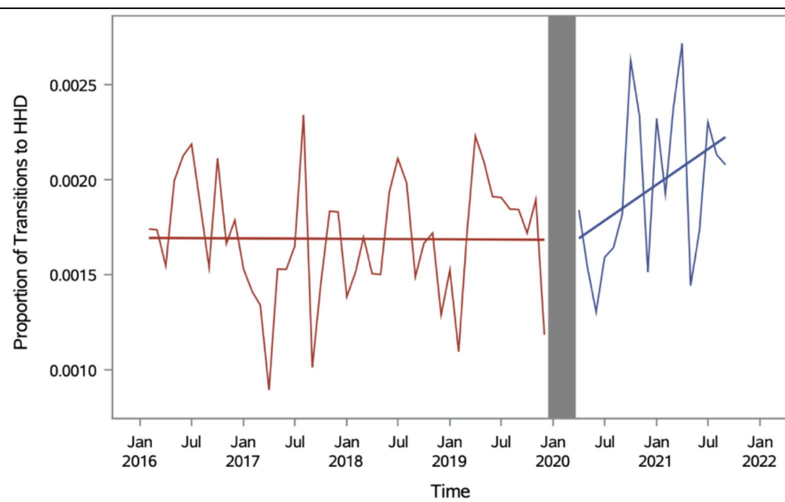
The monthly proportions of individuals transitioning from facility-based hemodialysis to HHD dialysis did not immediately change at the onset of the pandemic (level change = 0.0000200, p=0.9288), nor over the course of the COVID-19 pandemic period (trend change = 0.0000292, p=0.1086) relative to an unchanging pre-pandemic monthly rate of transitions of -5.496×10^{-6} in the pre-pandemic period (p=0.8949; Table 11, Figure 10).

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model of transitions from facility-based hemodialysis to HHD. Second order autocorrelation was identified so a lag term of 2 was applied for best fit. No heteroskedasticity of residuals was observed. The final model had an R-square of 0.1900, Akaike Information Criterion of -846.24436, Mean Absolute Percentage Error of 16.108543 and normal residuals (Shapiro-Wilk p = 0.7423, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p>0.250, Anderson-Darling p > 0.250). The Durbin-Watson statistic was 1.9740, indicating little likelihood of autocorrelation.

Table 11. Parameter estimates, standard errors and P-values from the most parsimonious segmented regression model predicting transition from facility-based hemodialysis to home hemodialysis in Canada over time

	Coefficient	SE	95% CI	*P*-value
Intercept β_0	0.001700	0.000114	0.001477, 0.001923	<0.0001
Baseline trend β_1	-5.496×10^{-6}	4.141×10^{-6}	-0.000014, 0.000003	0.8949
Level change after pandemic (wave 1) onset β_2	0.0000200	0.000223	-0.000417, 0.000457	0.9288
Trend change after pandemic (wave 1) onset β_3	0.0000292	0.0000179	-0.000006, 0.000064	0.1086

Figure 10. Transitions from facility-based hemodialysis to home hemodialysis in Canada over time as a proportion of monthly prevalent individuals on facility-based hemodialysis.



3. *Changing the definition of a period to ≥ 21 days*

When we counted any time on facility-based hemodialysis of 21 days or greater as a period, the periods at-risk for transition became 42,601 (2.0% increase compared to 30-day cut-off), and there were 5,789 transitions (15.3% increase compared to 30-day cut-off). Similarly, when we counted any time of 21 days or greater on home dialysis as a period, the periods at risk for failure became 9,733 (a 7.5% increase compared to 9,054 of 30-day cut-off), and there were 5,247 failures (an increase of 20.6% compared to 4,349 of 30-day cut-off).

4. *Overall home dialysis failures when pre-pandemic period restricted to Jul. 1, 2018 – Dec. 31, 2019*

When the pre-pandemic period was restricted to July 1, 2018 to Dec. 31, 2019, home dialysis failures did not demonstrate an immediate change (level change = -0.000357, p=0.8717), but there was a significant increase in failures over the course of the pandemic (trend change = 0.000691, p=0.0005). Notably, the baseline trend changed from having been significantly increasing in the original analysis of failures to being effectively flat with the restriction of the pre-pandemic period (baseline trend = -0.000178, p=0.1779; Table 12, Figure 11.)

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model. Second order autocorrelation was identified so a lag term of 2 was applied for best fit. No heteroskedasticity of residuals was observed. The final model had an R-square of 0.4622, Akaike Information Criterion of -304.22252, Mean Absolute Percentage Error of 8.35573256 and normal residuals (Shapiro-Wilk p = 0.1078, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p>0.250, Anderson-Darling p > 0.250). The Durbin-Watson statistic was 1.8635, indicating mild to moderate likelihood of autocorrelation.

Table 12. Parameter estimates, standard errors and P-values from the most parsimonious segmented regression model predicting failures from home dialysis to facility-based hemodialysis in Canada over time (with restricted pre-pandemic period)

	Coefficient	SE	95% CI	*P*-value
Intercept β_0	0.0289	0.001387	0.026181, 0.031619	<0.0001
Baseline trend β_1	-0.000178	0.000129	-0.000431, 0.000075	0.1779
Level change after pandemic (wave 1) onset β_2	-0.000357	0.002190	-0.004649, 0.003935	0.8717
Trend change after pandemic (wave 1) onset β_3	0.000691	0.000178	0.000342, 0.001040	0.0005

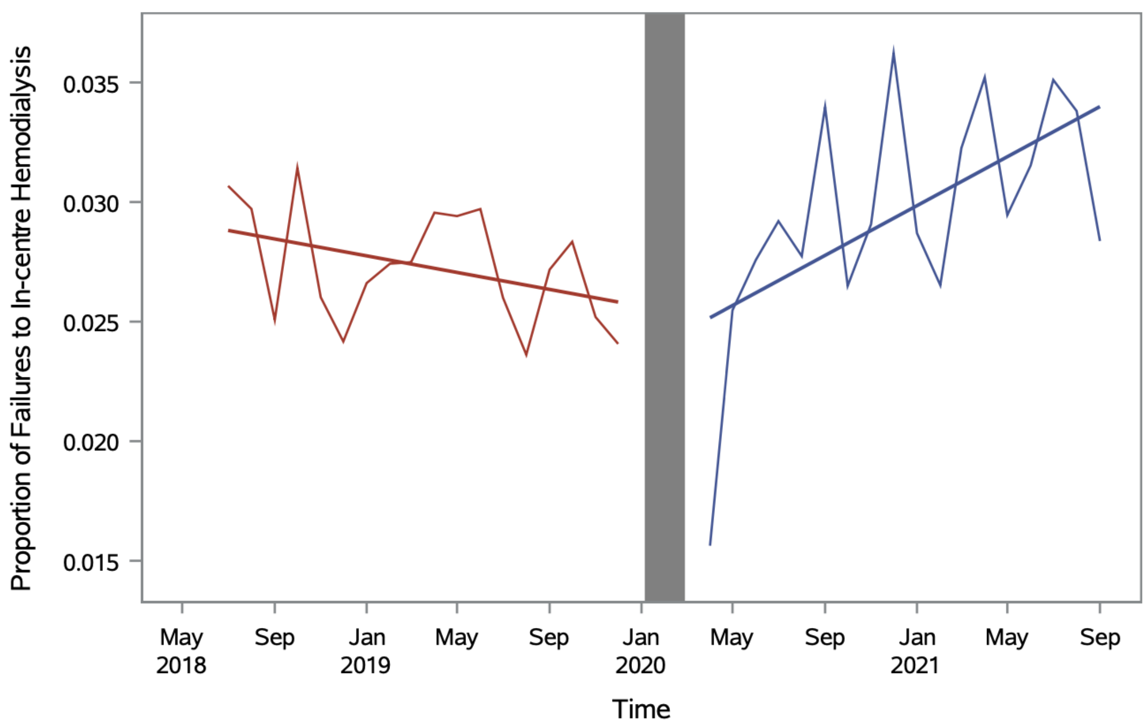


Figure 11. Failures from home dialysis modalities in Canada over time as a proportion of monthly prevalent individuals on home dialysis when pre-pandemic period restricted to July 1, 2018 – December 31, 2019

5a. Home hemodialysis failures when pre-pandemic period restricted to Jul. 1, 2018 – Dec. 31, 2019

When the pre-pandemic period was restricted to July 1, 2018 to Dec. 31, 2019, the monthly proportion of HHD failures among the prevalent individuals on HHD did not demonstrate an immediate change (level change = -0.003670, p=0.1377), but there was a significant increase in failures over the course of the pandemic (trend change = 0.000912, p=<0.0001). The pre-pandemic trend of failures had a significant decreasing slope (baseline trend = -0.000268, p=0.0677; Table 13, Figure 12.)

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model. Second order autocorrelation was identified so a lag term of 2 was applied for best fit. No heteroskedasticity of residuals was observed. The final model had an R-square of 0.3847, Akaike Information Criterion of -280.57874, Mean Absolute Percentage Error of 18.12221793 and normal residuals (Shapiro-Wilk p = 0.7788, Kolmogorov-Smirnov p >0.150, Cramer-von Mises p>0.250, Anderson-Darling p > 0.250). The Durbin-Watson statistic was 1.9807, indicating very little likelihood of autocorrelation.

Table 13. Parameter estimates, standard errors and P-values from the most parsimonious segmented regression model predicting failures from home hemodialysis to facility-based hemodialysis in Canada over time

	Coefficient	SE	95% CI	*P*-value
Intercept β_0	0.0240	0.001521	0.021019, 0.026981	<0.0001
Baseline trend β_1	-0.000268	0.000142	-0.000546, 0.000010	0.0677
Level change after pandemic (wave 1) onset β_2	-0.003670	0.002407	-0.008388, 0.001048	0.1377
Trend change after pandemic (wave 1) onset β_3	0.000912	0.000194	0.000532, 0.001292	<0.0001

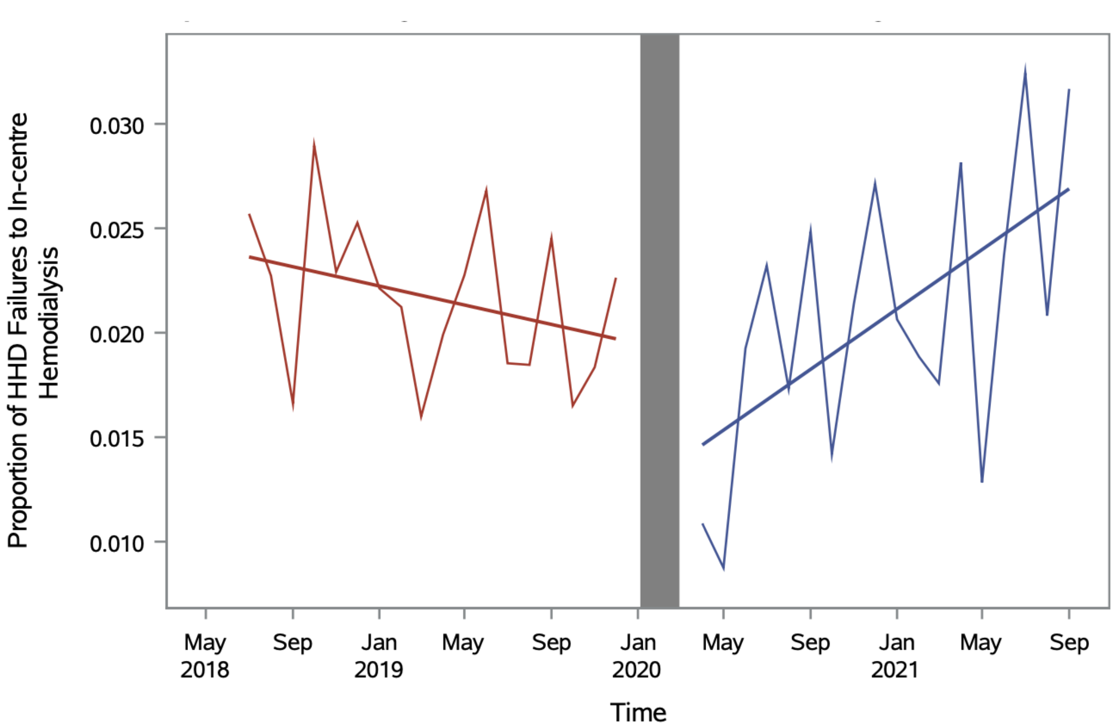


Figure 12. Failures from home hemodialysis in Canada over time as a proportion of monthly prevalent individuals on home hemodialysis when pre-pandemic period restricted to July 1, 2018 – December 31, 2019

5b. Peritoneal dialysis failures when pre-pandemic period restricted to Jul. 1, 2018 – Dec. 31, 2019

When the pre-pandemic period was restricted to July 1, 2018 to Dec. 31, 2019, the monthly proportion of PD failures among the prevalent individuals on PD did not demonstrate an immediate change (level change = 0.002280, p=0.5064), but there was a significant increase in failures over the course of the pandemic (trend change = 0.000620, p=0.0245). The pre-pandemic trend of failures had was stable (baseline trend = -0.000144, p=0.4463; Table 14, Figure 13.)

Autocorrelation function plots demonstrated no seasonality for the full and most parsimonious model. Fifth order autocorrelation was identified so a lag term of 5 was applied for best fit. No heteroskedasticity of residuals was observed. The final model had an R-square of 0.3847, Akaike Information Criterion of -280.57874, and a Mean Absolute Percentage Error of 18.12221793. Residuals were non-normal (Shapiro-Wilk p = 0.0011, Kolmogorov-Smirnov p =0.0256, Cramer-von Mises p>0.0229, Anderson-Darling p > 0.0063). The Durbin-Watson statistic was 1.7995, indicating moderate likelihood of autocorrelation.

Table 14. Parameter estimates, standard errors and P-values from the most parsimonious segmented regression model predicting failures from peritoneal dialysis to facility-based hemodialysis in Canada over time

	Coefficient	SE	95% CI	*P*-value
Intercept β_0	0.0317	0.002065	0.027653, 0.035747	<0.0001
Baseline trend β_1	-0.000144	0.000195	-0.000526, 0.000238	0.4663
Level change after pandemic (wave 1) onset β_2	0.002280	0.003386	-0.004357, 0.008917	0.5064
Trend change after pandemic (wave 1) onset β_3	0.000620	0.000260	0.000110, 0.001130	0.0245

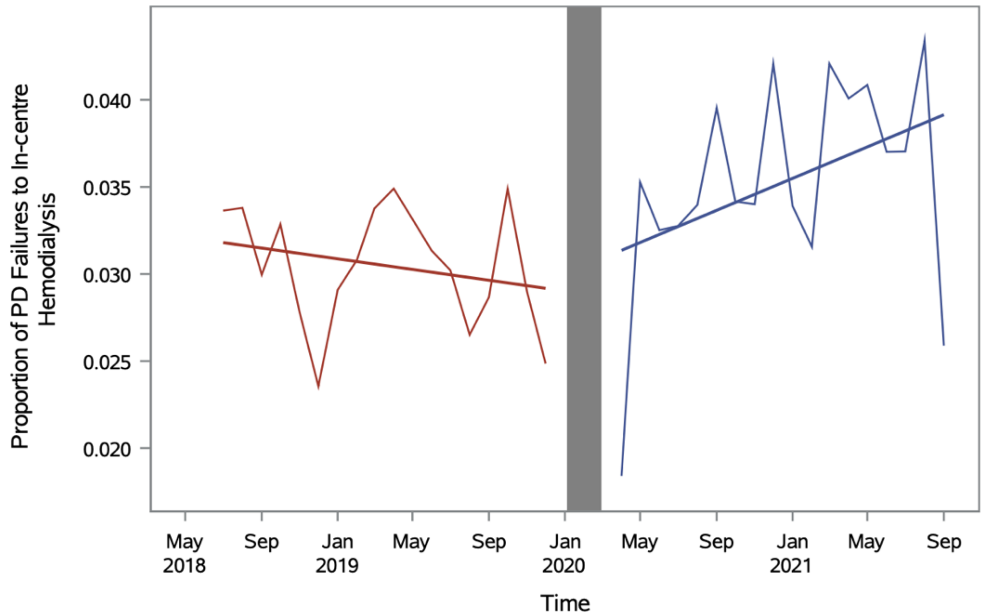


Figure 13. Failures from peritoneal dialysis in Canada over time as a proportion of monthly prevalent individuals on peritoneal dialysis when pre-pandemic period restricted to July 1, 2018 – December 31, 2019

6 – Multivariate logistic regression model predicting failures between July 1, 2018 – December 31, 2019

Following the same logic for restricting the examination of failures to 18 months prior to the pandemic as discussed above, univariate regression models were attempted with the restricted time period of July 1, 2018 to December 31, 2019. Only dialysis vintage was significant – accordingly, multivariate models could not be attempted.

Discussion

In the four years preceding the COVID-19 pandemic, the rate of transitions of Canadian individuals who were on facility-based hemodialysis to home dialysis modalities was stable. This was true for both transitions to peritoneal dialysis and to home hemodialysis. In the first 18 months of the pandemic, individuals' rate of transitions to home dialysis modalities steadily increased.

To both mitigate the increased risk of COVID-19 transmission and infections in facility-based hemodialysis units and adverse outcomes with COVID-19 infection in people receiving hemodialysis and to address hemodialysis capacity issues due to lower transplantation rates during the COVID-19 pandemic, in April 2020, the Canadian Society of Nephrology recommended that, where possible, individuals receiving facility-based hemodialysis should be transitioned to home dialysis modalities.[17] Our findings of a statistically significant increase in the rate of transitions from facility-based HD to home modalities during the pandemic period suggests that these recommendations were likely followed and implemented in multiple kidney care programs across Canada. Whether this shift to home modalities was solely due to these recommendations or contributed to by additional regional changes in policies and procedures is uncertain, but the timing of the significant increase in transitions suggests that the onset of the COVID-19 pandemic had an impact on this outcome.

When assessed in separate models, neither transitions to home hemodialysis nor to peritoneal dialysis increased significantly during the pandemic period. This is likely an issue of insufficient statistical power due to insufficient sample size in the HHD and PD subgroups. Despite lack of statistical significance, there was a visible trend of increased transitions to home hemodialysis during the pandemic as compared to transitions to peritoneal dialysis. Considering the shorter training requirement for PD of approximately three to five days, compared to HHD which requires six to ten weeks of training, it is unexpected that HHD may have had a greater relative increase over the course of the pandemic compared to PD. It is possible that new training pathways and schedules for HHD were implemented at some centres where training time was truncated in some fashion. We did not find any literature to support this possibility.

Home dialysis failures

In our cohort, home dialysis failures increased significantly during the pandemic as compared to the pre-pandemic period. This observation remained consistent in sensitivity analyses when the pre-pandemic period was adjusted to 18 months to be comparable to the duration of the post pandemic period and when peritoneal dialysis and home hemodialysis failures were analyzed separately.

It is possible that this increase in home dialysis failures in the pandemic period is entirely attributed to failures in the excess individuals who, perhaps inappropriately, transitioned from facility-based hemodialysis to home modalities during the pandemic period, but this is not the only plausible explanation. In time series methodology there is no matching and thus the individuals accounting for excess home dialysis failures are not necessarily the same individuals who account for the excess transitions from facility-based hemodialysis to home modalities during the pandemic period.

A scan of the global literature in other areas of healthcare makes it clear that the phenomenon of delayed care was ubiquitous during the COVID-19 pandemic. A systematic review of COVID-19 related disruptions to cancer care found that there were delays in cancer-related laboratory tests and cancer-related imaging and reductions in the number of cancer diagnoses.[124] Acute medical issues were not exempt from delayed presentation either. For example, the number of individuals presenting with acute ischemic stroke in the first two months of the pandemic was decreased compared to the two months leading up to the pandemic in comprehensive stroke centers in the United States.[125] Moreover, the time interval between the last time each individual was known to be well and their arrival at the stroke centre increased significantly. The authors suggest that the delay of presentation may have been due to individuals' fears of interacting with the healthcare system during the pandemic.[125]

The observation of a transient decrease in home dialysis failures in the month of April 2020 compared to December 2019, although not statistically significant, is a strong suggestion that individuals on home dialysis temporarily delayed or forewent seeking out medical care. With stay-at-home public health orders, and anxiety surrounding contraction of COVID-19 in this population, medical and social problems including peritonitis and catheter malfunction were likely not being addressed until the situation became critical and the individual required hospitalization and transition to facility-based hemodialysis. It is reasonable to expect that these behaviours persisted through much of the pandemic period and may have contributed to the excess rates of home dialysis failures observed in our study.

This hypothesis is supported by the observation that the increase in transitions to home dialysis occurred later than the increase in home dialysis failures in the pandemic period. The first month in the pandemic period where home dialysis transitions eclipsed the pre-pandemic regression line was October 2020. Prior to that time, transitions remained stable below the pre-pandemic regression line. In contrast, home dialysis failures peaked in September 2020 and continued to increase following this date. If the individuals who transitioned to home modalities during the pandemic period uniquely accounted for the excess home dialysis failures, we would not expect excess failures until at least November 2020 at the very earliest, since the initial observed increase in transitions occurred in October, and it took 30 days for an individual in our cohort to be registered as a failure. This suggests that, at least for the first months of the pandemic up until November 2020, there was another process driving excess failures such as delayed care. Ultimately, we are unable to determine whether this additional process accounted entirely for the observed increase in failures or if it subsided part way through the first two years of the pandemic and gradually gave way to failures from individuals who had been among the excess transitions of the pandemic period.

The observed delay in the increase in home dialysis transitions during the pandemic period is interesting and warrants further discussion. This could represent the time frame kidney care centres required to make and adapt to institutional changes brought on by the pandemic including changes in home dialysis eligibility and training requirements. The delay could also indicate that the excess transitions seen during the pandemic period were in part due to individuals who initially had home dialysis failure due to delays in seeking out medical care, and after stabilization during a period of facility-based hemodialysis were transitioned back to a home modality. A study of home dialysis care in Ontario from 2010 to 2016 found that approximately 7.2% of individuals who initiated PD and transitioned to facility-based hemodialysis for more than 60 days subsequently transferred to home hemodialysis. [126] Since technique survival on PD diminishes significantly after 2 years, home PD to home HD transitions are an ideal dialysis strategy when a kidney transplant is unavailable.[126] This may have contributed to increased home dialysis transitions in the pandemic period due to the decrease in kidney transplants during that time.

The question then becomes whether the proportion of PD to facility-based hemodialysis to home dialysis pathways was the same in the pre-pandemic and post-pandemic periods. If the number of individuals taking this pathway increased, the observed increase in transitions may have been partly or even completely explained by this pathway. With close agreement to the figures from Ontario rates of PD to facility-based hemodialysis to HHD care pathways between 2010 and 2016, 7% (66/939) took this pathway in the pre-pandemic period, though the threshold for failure to facility-based hemodialysis was 30 days in our case rather 60 days. A similar percentage of 5.6% (58/1042) took this pathway in the pandemic period. More importantly, the total transitions back to any home modality after failure from PD to facility-based hemodialysis for greater than 30 days were 33.5% (315/939) pre-pandemic and 29.3% (305/1042) during the pandemic. This suggests that the observed increase in overall transitions to home modalities during the pandemic period was not due to an increase in prevalent individuals on PD with technique failure who temporarily transitioned to facility-based hemodialysis before returning to a home modality. Rather, this supports the notion that excess transitions to home modalities during the pandemic period were the result of transitions in prevalent individuals who were stably on facility-based hemodialysis.

Shift in reasons for home modality failures

Three key changes in the reasons for failures occurred during the pandemic period that can help contextualize the findings of the time series. These included an increase in failures due to peritonitis, a doubling of resource/geographical-related failures, and decrease in failures due to individuals and family burnout.

While peritonitis rates in general may have increased and consequently caused a proportional increase in home modality failures, this is not necessarily the case. Peritonitis rates have been associated with various risk factors across several countries. The Peritoneal Dialysis Outcomes and Practice Patterns Study (PDOPPS) included 7051 adults receiving PD from 209 centres across seven countries (Canada, Japan, Australia, New Zealand, Thailand, the UK, and the USA) and found that when facilities had higher automated PD use, antibiotics were prescribed before catheter insertion, PD training was six or more days, and facilities were larger in size, peritonitis risk was lower.[127] It is possible that during the pandemic, PD training time was decreased in some centres or that PD was utilized more in smaller facilities where healthcare teams were less experienced with the technique and in training individuals in its use contributing to higher peritonitis rates. However, considering the documented broader milieu of hesitancy among individuals on dialysis in general to present with chronic or acute concerns during the pandemic, it seems more plausible that the increase in failures caused by peritonitis was driven by individuals on dialysis holding off on seeking help for their infections so that what could have been manageable with antibiotic therapy became unmanageable and required peritoneal dialysis catheter removal and transition to facility-based hemodialysis. In this latter scenario, a higher proportion of individuals with peritonitis would fail on PD due to late intervention rather than higher rates of peritonitis driving the increased failure rates.

Resource/geographical reasons for home dialysis failure more than doubled during the pandemic period suggesting a pandemic-related effect. In a cross tabulation of the reasons for failure by distance from a dialysis facility in the pre-pandemic and pandemic periods, the absolute number of home dialysis failures due to resource/geographical reasons among individuals 25 or more kilometres away from a dialysis centre was not significantly different during the 2 time periods. However, home dialysis failures for a resource/geographical reason among those who were 0 to 24 kilometres from a dialysis facility increased substantially from 24 total cases in the pre-pandemic period to 61 total cases during the pandemic period. According to correspondence with CIHI senior analyst, Frank Ivis, geographical reasons for modality change include transfer to a clinic closer to an individual's residence or a move to another location when there are staffing issues, equipment issues, or a lack of physical space in the home for dialysis machines and supplies.

There are other plausible reasons for home dialysis failure that fall under the geographical/resource code or an increase in this home dialysis failure for this reason. It is possible that individuals transitioned to home dialysis without a full training period, and later ran into difficulties adapting to independent dialysis at home. Individuals may have been sent home without adequate home assessment, and their physical environment may have turned out to be less appropriate in terms of size for dialysis treatments, ease of maintaining sterility, and storage of dialysis supplies. A comprehensive description of the infrastructure necessary for hemodialysis in the home was published by Agar et al. in 2015, including an examination of physical requirements and the organization of plumbing and water for the express purposes of the dialysis machine.[128] In particular, the authors note that in order to prevent infectious complications associated with HHD, the building in question must not be affected by dampness, mold, or excessive environmental pollution and the individuals and family must adhere to standard hygiene procedures. The dialysis room itself must have no overt hygiene hazards such as frequent through traffic or clutter, there must be restricted access to small children and pets during HD, and surfaces and furnishings must be easy to clean (curtains and carpets are generally undesirable).[128] Similar requirements exist for PD. Beyond the parameters successful home dialysis requires of individuals, those who share their living space, and their space itself, the stressed supply chains of the pandemic could have also resulted in difficulty in timely delivery of dialysis supplies.

The decrease in home dialysis failures due to burnout is less straightforward to interpret, since pressures on individuals dialyzing at home during the pandemic were surely greater than pre-pandemic. One explanation could be that individuals were failing for other competing reasons before they could be classified as having failed for burnout reasons. In particular, the resource-related and peritonitis reasons for failure seem likely culprits given their overrepresentation during this period. It is possible that alternatively, individuals knew resources were limited and that risks were high with facility-based hemodialysis, so individuals on dialysis and their loved ones continued on their home modality despite burnout.

Results of our exploratory analysis for predictors of home modality failure are generally consistent with prior studies that used proportional hazards regression models, a more informative method that considers time-to-event and can handle censored data.

In the pre-pandemic cohort prior myocardial infarct was predictive of home modality failure. Conversely, lower dialysis vintage and residence in a province other than Ontario or the Atlantic provinces was associated with lower risk of home modality failure.

At first glance, Ontario's higher likelihood of home dialysis failure in the pre-pandemic period could be attributed to the province's broadened criteria for home dialysis eligibility that have resulted in proportion of home modality use from 21.9% in 2012 to 26.2% in 2019. However home dialysis failure rates did not increase over this timeframe.[108] PD use is more concentrated in urban centres and individuals who live in urban centres are more likely to start on PD in Canada.[129] In addition, more people on home dialysis in Ontario live within city limits or in suburbs and thus closer to dialysis facilities than in other provinces. It is possible that their ability to transition to a facility-based modality was greater, simply because it was a more viable alternative compared to individuals living in rural areas, who would have to relocate to permanently transition to a facility-based modality.

Our finding that a history of prior myocardial infarction is associated with an increased risk of home dialysis failure is relatively novel and has not specifically been previously reported. However, coronary artery disease has been reported to be a predictor for increased home hemodialysis failure.[88] This variable may also be a surrogate marker of congestive heart failure and associated fluid overload, which has been previously identified as a risk factor for increasing the likelihood of PD failure in two studies.[88,130]

Shorter time on dialysis before the endpoint of a patient's treatment period (which could have been a failure or alternatively a death, transplant, or withdrawal) was associated with higher odds of home dialysis failure in our pre-pandemic and pandemic models. Kolesnyk et al.'s study of PD failure found that it occurred most frequently early in the few months after treatment initiation, but decreased later due to fewer catheter and abdominal complications and less influence of psychosocial factors.[121] Notably, a systematic review and meta-analysis found that individuals who transitioned from facility-based hemodialysis to PD had a higher probability of failure and reduced overall survival relative to individuals whose initial modality was PD.[131] By contrast, dialysis vintage has not been found to be a significant predictor of HHD technique failure, though it has been found to increase the likelihood of the composite of death and technique failure in individuals on HHD.[78,86,130] Accordingly, it may be presumed that the majority of what drove the association of dialysis vintage with reduced odds of failure was the greater PD representation within the sample.

Pulmonary edema being associated with an increased likelihood of home dialysis failure during the pandemic likely occurred because this variable served as another surrogate marker of fluid overload associated with heart failure.

Finally, it is important to comment on why age was not a significant predictor in either model. Advanced age was a significant positive predictor for HHD failure in Trinh et al.'s study, and it was a positive predictor for PD failure in multiple other observational studies[121,130,132] Our lack of similar findings is likely due to the categorization of age into 5-year bins by CORR to maintain anonymity of individuals in the study. As such, it was analyzed as a categorical variable rather than a continuous variable. Categorization of a variable is known to reduce power, with one estimate noting that dichotomization of a variable, for instance, reduced power by the same amount as would discarding a third of the data.[133,134]

Strengths

This study was the first nationwide study on the impact of the COVID-19 pandemic on transitions from facility-based hemodialysis to home dialysis, subsequent home dialysis failures and reasons for home dialysis failure. Wetmore et al. and Naljayan et. al.'s studies from the United States are the only other national-level studies on this topic, and exclusively focused on individuals who were initiating HD during the pandemic and on the change to the prevalent home dialysis population, respectively; not on the transitions to home dialysis from patients on facility-based hemodialysis.

This study was the first update to a study that examined transitions from facility-based hemodialysis to peritoneal dialysis in the Canadian population using 2001-2010 CORR data.[135] To our knowledge, it was also the first nation-wide study to examine transitions from facility-based hemodialysis to home hemodialysis.

The use of ITS methods with data from CORR, a national administrative database, provided the strongest inference-making ability among the possible retrospective methods about the effects of the pandemic on our primary outcomes of interest. Unlike cross-sectional observational studies, segmented regression analysis of interrupted time series data permits analysts to control for the pre-intervention trends in the outcome and to study the change in response to an intervention over time. In our study we were able to assess whether the onset of specific COVID-19 pandemic waves were associated with any notable changes relative to the historical trend. Additionally, by having multiple assessments of the outcome variable both before and after the intervention, segmented regression analyses address historical threats to internal validity which cannot be determined with pre-post studies. Moreover, interrupted time series analyses display whether an effect happens instantly or with a delay, over a short window or gradually, and whether the effect endures over time or is short-lived.

The quality of the CORR data was such that missingness of key variables used in analysis for the first four research questions was minimal, while that of the many covariates used for the 5th research question was variable. Our observation of an increase in the number of individuals initiating facility-based hemodialysis in Canada over time is consistent with CORR annual statistics and supports the generalizability of our findings.[136] Notably, our finding that the increasing trend in facility-based initiations in Canada did not change during the pandemic seems to stand in contrast to the literature regarding individuals in the United States, which found that the number of individuals starting treatment for end-stage kidney disease fell to a level not observed since 2011.[137]

Limitations of our data

This study had several limitations. Provincial stratification was not feasible for this study as minimal counts of outcomes in the monthly time periods for many provinces would have resulted in insufficiently powered analyses. The absence of Québec data meant an exclusion of rich data from analyses. Further, since this study considered data from a universal health care setting, it is unknown whether its results may be generalizable to a privately funded setting, as insurance schemes could affect choices of dialysis modalities.

The scope of the CORR database imposed further restrictions. It is known that the COVID-19 pandemic impacted mental health. Although measures of mental health and cognition are highly relevant to capacity to self-manage on home modalities and home modality failure, lack of data in the CORR database for these variables meant we were unable to examine whether they were important reasons for and significant risk factors for home dialysis failure. This area is of special concern, for future studies, considering that CKD is a strong risk factor for cognitive impairment.[138,139] Moreover, educational level was not captured in the data.

Within the 2019 CORR data, New Brunswick had an estimated 53 missing incident adult dialysis records (accounting for ~35% missing data within the province), and Newfoundland and Labrador had 10 missing incident dialysis records from one of its centres.[140] While Québec's missing data concern had been growing since 2011 due to administrative issues, CIHI reported no incompleteness of modality-related records from 2010-2018 from non-Québec provinces, nor did this become a matter of concern during analyses.[140] Accordingly, Québec's limited data were excluded from our analyses while Ontario, New Brunswick and Newfoundland's missing data were disregarded.[140]

Limitations of our methods

Adjustment for distance from a dialysis facility and other social, clinical, and demographic covariates was not attempted in the segmented regression models. Doing so could have allowed us to isolate the specific effect of the pandemic on the proportions of transitions, facility-based hemodialysis initiations, and the proportions of failures with more certainty while accounting for the influence of other variables.

While there is no one standard definition of home modality failures, transition to facility-based hemodialysis for 30-90 days is often reported in the literature (with 60 days most common).[141] Our choice of the shorter cut-point of 30 days may have failed to distinguish the individuals who were temporarily on facility-based hemodialysis from those who made permanent moves from home dialysis to facility-based hemodialysis.

Our pre-defined cohort included individuals who spent at least 30 consecutive days on hemodialysis at some point between January 1, 2016 and December 31, 2021. By definition this excluded all individuals who entered the study window with PD as their initial modality and never failed to facility-based hemodialysis or transitioned to HHD. Therefore, findings related to proportions of home modality transitions and failures are relevant to our particular cohort of individuals with hemodialysis experience and cannot be extrapolated to all individuals receiving peritoneal dialysis during the study time period. This introduced two main sampling biases. Firstly, individuals on peritoneal dialysis with longer technique survival were less likely to be included in the overall cohort. Secondly, individuals who entered the study towards the end of the study period had increasingly shorter time to have the opportunity to fail (see Table 6 in Appendix and Figure 2 in Appendix). This resulted in a lower prevalent monthly home dialysis sample in the last couple years of the study and falsely inflated proportions of failures, because while the denominator artificially decreased, the number of absolute failures did not (recall that spending time on facility-based hemodialysis for more than 30 days was the criteria of inclusion for individuals on PD). In brief, our study was unable to make concrete inferences about the changes in the proportion of failures in all prevalent individuals on PD using true month-level denominator data.

Critically, the results of the pre-pandemic and pandemic logistic regression modelling risk factors cannot be in free communication with each other, nor with those of the interrupted time series analysis. The exclusion of participants who never failed from PD to facility-based hemodialysis means that failures as a proportion of all prevalent individuals on home dialysis within our cohort were overestimated in the last couple of years and increasingly so as the study endpoint approached. Moreover, the ratio of non-failures to failures was inaccurate, as the lack of individuals on PD who never spent time on a hemodialysis modality during the study period meant that the logistic regression models had far fewer non-failures than there should have been. The poor discrimination of the pre-pandemic failure model when the pre-pandemic period included 2016-2019, and the inability to create a successful multivariate model when the pre-pandemic period was restricted to July 2018 to December 2019 is likely an indicator that the biases of the cohort were too great to be able to draw meaningful conclusions from it. Even with a complete study cohort, Cox proportional hazards regression models would have been more appropriate methods to model failures as an endpoint, as they could have also handled censorship of the competing events of death, transplant, and treatment withdrawal. They would have also offered more useful information about whether time to technique failure changed before and after the pandemic.

Conclusion

In this interrupted time series, our finding of a statistically significant increase in transitions from facility-based hemodialysis to home dialysis modalities during the first 2 years of the COVID-19 pandemic in Canada as compared to the pre-pandemic period, suggested that recommendations from nephrology societies to facilitate transitions from facility-based hemodialysis to home dialysis to decrease risk of COVID-19-related infection and adverse events in this population were implemented by kidney programs across the country.

In our cohort, which included individuals between Dec. 31, 2015 and Dec 31, 2021 who had at least 30 consecutive days of facility-based hemodialysis exposure, we also observed a significant increase in home modality failures in the pandemic period as compared to the pre-pandemic period. Study methodology did not allow us to definitively identify whether the increase in home dialysis failures was attributable to excess transitions from facility-based hemodialysis or other pandemic-related factors such as delays in accessing medical care. Observed differences in reasons for home modality failure between study time periods suggest pandemic-related factors may have magnified failure risk factors in this population.

The hypothesis that the excess transitions during the pandemic were attributable to patients who were stably on facility-based hemodialysis is further supported by the fact that all the individuals who went from PD to facility-based hemodialysis during the pandemic period were not any more likely to transition back to home dialysis compared to individuals who went from PD to facility-based hemodialysis during the pre-pandemic period. It is important to keep in mind that the individuals who entered the study through the facility-based hemodialysis to home dialysis route during the pandemic period did not have as long to fail as individuals who initiated earlier in the study, so there is an inherent bias towards this cohort not experiencing as many failures during the study period. Extending our study to include the entire course of the pandemic and observing the technique survival of the individuals who started during the pandemic would be beneficial to understand how they performed long term on home modalities relative to individuals starting in other eras. It would also be helpful to understand the demographics of individuals who transitioned to home dialysis from having initiated on a facility-based hemodialysis modality and whether they differed compared to other eras.

Exploratory findings from this study may help healthcare providers expand criteria, education, and resources for home dialysis and prepare for changes in dialysis care to reduce home dialysis failure such as assisted home dialysis and to improve access to resources in future pandemics to improve access to resources. Seeing resource-related home dialysis failure reasons held disproportionately by individuals within city limits may prompt further program-level inquiry into whether such failures were associated with specific alterations to training practices, eligibility relaxation, or less rigorous housing assessments. With resources having turned out to be a larger stumbling block for individuals on home dialysis during the pandemic period than previously, further investigation may guide policymakers and healthcare providers to extend services to include in-home dialysis assistance in which nurses or caregivers are formally trained and assist in home-based modalities.[67] This is particularly important for individuals with strained caregiver support, cognitive impairment, and mobility issues, as well as those who reside in remote regions of Canada.

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Appendix

Budget

This study did not incur any novel expenses. The only cost associated with this study was that of getting CORR data from CIHI, which was previously paid for acquiring a data cut for another study that also included DAD/NACRS databases – which will not be used for this project. This cost $4851 and was covered by my thesis co-supervisor, Dr. Clara Bohm.

Tables

Table 1: Surgery delay and resumption

Province	***Implementation Date***	***Order***	***Governing body that issued order***
Alta.	2020-03-18	Non-urgent procedures and elective surgeries postponed	Government of Alberta, Premier, Chief Medical Officer of Health
Alta.	2020-05-13	Elective surgeries resumed, with exceptions	Government of Alberta
Alta.	2020-05-25	Overnight non-urgent surgeries resumed	Government of Alberta
Alta.	2020-06-12	Additional surgeries resumed	Government of Alberta
Alta.	2020-11-18	Elective surgeries and procedures reduced to increase COVID-19 patient intake capacity	Chief Medical Officer of Health
Alta.	2020-12-08	Non-urgent surgeries requiring hospital stay, clinical support services, and other visits and procedures reduced (Edmonton)	Chief Medical Officer of Health
B.C.	2020-03-16	Non-urgent procedures and elective surgeries postponed	Minister of Health, Provincial Health Officer
B.C.	2020-05-18	Elective surgeries resumed	Government of British Columbia
B.C.	2021-04-22	Scheduled non-urgent surgeries in 9 Lower Mainland hospitals will be temporarily postponed for the next 2 weeks	Ministry of Health
B.C.	2021-05-25	Announced plan to resume non-urgent scheduled surgeries in 9 Lower Mainland hospitals	Government of British Columbia
Man.	2020-03-23	Non-urgent procedures and elective surgeries postponed	Public health officials

Man.	2020-04-24	Surgical capacity of facilities increased	Public health officials
Man.	2020-11-02	Non-urgent and elective diagnostics and surgeries postponed (Winnipeg Metropolitan Region)	Government of Manitoba
N.B.	2020-03-16	Non-urgent procedures postponed	Horizon Health Network, Vitalité Health Network
N.B.	2020-05-08	Elective surgeries resumed	Office of the Premier
N.B.	2020-06-05	Additional non-urgent procedures and non-emergency surgeries resumed	Premier, Chief Medical Officer of Health
N.L.	2020-03-16	Non-urgent procedures and elective surgeries postponed	Department of Health and Community Services
N.L.	2020-06-25	Regional health authorities to further resume services (e.g., non-urgent procedures, surgeries and elective testing)	Department of Health and Community Services
N.W.T.	2020-03-19	All non-urgent procedures and elective surgeries postponed	Northwest Territories Health and Social Services Authority
N.W.T.	2020-05-20	Non-urgent and non-emergency surgeries resumed	Northwest Territories Health and Social Services Authority
Nun.	2021-04-15	Lab services reduced to emergency blood services only; outpatient appointments/non-urgent medical travel/surgery/diagnostic training postponed (Iqaluit)	Government of Nunavut, Department of Health Services
Nun.	2021-04-15	Lab services reduced to emergency blood services only; outpatient appointments/non-urgent medical travel/surgery/diagnostic training postponed (Baffin [excluding Iqaluit], Rankin Inlet)	Government of Nunavut, Department of Health Services

Ont.	2020-03-15	Non-urgent procedures and elective surgeries postponed	Ministry of Health
Ont.	2020-04-02	Order providing public health units the authority to make staffing decisions to support surge capacity issued	Ministry of Health
Ont.	2020-05-19	Gradual resumption of scheduled surgeries announced	Office of the Premier
Ont.	2021-04-12	Elective surgeries and non-urgent activities delayed	Ontario Health
Ont.	2021-03-30	Gyms/fitness studios, casinos, bingo halls limited to 10 people indoors or 25 people outdoors; indoor cinemas closed (Middlesex); see scan	Government of Ontario, Chief Medical Officer of Health
Ont.	2021-04-20	Cancellation of all non-emergency and non-urgent surgeries	Chief Medical Officer of Health
Ont.	2021-05-19	Resumption of all non-emergency and non-urgent surgeries	Chief Medical Officer of Health
P.E.I.	2020-03-15	Non-urgent procedures postponed	Chief Public Health Officer
P.E.I.	2020-05-01	Resumption of priority non-urgent procedures announced	Government of Prince Edward Island, Chief Public Health Officer
Que.	2020-05-18	Surgeries resumed (with guidelines)	Office of the Premier
Sask.	2020-03-23	Non-urgent procedures and elective surgeries postponed	Saskatchewan Health Authority
Sask.	2020-05-19	Resumption of routine services and urgent surgeries announced	Saskatchewan Health Authority
Sask.	2020-06-16	Surgeries, medical imaging and specialty clinic testing further resumed	Saskatchewan Health Authority

Y.T.	2020-03-23	Non-urgent procedures and elective surgeries postponed	Chief Medical Officer of Health
Y.T.	2020-05-01	Limited resumption of non-urgent procedures and elective surgeries announced	Government of Yukon

Table 2: Included Variables

Data Element	Variable Name (in CORR)	Notes
Recipient treatment (variables directly related to outcomes of interest)		
Patient Id	recipient_id_e	Encrypted patient id. Use to link to RECIPIENT table
Treatment Id	recipient_treatment_id_e	Unique treatment Id, encrypted
Modality	TREATMENT_CODE	Separate code table will be included
Transfer/Withdrew/Died Change Codes	TRANSFER_CODE	C= Change of treatment D= Recipient Died F= Facility Reform M= Recipient transfer as result of facility merge R= Transfer out S= Recipient transfer as result of facility split T= Transfer W= Withdrew from treatment
Major reason for change	MAJOR_CHANGE_REASON_CODE	Separate code table will be provided. Includes recovered function
Transfer from facility date	transfer_from_facility_date_s	End date of treatment or transfer to facility (with random shift)
Reason for withdrawal	WITHDRAWAL_REASON_CODE	Separate code table will be provided
Demographic variables		
Age of recipient	Age_grp	As of December 31, 2015 OR initial dialysis treatment date for incident patients (2016-2019) , 5-year categories (27=<30, 32=30-34,37=35-39…77=75+)
Sex	SEX_CODE	M = Male F = Female
Initial Height (for BMI calc.)	Initial_height_grp	In 10 centimetre groupings 5 = 0-9cm 15 = 10-19cm 25 = 20-29cm etc.
Initial Weight (for BMI calc.)	Initial_weight_grp	In 5 kg groupings 2 = 0-4kg 7 = 5-9kg

		12 = 10-14 kg etc.
Race/ethnic origin	Race_grp	1 = Caucasian 2 = All other groups/unknown/includin g Aboriginal
Province	PROVINCE_CODE	Province of treatment as of December 31, 2015 or initial facility 2016-2019 NWT = Merged with AB ATL = All Atlantic provinces
Social factors		
SES	DA_QAIPPE_CODE	Income quintiles by dissemination area (1 = lowest, 5 = highest)
Distance from patient residence to dialysis facility	Distance_to_facility_grp	5 km categories (2 = 0-4, 7=5-9…152=150+ Based on most recent facility
Clinical covariates		
Date of first renal replacement therapy	initial_treatment_date_s	Includes dialysis or kidney transplant Random shifting will be applied.
Angina (baseline)	ANGINA_FLAG	Indicate whether the patient suffered from angina at the time of initiating RRT N = No Y = Yes U = Unknown/missing response
Myocardial Infarct before beginning RRT	MYOCARDIAL_INFARCT_FLAG	Indicate whether the patient had a confirmed myocardial infarct (acute myocardial infarction, status post-myocardial infarction, acute coronary syndrome) on the basis of an EKG, cardiac enzymes, echocardiogram or thallium scans prior to beginning RRT.

		N = No Y = Yes U = Unknown/missing response
Malignancy	MALIGNANCY_FLAG	Indicate whether the patient had a malignancy that existed prior to the first treatment for chronic renal failure. Do not code malignancy if it is located in the kidney and the primary cause of renal failure is kidney cancer. N = No Y = Yes U = Unknown/missing response
Pulmonary edema	PULM_EDEMA_FLAG	Indicate whether the patient had a recent history of pulmonary edema prior to beginning RRT. This includes episode(s) of congestive heart failure or severe fluid overload in the 6 months prior to start of dialysis. N = No Y = Yes U = Unknown/missing response
Cerebrovascular disease	CEREBVAS_ACCIDENT_FLAG	Indicate whether the patient had a cerebrovascular event, such as a transient cerebral ischemic attack, carotid surgery, cerebral infarct, cerebral hemorrhage, stroke or cerebrovascular accident (CVA), prior to beginning RRT. Includes intracerebral hemorrhage, cerebral and pre-cerebral arterial occlusion, stroke syndrome and transient cerebral ischemia.

		N = No Y = Yes U = Unknown/missing response
Vascular disease	PERIPH_VASCULAR_DISEASE_FLAG	Indicate whether the patient has been described as having intermittent claudication at rest or on exercise or has had aorto-femoral bypass surgery, femoropopliteal bypass, graft, iliac or femoral endarterectomy, angioplasty, direct aortic thrombectomy, abdominal aortic aneurysm repair, peripheral arterial disease, arteriosclerosis obliterans, amputation of toes, lower legs, etc. N = No Y = Yes U = Unknown/missing response
Diabetes Type 1	DIABETES_MELLITUS1_FLAG	Indicate whether the patient was diagnosed with type 1 diabetes prior to beginning RRT. Type 1 occurs when the pancreas no longer produces, or produces very little, insulin. Type 1 diabetes usually develops in childhood or adolescence and affects about 10% of people with diabetes (Canadian Diabetes Association). (Code Y if type 1 is the secondary cause of the patient's renal failure and not the primary cause. Code as type 1 if reference is made to childhood, juvenile or insulin-dependent.) For patients whose ESRD is the result of their diabetes, this information is captured under Primary Diagnosis.

		N = No Y = Yes U = Unknown/missing response
Diabetes Type 2	DIABETES_MELLITUS2_FLAG	Indicate whether the patient was diagnosed with type 2 diabetes prior to beginning RRT. Type2 diabetes occurs when the pancreas does not produce enough insulin to meet the body's needs or the insulin is not metabolized effectively. Type 2 usually occurs later in life and affects about 90% of people with diabetes (Canadian Diabetes Association). Type 2 would be a secondary cause of the patient's renal failure and not the primary cause. (Code only if it is the secondary cause of the patient's renal failure and not the primary cause.) Code as type 2 if reference is made to adult onset or non–insulin dependent diabetes. N = No Y = Yes U = Unknown/missing response
Chronic Obstructive Lung Disease, Chronic Bronchitis, or Emphysema	LUNG_DISEASE_FLAG	Indicate whether the patient had clinically significant chronic chest disease requiring medical management prior to beginning RRT. This will usually be described as chronic obstructive lung disease, chronic obstructive pulmonary disease, chronic bronchitis or emphysema. Patient may be on oral bronchodilators (e.g.,

		Choledyl) or inhalation drugs (e.g., Ventolin). N = No Y = Yes U = Unknown/missing response
Medications for hypertension	HYPERTENSION_MEDICATION_FLAG	Indicate whether the patient was receiving medication such as calcium-blocking agents, vasodilators, beta blockers, diuretics or ACE inhibitors (e.g., captopril, enalapril) in order to control hypertension at the time RRT was initiated. N = No Y = Yes U = Unknown/missing response
Other serious illness that could shorten life by 5 years	SERIOUS_ILLNESS_FLAG	Indicate whether the patient has had any other illness that may shorten life expectancy (e.g., aortic aneurysm, AIDS) at the time of starting RRT. Other examples include sleep apnea, chronic liver disease with cirrhosis, Alzheimer's disease, chronic rheumatoid arthritis, peptic ulcer disease and dementia. N = No Y = Yes U = Unknown/missing response; If yes, record the condition in detail.
Current smoking	CURRENT_SMOKER_FLAG	Indicate whether the patient is a current smoker. Current smoker: A person who has smoked cigarettes, cigars or a pipe in the last 3 months. N = No Y = Yes U = Unknown/missing response

Coronary Artery Bypass Grafts/Angioplasty	CA_BYPASS_GRAFT_FLAG	Indicate whether the patient had previous coronary artery bypass graft surgery (stent [coronary] and percutaneous transluminal coronary angioplasty) prior to beginning RRT. N = No Y = Yes U = Unknown/missing response
Death date	Death_date_s	Random shift applied

Table 3: CORR: Major Reasons for Modality Change[114]

HD-Specific
15 = HD access failure
17 = Cardiovascular instability
PD-Specific
01 = Peritonitis
02 = Other abdominal complications
16 = Other complications related to PD
Other
03 = Inadequate dialysis
08 = Transferred to originally intended treatment
14 = Patient/family unable to cope with current treatment (patient/family initiated change)
18 = Resource/geographical (non-medical)
09 = Transplanted
10 = Recovered function
11 = Lost to follow-up
19 = Failed transplant
20 = Left country
99 = Other — specify:

Table 4: Reasons for home modality technique failure

		PD-related	HHD-related	PD- & HHD-related
Individual-related	Social	Inadequate modality education, geography/distance from care teams' bases[79]	Marital dissolution, loss of residence, eviction, loss of support system, non-adherence due to cognitive issues. [76,77]	Relocation,[79,88] dialysis recipient/caregiver fatigue and burnout,[88-90] issues with physical space[90]
	Medical	Abdominal surgeries/hernia, or malnutrition and/or excess protein loss[79]	Bacteremia/other infections, hypotension, other major surgical procedures[76]	Strokes or severe illnesses[76,79]
Modality-related		Peritonitis, catheter dysfunction, ultrafiltration failure, volume overload, hernia/leak/other surgical complications[79-81]	Dialysis access, cannulation difficulties, change in access site/type, malfunctioning dialysis equipment, change in water quality, plumbing issues, inadequate dialysis monitoring, new psychoactive medication[76]	.
System-related		.	.	Low patient attachment (-'ve effects for PD, +'ve effects for HHD)[82-86]
Risk factors		Diabetes,[86,142] age[86], education level[95]	Medicaid enrolment in the United States,[86] male sex[81]	Obesity, [85] black race in the US, smoking, [81,92] and frailty,[52,91,93]
Potential pandemic risk factors	Difficulty securing dialysis supplies due to stressed supply chains, getting remote advice on access and technical issues, less perceived support for emergencies, lower in-person access to home dialysis units for assistance, social isolation exacerbating mental health issues			

Table 5: Comparison of prevalent home dialysis population included in study cohort versus the complete cohort published by CIHI

	Prevalent home-dialysis population		Change from prior year		Failures
	Our data	CIHI's data	Our data	CIHI's data	Our data
2016	1529.455	5425	.	.	365
2017	2168.75	5613	639.295	188	603
2018	2566.25	5707	397.5	94	828
2019	2696.75	5826	130.5	119	875
2020	2758.67	6090	61.92	264	930
2021	2662.33	6134	-96.34	44	998

Year-over-year increases in the average prevalent home dialysis population from 2016-2021 had vastly greater absolute increases from 2016 to 2017 and 2017 to 2018 compared to the yearly prevalent home dialysis population published by CIHI. If anything, our cohort should have had the same or smaller absolute year over year increases in failures. This excessive increase could not have occurred unless the initial population at risk in 2016 were incomplete by some other mechanism beyond our mere population exclusion criteria. The fact that failures nearly doubled from 2016-2017, in lockstep with the near doubling of our restricted prevalent population in the same time frame suggest that perhaps not all failures were picked up because not all individuals at risk of failure were yet in the home dialysis cohort. Considering that our prevalent home dialysis cohort included individuals who were either on PD and failed or those who entered the study on facility-based hemodialysis and had to transition to PD before being included in the home dialysis cohort (and by extension, having the opportunity to fail), we hypothesized that the individuals who ended up failing from a home modality but who had initially entered the study on facility-based hemodialysis took more time to present as prevalent home modality individuals because of their preceding transition to a home modality from facility-based hemodialysis.

Table 6: Comparison of individuals incident on peritoneal dialysis included in study cohort each year versus the complete yearly peritoneal dialysis incidence published by CIHI

	Peritoneal dialysis incidence	
Year	Our cohort	CIHI public statistics
2016	397	1276
2017	365	1324
2018	356	1363
2019	262	1351
2020	211	1447
2021	92	1403

Table 7: Reasons for transition from home modality to facility-based hemodialysis before and after April 01, 2020

Reason[a]	***Time***		
	Jul.1, 2018 – Dec. 31, 2019 *(n=1,294)*	**Apr. 1, 2020 – Sep. 30, 2021 *(n=1,437)***	***P* from two sample z-test for proportions[b]**
PD-related	**259 (20.0)**	**279 (19.4)**	0.3359
Peritonitis	95 (7.3)	132 (9.2)	0.0423*
Other abdominal complications	79 (6.1)	72 (5.0)	0.1030
Other complications related to PD	85 (6.6)	75 (5.2)	0.0649
Home hemodialysis related	**<10**	**<10**	0.3154
Hemodialysis access failure	Supp.	Supp.	0.1711
Cardiovascular instability	Supp.	Supp.	0.3713
Miscellaneous			
Inadequate Dialysis	68 (5.3)	82 (5.7)	0.3077
Transferred to originally intended treatment	105 (8.1)	126 (8.8)	0.2760
Dialysis recipient/family unable to cope with current treatment	76 (5.9)	62 (4.3)	0.0307*
Resource/geographical	35 (2.7)	84 (5.8)	<0.0001*
Left country	Supp.	Supp.	0.2510
"Other" reason	726 (56.1)	779 (54.2)	0.1441

[a]Results stated as n (% of total failures in period) [b] Proportion = number of failures for given reason in period/total failures in period. Supp.=suppressed for privacy due to insufficient cell size. Mean number of participants at risk per month: pre-pandemic period = 2675.9; pandemic period = 2713.8. Number of missing reasons for failure: pre-pandemic period = 17; pandemic period = 19. One-sided z-test used for each reason in the appropriate direction.

Figures

Figure 1: Yearly failures as a proportion of prevalent population on home modalities – complete population versus restricted study population

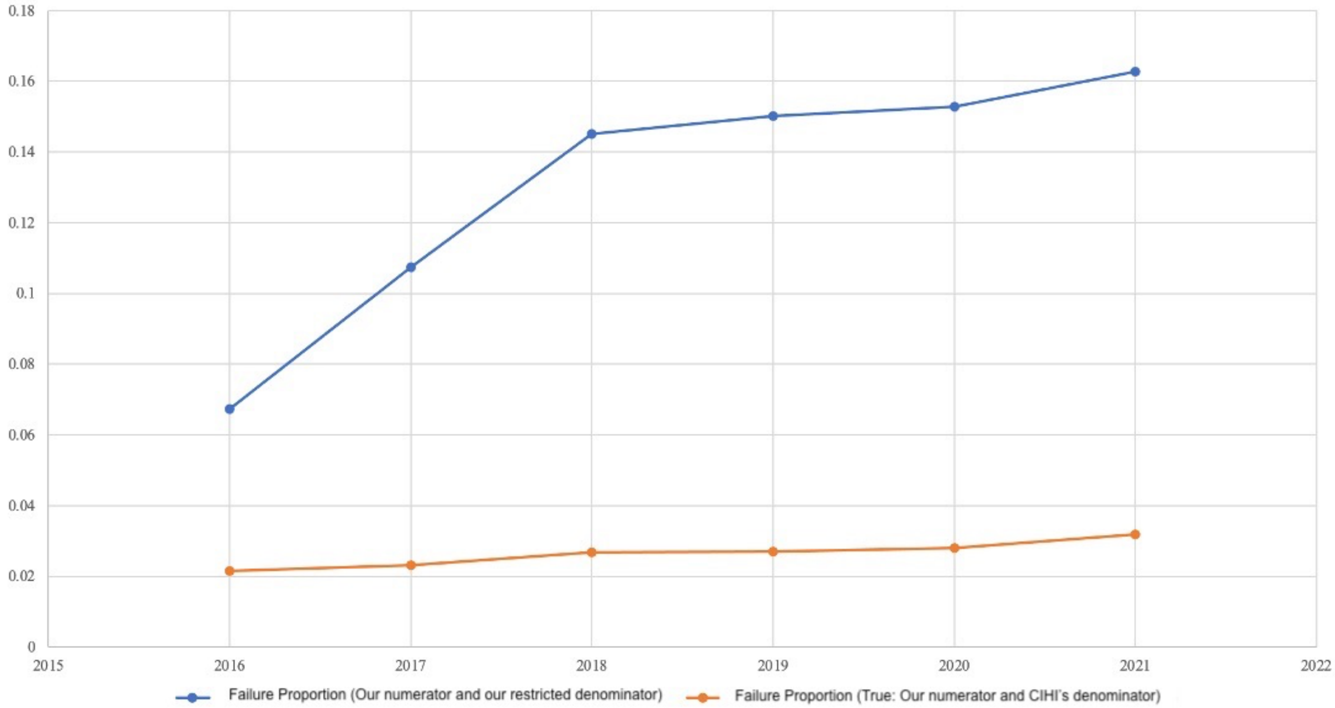

Figure 2: Yearly peritoneal dialysis incidence – CIHI numbers versus restricted study population