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ORIGINAL ARTICLE

Peritoneal dialysis in a crisis: Navigating a severe drought and pandemic in Cape Town, South Africa

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ABSTRACT

Background: A severe drought, followed by the COVID-19 pandemic, posed significant challenges to a South African peritoneal dialysis (PD) programme in Cape Town. The study reported here assessed the impact of these crises on peritonitis rates, bacterial organisms cultured, and patient and technique survival.

Methods: This observational cohort study used data from a peritoneal dialysis registry from 2007 to 2022. The study population was categorized according to three periods: "Baseline" (2007–2014), "Drought" (2015–2019), and "COVID-19" (2020–2022). Baseline characteristics were recorded when PD began. Trends in peritonitis rates, organisms cultured and causes of technique failure were evaluated during each period. A drought-specific questionnaire explored water quality and source.

Results: The cohort comprised 405 patients, representing 559 peritonitis events. There was no statistical difference overall in peritonitis rates, nor peritonitis-free survival at one year among the three periods. Despite Gram-positive organisms being the predominant species cultured, there was an increasing trend in Gram-negative peritonitis during the drought (24%, 46/195) compared to baseline (16%, 37/230) and COVID-19 (15%, 20/134) periods. *Klebsiella pneumoniae* was the predominant Gram-negative organism cultured overall. However, there was a rise in the proportion *Escherichia coli* cultured in the drought (17%) compared to the pre-drought (3%) periods. The proportion of Gram-negative catheter-related infections increased during the drought and COVID-19 periods (P = 0.001), with a predominance of *Pseudomonas aeruginosa*. Only 18% of patients boiled their water as instructed.

Conclusion: The similarity in overall peritonitis rates for the three periods highlights the adaptability and sustainability of peritoneal dialysis as a treatment option, especially at a time of increasing environmental and public-health crises.

Keywords: peritoneal dialysis; drought; pandemic; COVID-19; South Africa.

INTRODUCTION

The current prevalence of peritoneal dialysis (PD) in Africa is estimated to be 23.3 per million population (pmp), with South Africa providing 85% of the total PD services on the continent [1]. In Cape Town, we promote a PD-first policy, unless compelling medical, physical or psychosocial factors preclude PD. In 2018, we reported the challenges of managing a PD-first programme in a resource-limited setting in South Africa [2]. Since that report, our PD programme, based in Cape Town, has experienced further obstacles, including a 4-year drought with severe water restrictions and the global coronavirus (COVID-19) pandemic. There are limited data on how PD programmes adapt in environmental or public health crises and how these events affect patient outcomes. This study aimed to evaluate patient outcomes, of a PD programme in a resource limited setting experiencing these crises.

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PD programme in our setting

The institute where this study was conducted is one of three public facilities offering chronic dialysis to approximately 2.67 million uninsured patients. Chronic dialysis, in our public sector, is free for those who cannot afford it. However, due to resource constraints, it is rationed through an ethically endorsed process, with suitability for transplantation being the overarching factor for acceptance onto the chronic dialysis programme. Despite a heavy demand, only 155 patients can be offered chronic dialysis (100 haemodialysis [HD] and 55 PD). Owing to the limitation of HD slots, therefore, we have instituted a PD-first programme.

The PD-first programme is run by two qualified PD-trained nurses. Nurse-led instruction of new patients is performed in a 2-week intensive, one-on-one training course. Continuous ambulatory peritoneal dialysis (CAPD) via twin-bag, flush-before-fill system is used. Limited automated peritoneal dialysis (APD) is available for working individuals or students. Due to safety concerns and regulations, home visits are not conducted. Throughout the period of this study, few changes were made to the management of the PD programme. Peritonitis treatment has always followed the International Society of Peritoneal Dialysis (ISPD) recommendations, with empiric treatment consisting of giving the patient cephalosporin or vancomycin antibiotics. New patient training was performed by the same two experienced nurses. During COVID-19, the few patients that required instruction received the same in-person training as described above, with personal protective equipment. This was due to the extreme poverty of our patients and their lack of access to technology for remote training. Our more experienced PD nurse retired in 2022; however, her successor (trained in PD for more than 5 years) led the team thereafter. Only glucose-containing fluid was available prior to 2015. Thereafter, icodextran became available but limited due to cost. Routine mupirocin ointment for exit sites began to be given in 2015.

Climate changes and water crisis

Climate change directly contributes to humanitarian crises, with floods, hurricanes, droughts, heat waves and wildfires. It is anticipated that climate change will have a profound impact on global health. The consequent crises give rise to fluctuations within the water cycle, diminished predictability in water availability, heightened instances of water scarcity, reduced agricultural productivity, and adversely affected water quality [3]. According to the United Nations World Development Report, approximately 3.6 billion individuals worldwide reside in regions facing potential water scarcity for at least one month annually [3]. Furthermore, it is projected that water scarcity will affect 4.8–5.7 billion people by 2050 [4]. This will be compounded by competition for water resources among nations and ultimately perpetuate a disproportionate influence on already vulnerable low-income countries.

Cape Town has a Mediterranean climate, with winter rainfall and dry summers. The rainfall pattern has been affected by climate change, and the city suffered an exceptional 3-year rainfall deficit from 2015 to 2018 [5]. When coupled with population growth, there has been a declining volume of water stores serving the city [5]. This culminated in the most severe drought in over 80 years with severe water restrictions, commonly referred to as the "Day Zero" drought. In May 2018, the water reservoirs that provide safe water to approximately 3.7 million Capetonians declined to 20% of capacity [5]. The local government imposed stringent water restrictions to all districts in Cape Town: from January 2015 to January 2018, household water usage was limited from 540 litres [L] to 280 litres per day [5]. Alternative water sources, including spring, borehole and "grey water", were sought during this time. At its worst, from February to September 2018, families were limited to 50 L per person per day. The water restrictions were relaxed to 100 L daily per household in December 2018. Unfortunately, managing PD programmes in the setting of severe water scarcity will be faced by more PD programmes globally, as it is predicted that similar droughts will occur more frequently in the future [6]. This water scarcity will affect access to clean water, affecting hand-washing practices and increasing risk of infection.

Global COVID-19 pandemic

Cape Town's drought came to an end in early 2019, prompting the relaxation of water restrictions. However, by March 2020, the COVID-19 pandemic had reached South Africa, leading to the implementation of rigorous lockdown measures [7], which restricted access to non-emergency health care and reduced patient willingness to seek health care for fear of contracting the virus [8]. The use of alcohol-based hand-rubs increased as a containment measure. Little is known regarding the impact of COVID-19 on chronic PD programmes.

Data have shown a link between severe drought and human diseases, including waterborne enteric diseases [9]. The study reported here was undertaken due to the substantial changes in socio-environmental crises faced by our PD programme in the last decade. The primary aim was to evaluate the impact of public-health crises on peritonitis rates and the spectrum of responsible organisms cultured. The secondary aims were to evaluate whether patient and technique survival rates were influenced by the crises.

METHOD

This retrospective observational review of a cohort was conducted at Groote Schuur Hospital in Cape Town. The study reported anonymised data from a PD registry (HRECR007/2014) using patient records from 1 January 2007 to 31 December 2022. Approval for this study, including the patient questionnaire on water usage, was granted by the Human Research Ethics Committee of the University of Cape Town (HREC508/2020). Due to the study's retrospective review of registry data, patient consent was waived. Three distinct time periods were analysed, which grouped patients into the following cohorts:

1. "Baseline": January 2007 to December 2014.
2. "Drought": January 2015 to December 2019. This period was defined by severe water restrictions.
3. "COVID-19": January 2020 to 31 December 2022.

The varying durations of each period ("baseline", 8 years; "drought", 4 years; and "COVID-19", 3 years) reflect distinct public health and environmental events during the course of the study. The inclusion criterion was all patients, older than 18 years, on our chronic PD programme.

Baseline characteristics were collected at the start of PD. These included clinical, biochemical and demographic data, which comprised age, gender, cause of end-stage kidney disease (ESKD) and body mass index (BMI) (kg/m^2). The presence of concomitant comorbidities (diabetes, hypertension, human immunodeficiency virus [HIV], hepatitis B and cardiovascular disease) was also documented. Biochemical parameters included albumin (g/L), haemoglobin (g/dL), cholesterol (mmol/L), creatinine (µmol/L), urea (mmol/L), calcium (mmol/L) and phosphate (mmol/L). Mortality data were obtained from patient folders, death certificates, clinic records and patients' families. A questionnaire was completed by patients who were on PD during the drought, which explored also the quality and source of water used at that time. This included water source (tap/spring/well/borehole/"grey water") and water purification methods (boiled/not boiled).

Definitions

Peritonitis was defined as two of the following: 1) clinical features of peritonitis (abdominal pain or cloudy dialysate fluid), 2) dialysate leucocytosis [raised white blood cell count (>100/µL or >0.1 × 109/L with >50% neutrophils)], and 3) positive effluent culture. Peritonitis and its subcategories of recurrent, relapsing, repeat, refractory and catheter-related infections were defined using the ISPD guidelines [10]. Peritonitis events excluded relapsing events as these were removed from analysis as they are defined as an extension of the initial episode [10]. Catheter-related infections were analysed separately.

Technique failure was defined as "any PD-related complication that leads to the permanent cessation of the therapy as described in the PDOPPS study" [11]. Causes of technique failure included peritonitis, inadequate dialysis, catheter malfunction, leak, patient-related factors and ultrafiltration failure.

Data analysis

The patients' baseline demographic and clinical characteristics at PD initiation were analysed using two methods and compared among the three periods. The first method analysed the baseline characteristics of those assigned to one of the three periods by the date of PD initiation. The second method analysed characteristics of all patients dialysing within each time interval. Data were gathered from the initial visit within each designated period. Some patients underwent dialysis across multiple periods. Median with interquartile range (IQR) were recorded to summarise continuous variables and frequency and percentage for categorical variables. The Kruskal–Wallis test was used to compare continuous variables among the three time periods due to non-normal distributions. Chi-squared or Fisher's exact test was used to compare categorical distributions, depending on sample size.

Peritonitis rate was reported as number of episodes per patient-year between 2009 and 2022. Years 2007 and 2008 were not analysed due to the extent of missing data on organism type. The total number of peritonitis episodes per year was divided by dialysis-years' time at risk for each calendar year [10]. Peritonitis-free survival (time to first peritonitis episode) and technique survival (time to technical failure) were calculated using the Kaplan–Meier survival estimate in patients on PD for a minimum of 90 days. For peritonitis-free survival, patients who did not experience a peritonitis event were censored at death, transplant, transfer to haemodialysis or last follow-up date. For technical survival, patients that did not experience a technical failure were censored at death, transplant, or last follow-up date.

RESULTS

A total of 405 patients were started on PD from 2007 to the end of 2022. Of the total cohort, 185 began PD in the baseline period, 137 during the drought and 83 during the COVID-19 pandemic. Table 1 compares the baseline biochemical and clinical features collected at the start of PD for the three time periods. The main causes of ESKD were hypertension and chronic glomerulonephritis. The higher proportions of African race and mixed ancestry representatives reflect the predominant demographic populations served by the public-health service in Cape Town.

Table 1. The baseline biochemical and clinical features of the cohort.

	Total	Baseline 2007–2014	Drought 2015–2019	COVID-19 2020–2022	P value
Number in each cohort	405	185	137	83	
Age at PD initiation (years)	38 (31–45)	40 (32–47)	37 (30–44)	37 (30–45)	0.160
Female	205/404 (51%)	89/185 (48%)	67/136 (49%)	49/83 (59%)	0.240
APD	53/400 (13%)	15/182 (8%)	27/135 (20%)	11/83 (13%)	0.011
Race					0.015
African	148/371 (40%)	62/185 (34%)	46/114 (40%)	40/72 (56%)	
Mixed ancestry	208/371 (56%)	112/185 (61%)	65/114 (57%)	31/72 (43%)	
Other	15/371 (4%)	11/185 (6%)	3/114 (3%)	1/72 (1%)	
Cause of ESKD					0.016
Hypertension	131/381 (34%)	64/180 (36%)	35/119 (29%)	32/82 (39%)	
Chronic GN	117/381 (31%)	60/180 (33%)	35/119 (29%)	22/82 (27%)	
Diabetes	25/381 (7%)	15/180 (8%)	7/119 (6%)	3/82 (4%)	
Other	108/381 (28%)	41/180 (23%)	42/119 (36%)	25/82 (30%)	
Reason For PD*					0.539
Failed transplant	19/397 (5%)	8/185 (4%)	7/132 (5%)	4/80 (5%)	
Out of vascular access	10/397 (3%)	5/185 (3%)	5/132 (4%)	0/80 (0%)	
PD first	366/397 (92%)	171/185 (92%)	119/132 (90%)	76/80 (95%)	
Blood pressure >140/90 mmHg	270/391 (69%)	134/179 (75%)	80/131 (61%)	56/81 (69%)	0.034
Diabetes mellitus	32/399 (8%)	19/181 (10%)	8/137 (6%)	5/81 (6%)	0.320
HbA1c >8%	24/38 (63%)	17/25 (68%)	4/8 (50%)	3/5 (60%)	0.690
Albumin	39 (35–42)	39 (36–42)	37(32–41)	39 (35–42)	0.002
BMI classification					0.160
Normal weight	178/398 (45%)	88/181 (49%)	59/134 (44%)	31/83 (37%)	
Underweight	16/398 (4%)	5/181 (3%)	7/134 (5%)	4/83 (5%)	
Overweight	136/398 (34%)	60/181 (33%)	39/134 (29%)	37/83 (45%)	
Obese	68/398 (17%)	28/181 (15%)	29/134 (22%)	11/83 (13%)	
Pack years					0.350
Non-smoker	375/405 (93%)	175/185 (95%)	124/137 (91%)	76/83 (92%)	
>10 pack years	30/405 (7%)	10/185 (5%)	13/137 (9%)	7/83 (8%)	
HIV positive	33/404 (8%)	9/185 (5%)	12/136 (9%)	12/83 (14%)	0.030
Chronic hepatitis B	12/398 (3%)	5/185 (3%)	7/132 (5%)	0/81 (0%)	0.084

PD, peritoneal dialysis; CAPD, continuous ambulatory PD; APD, automated PD; ESKD, end-stage kidney disease; GN, glomerulonephritis; Hep B, hepatitis B; ESKD Other group comprised: familial, HIV-associated nephropathy, rapidly progressive glomerulonephritis, urological, analgesic.
*Reason for PD – patient preference (n = 2) patients were left off the table due to small number.
Periods: Baseline period (2007–2014); Drought period (2025–2019) reflects when dam levels had dropped and water restriction implemented; COVID-19 period (2020–end of 2022).
When denominator does not reflect the total, this indicates missing data.

There was an increase in the proportion of females started on PD in the COVID-19 period, whereas the proportion of black Africans increased linearly over all periods. The proportion of overweight or obese patients and people with HIV increased over the three time periods. Patients in the COVID-19 period demonstrated the worst blood pressure control. Supplementary Table 1 outlines the profile of all patients dialysing within each period. The cohorts for each period were similar, due to the strict selection criteria for our chronic dialysis programme. However, the "baseline" cohort had a longer mean duration on PD (P = 0.001) and fewer patients on automated PD (APD) (P = 0.001). (Supplementary table 1) The differences between the cohorts (length of time on PD, increased APD, increased HIV) were not associated with peritonitis during either crisis. During the drought, patients were advised to boil their water before use; however, a survey revealed that all PD patients at this time used municipal water and only 18% boiled their water.

The total number of peritonitis events over the study period was 559. There were 230 events during the baseline period, 195 during the drought and 134 events during COVID-19. When analysed per period there was no difference in overall peritonitis rates among the three periods. Figure 1 demonstrates the yearly peritonitis rate from 2009 to 2022, and the rate between the three periods. Years 2007 and 2008 were not analysed due to

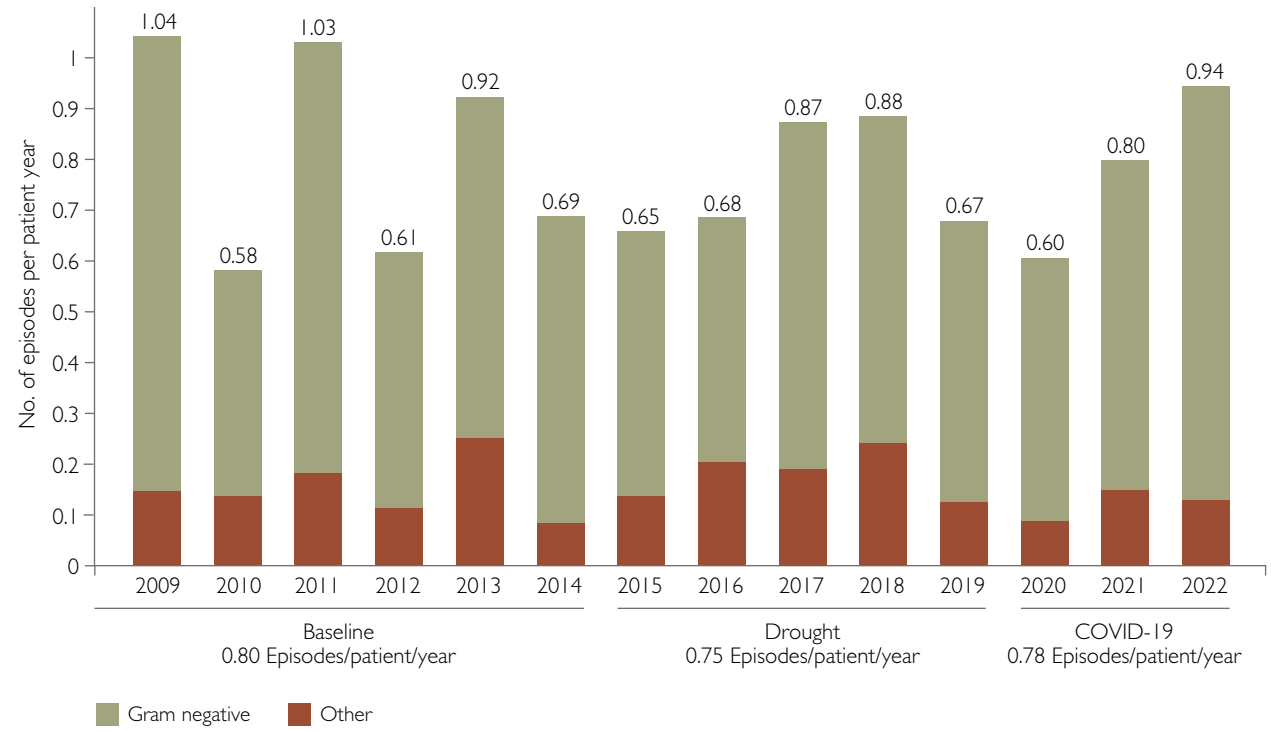


Figure 1. Graph depicting the peritonitis rate per period. Peritonitis rate represents number of episodes of peritonitis per patient year.
Note: 2007 & 2008 removed due to large number of missing organism type.

the extent of missing data on organism type. The peritonitis rate was relatively stable over the three periods, despite large variations between some years. In the baseline period the rate was 0.80 episodes per patient year, during the drought it was 0.75 and during COVID-19 it was 0.78. The yearly peritonitis rate within the drought period demonstrated a modest increase from 0.65 in 2015 to 0.88 in 2018, which correlated with the most stringent water restrictions. In the first year of the COVID-19 pandemic (2020), the unit achieved its lowest peritonitis rate (0.60) throughout the study. The Gram-negative peritonitis events were highest in 2013, and trended upwards during the drought.

The identification of bacterial organisms responsible for peritonitis events during the three periods is illustrated in Figure 2. Gram-positive organisms accounted for the majority of peritonitis events among the three periods and increased slightly in the COVID-19 period. The three most prevalent Gram-positive organisms cultured were Staphylococcus epidermidis 98/309 (32%), Staphylococcus aureus 80/309 (26%), and Coagulase-negative Staphylococcus 48/309 (16%).

Overall, the three most prevalent Gram-negative organisms were Klebsiella pneumoniae (22%, 24/101), Serratia marcescens (18%, 18/103) and Pseudomonas aeruginosa (15%, 15/101). There was an increasing trend of Gram-negative peritonitis during the drought (24%, 46/195) compared to the baseline (16%, 37/230) and COVID-19 (15%, 20/134). During the drought there was a notable increase in the frequency of E. coli, from 3% to 17% between baseline and drought period, (Supplementary Table 2) whereas Acinetobacter baumannii (25%) was the commonest Gram-negative organisms cultured in the COVID-19 period. The proportion of culture-negative events remained stable, ranging from 20% to 23%. Fungal and tuberculosis peritonitis declined over time.

A total of 48 catheter-related infections (exit site) were recorded over the study period. These comprised 21 events in the baseline cohort, 15 during the drought and 12 events during COVID-19. Figure 3 demonstrates the causative organisms of the catheter-related infections during the three periods. Catheter-related infections indicated a linear decline in the proportion of Gram-positive organisms cultured, over the three periods, and a corresponding rise in Gram-negative organisms (P = 0.001). The predominant organism cultured was P. aeruginosa. It rose from 5% at baseline to 40% in the drought and 50% during COVID-19.

Outcome data demonstrated similar peritonitis-free survival at one year between the three periods (Figure 4a). Overall

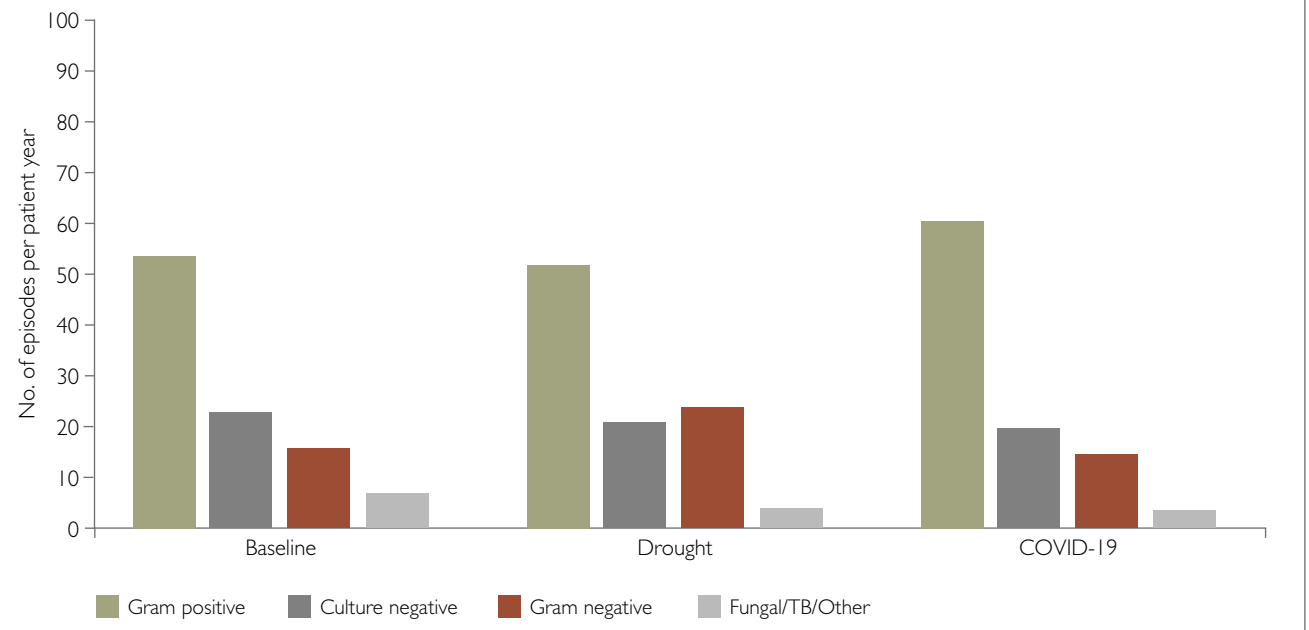


Figure 2. Distribution of organisms causing peritonitis cultured per period. They are represented as proportion of Gram-positive (khaki), Gram-negative (maroon), culture-negative (grey) and other (tuberculosis, fungal and other organisms) (light grey).

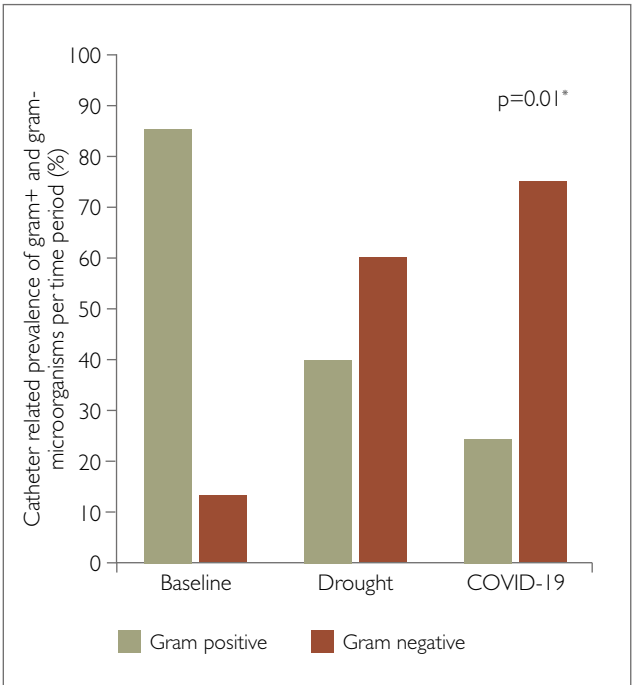


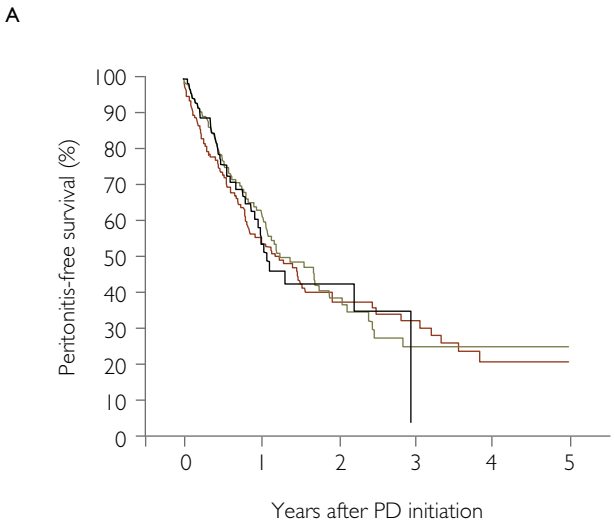
Figure 3. Graph demonstrating the changes in distribution of Gram-positive and Gram-negative organisms catheter-related infections, over the three periods.
Note: *Distributions of gram negative and gram positive are significantly different between eras.

technique failure occurred in 45% (181/405) of patients. Of these, 88 were in the baseline cohort, 59 during the drought and 34 during COVID-19. The Kaplan–Meier curve (Figure 4b) did not demonstrate any noticeable difference in technique survival, within the first two years, among the three periods [baseline 70% (CI 61–78%), drought 74% (CI 64–82%), and COVID-19 80% (CI 65–90%)]. A greater proportion of patients (44%, 16/36) experienced technique failure due to peritonitis during the drought than the 38% (25/66) and 27% (7/26) in the baseline and COVID-19 periods, respectively. Figure 5 illustrates the causes of technique failure during the three periods. Peritonitis was highest during the drought and catheter malfunction was greatest in the COVID-19 period, although neither demonstrated statistical significance (P = 0.370 and P = 0.320, respectively). Inadequate PD was higher in both the drought and the COVID-19 periods compared to baseline.

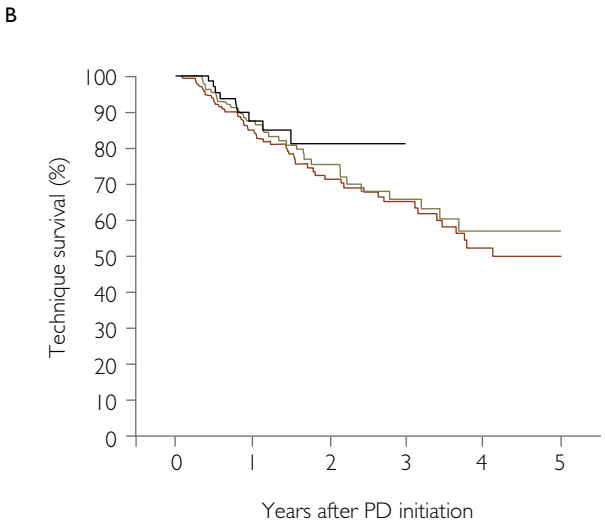
There were 90 deaths in the study period. Death rate increased over time from 29/185 (16%) at baseline, 35/137 (26%) during the drought, and up to 26/83 (31%) during COVID-19. During the drought, the highest proportion of infection-related deaths (17%, 6/35) was from peritonitis, compared to 14% (4/29) at baseline and 12% (3/26) during COVID-19. Sudden death rose sharply during the drought (17%, 6/35) and COVID-19 (23%, 6/26). Cardiovascular death was more frequent during COVID-19 (16%, 4/26) (Figure 6). The numbers, however, were too small for meaningful statistical comparison.

DISCUSSION

This study has provided valuable real-world data on the experience of a PD-first programme in public-health crises, within a resource-limited setting. The study's key findings are, first, the overall peritonitis rate did not change among



Number at risk						
Baseline	161	59	23	14	6	3
Drought	129	57	19	9	2	1
COVID-19	71	22	7	0	0	0



Number at risk						
Baseline	163	107	60	36	23	13
Drought	130	83	46	25	10	6
COVID-19	71	36	12	0	0	0

Figure 4. A, Kaplan–Meier curves demonstrating differences in peritonitis-free survival between the three periods. B, Kaplan–Meier curves demonstrating differences in in technique survival among the three periods.
PD, peritoneal dialysis.

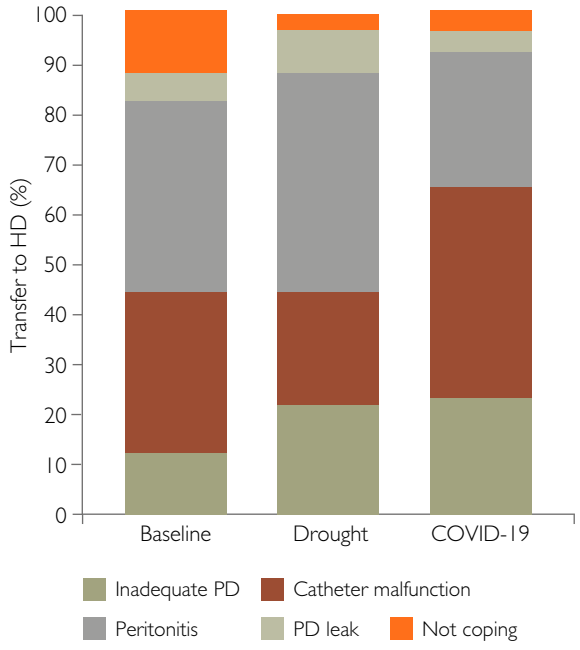


Figure 5. Comparison of the causes of technique failure (inadequate PD, catheter malfunction, peritonitis, PD leak, and not coping on PD) among the three periods.

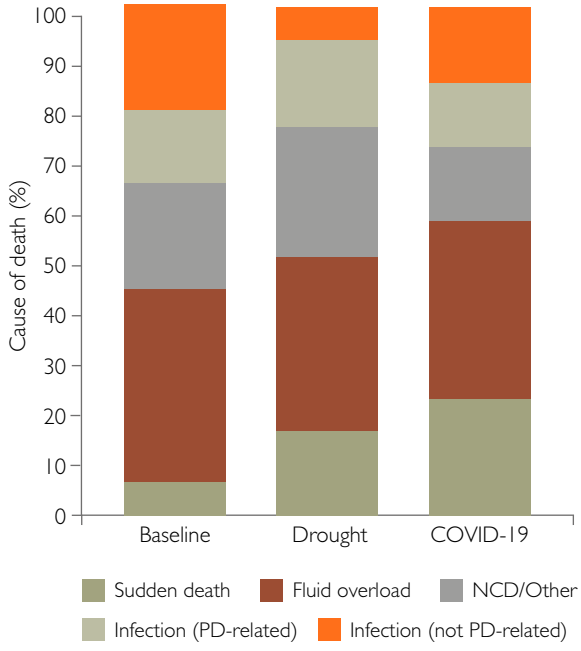


Figure 6. Comparison of the causes of death (sudden death, fluid overload, infection PD-related, infection not related to PD, and other*) among the three periods.
*Malignancy, trauma, unknown.

the three periods. However, Gram-negative peritonitis increased during the drought. Klebsiella pneumoniae was the predominant organism cultured. Additionally, there was a notable rise in the proportion of E. coli cultured, from 3% pre-drought to 17% during the drought. Second, the proportion of Gram-negative catheter-related infections increased during both the drought and COVID-19 periods. Third, there was a rise in the proportion of technique failure due to peritonitis during the drought, which, however, was not statistically significant.

There is an growing body of public-health literature demonstrating adverse health effects from climate change. However, there are limited published data regarding its influence on PD programmes. Supplementary Table 3 summarises studies on the effect of seasonal variations on the rate and organisms involved in PD-associated peritonitis. Tropical and sub-tropical regions demonstrate a strong correlation between humid climates and increasing peritonitis rates [12,13], with Gram-negative organisms peaking in summer [13,14]. Semi-arid and more temperate climates report no seasonal variation in peritonitis rates, although the incidence of Gram-negative organisms increased during the warmer seasons [15].

Little has been reported on how to run a PD programme in a drought with suboptimal water quality and water restrictions. However, numerous PD programmes have described successfully performing PD in informal settlements with lack of access to formal sanitation in South Africa [2,16], although how water restrictions affect the quality and accessibility in an already difficult setting has never been described. During the most severe water shortages and restrictions of the drought, water quality became significantly worse. Coastal water analyses demonstrated poor quality water with an increased incidence of acute diarrhoeal illnesses [17]. Moreover, in patients on HD in Cape Town, this period was linked to elevated blood aluminium levels in dialysis patients [18].

Increased rates of peritonitis and fungal peritonitis have been described for PD programmes following a crisis caused by an earthquake, hurricane or conflict [19-21]. However, data on peritonitis rates during a drought or water crisis are lacking. Droughts with water restrictions have been linked to disease outbreaks. Drought-related diseases have been well described and divided into "transmitted by water" (waterborne enteric diseases caused by E. coli and Vibrio cholera), "water-based" and "water-related" where the pathogen or vector has a life cycle involving water (e.g. Rift Valley fever, dengue, malaria, chikungunya) and "dust-related" (e.g. coccidioidomycosis, chronic bronchitis) [9,22,23]. In our patients on PD, Gram-negative peritonitis and Gram-negative catheter-related infections both increased (P = 0.001) during the drought compared to baseline. The increased proportion of E. coli peritonitis noted during the drought is postulated to have been due to a decline in water quality (reduced water flow in reservoirs and pipelines can lead to higher bacterial loads) and reduced hand-washing hygiene practices.

Exit site infections, culturing Pseudomonas aeruginosa, were also commonly seen during the drought. A local publication described an increase in pseudomonal infections during this period [24]. This rise was thought to be related to stagnant water and low water pressure levels in municipal water systems. This created a favourable environment for pseudomonas growth. Furthermore, the pseudomonal clone found in the outbreak was associated with biofilm formation [24]. Biofilms contain a matrix of extracellular polymeric substances that may reduce the effects of disinfectants such as alcohol-based hand rubs [25]. This may be an additional factor that could explain the increased catheter-related infections as patients may not have washed their hands with soap and water, which disrupts the biofilm.

The drought was followed by the COVID-19 pandemic, data on the effect of which on PD technique failure and peritonitis are limited. During the pandemic, South Africa instituted lockdown measures that aimed to limit human movement and interaction, while concurrently advocating hand sterilisation with alcohol-based rubs. During this period, a sustained rise in Gram-negative catheter-related infections was noted, and P. aeruginosa remained the predominant bacterial organism cultured. It was unclear why A. baumannii was the predominant organism cultured from peritoneal fluid. However, our hospital experienced an outbreak of carbapenem-resistant infections (unpublished data). However, the A. baumannii detected in this study on peritoneal fluid, did not have the same resistance profile as those cultured in the hospital outbreak, so we cannot make a causal link. Other programmes reported rare Gram-negative (Ralstonia pickettii) peritonitis during COVID-19 [26]. Catheter-related infections during the pandemic do not appear to have been described. In our cohort, catheter malfunction was the main cause of technique failure during the pandemic. This may be partialy explained by delayed access to healthcare services due to restricted social movement of patients.

Limitations

This study has several limitations. The study periods varied in length and sample size varied for each cohort, which makes comparisons difficult. However, given that the baseline period (prior to the drought and public-health crises) was the longest reported with the highest numbers, it formed a good base for comparison. The sample size was

small and reflected data from a real-world study. This limited meaningful statistical analysis, particularly when assessing the differences between changes in the organisms cultured and the corresponding intervals. The lack of data regarding potassium levels and diarrhoeal episodes coinciding with peritonitis events is also a limitation of our dataset. The missing data on organism type cultured in 2007 and 2008 limited our analysis of peritonitis in the pre-drought period. Additionally, the retirement of our most experienced nurse in 2022, with the loss of patient training expertise, may be a confounding factor to the changes seen in peritonitis during COVID-19.

Recommendations – How to adapt a PD programme to future crises; lessons learned

PD is ideal for crises due to its adaptability, sustainability, remote performance capability, with consumables stored at home [19,27-29]. However, global recommendations for managing PD during crises are scarce. Pre-emptive preparedness for crises includes a disaster kit (batteries, preserved food, water), antibiotics for peritonitis, a supply of PD consumables, and having a one-week reserve of CAPD if patients are on APD. They should also receive CAPD refresher training if on APD [19,30].

Given the trend in Gram-negative peritonitis events noted at the time of water scarcity, this may be relevant to future drought crises experienced on a larger scale. Therefore, our recommendation is to impose hand washing with hospital grade (at least 60–80%) disinfectant applied for 15–30 seconds and hands allowed to dry completely. This should mitigate the concern of declining water quality [31]. However given our local experience with increased P. aeruginosa catheter-related infections and associated biofilms, the need for additional sustained hand hygiene with soap and water is still apparent. Therefore, emphasis needs to focus on the comprehensive education of patients and families on the benefits of boiling water in this setting. In addition, strict adherence to hand hygiene to minimise the risk of contamination and urgent retraining for patients who have repeated peritonitis episodes, are essential.

During COVID-19, PD was an ideal modality especially when physical distancing was necessary and social movement restrictions were imposed. Two important aspects to managing PD were highlighted at this time. One was the importance of training close relatives of patients in bag exchanges as part of disaster preparedness. This is necessary irrespective of whether the patient is capable, and essential when the patient is too ill to perform PD themselves. Furthermore, the role of telemedicine during COVID-19 in managing PD, was reported in the international literature [32]. In a study of 946 patients on a PD programme, followed up virtually, there was no change in the peritonitis rates. Telemedicine facilitated patient monitoring and assessment of complications, thereby ensuring patient safety [32]. Tools to identify patients that required face-to-face visits were developed based on patient surveys and the virtual submission of pictures of their dialysis schedule and lower limb oedema. Adapting these tools will be important in future crises [32].

CONCLUSION

This study provides key insights into implementing a PD-first programme in public-health crises in a resource-limited setting. The lack of difference in overall peritonitis rate among our three study periods, highlights the adaptability and sustainability of peritoneal dialysis as a treatment option. Despite Gram-positive organisms being the predominant pathogens cultured, Gram-negative peritonitis increased. The predominant organism cultured was Klebsilla pneumoniae, although a rise in E. coli was observed during the drought. Additionally, there was a rise in P. aeruginosa catheter-related infections during both the drought and COVID-19 periods. This study emphasises the need for alternative hand-hygiene methods, comprehensive patient education, and the adaptability of PD in crises, supporting home-based care. These findings call for pre-emptive disaster preparedness plans and adaptive protocols to ensure PD programme resilience and patient safety in future crises.

Conflict of interest

The authors have no conflicts of interest to declare.

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Supplementary Table 1. Clinical profile of patients receiving PD (data collected at first assessment within the period).

	Total N=518	Baseline 2007–2014 N=200	Drought 2015–2019 N=181	COVID-19 2020–2022 N=137	P value
Age	40 (32-47)	41 (33-48)	40 (32-46)	39 (31-46)	0.340
Female	274/517 (53%)	103/200 (52%)	90/180 (50%)	81/137 (59%)	0.240
Time on PD (months)	5 (3-10)	9 (5-10)	4 (2-9)	5 (3-15)	<0.001
Mode Of Dialysis					<0.001
APD	67/486 (14%)	13/173 (8%)	33/178 (19%)	21/135 (16%)	
CAPD	409/486 (84%)	160/173 (92%)	143/178 (80%)	106/135 (79%)	
Change from APD to CAPD	3/486 (1%)	0/173 (0%)	1/178 (1%)	2/135 (1%)	
Change from CAPD to APD	7/486 (1%)	0/173 (0%)	1/178 (1%)	6/135 (4%)	
Albumin	38 (35-42)	39 (35-42)	38 (34-41)	39 (34-41)	0.130
Diabetes Mellites	41/487 (8%)	18/172 (10%)	13/180 (7%)	10/135 (7%)	0.480
HbA1C <8%	19/44 (43%)	10/26 (38%)	5/12 (42%)	4/6 (67%)	0.450
BMI	26 (23-30)	25 (22-29)	26 (23-30)	26 (23-30)	0.370
Normal weight	207/510 (41%)	83/196 (42%)	74/178 (42%)	50/136 (37%)	
Underweight	15/510 (3%)	9/196 (5%)	3/178 (2%)	3/136 (2%)	
Overweight	175/510 (34%)	64/196 (33%)	58/178 (33%)	53/136 (39%)	
Obese	113/510 (22%)	40/196 (20%)	43/178 (24%)	30/136 (22%)	
HIV Positive	35/491 (7%)	8/175 (5%)	13/179 (7%)	14/137 (10%)	0.160
Chronic Hepatitis B	23/490 (5%)	5/175 (3%)	9/179 (5%)	9/136 (7%)	0.160

PD, peritoneal dialysis; APD, automated peritoneal dialysis; CAPD, continuous ambulatory peritoneal dialysis; HIV, human immunodeficiency virus.

Supplementary Table 2. Causative gram negative organisms for peritonitis per period.

Gran Negative organism	Total cohort	Baseline N=37	Drought N=46	COVID-19 N=20
Acinetobacter baumanni	12/101 (12%)	4/37 (11%)	3/46 (7%)	5/20 (25%)
Klebsiella	24/101 (22%)	9/37 (24%)	11/46 (24%)	4/20 (20%)
Enterobacter cloacae	11/ 101 (11%)	6/37 (16%)	5/46 (11%)	0/20 (0%)
*Gram neg other**	12/101 (12%)	6/37 (16%)	3/46 (7%)	5/20 (25%)
Pseudomonas	15/101 (15%)	6/37 (16%)	7/46 (15%)	2/20 (10%)
Serratia	18/101 (18%)	5/37 (14%)	9/46 (20%)	4/20 (20%)
Escherichia coli	9/101 (9%)	1/37 (3%)	8/46 (17%)	0/20 (0%)

*Other organisms included: *Neisseria species, Proteus mirabilis, Pantoea Species, Raoutella ornithinolytica, Stenotrophomonas maltophilia, Neisseria sicca.*

Supplementary Table 3. Describes the effect of seasonal variations on the rate and organisms involved in PD-associated peritonitis.

Country	USA [1]	Austria [2]	Malta [3]	Japan [4]	Australia [5]	Australia [6]	Brazil [7]	India [8]	China [9] Mainland	China [10] Hong Kong	South Korea [11]
Time period		2007-2011	2008-2012	2009-2018	2003 - 2008	2003 - 2008	1990-1992	2010-2011	2011-2019	1995-2001	1996-1999
Study Design	Retrospective	Single centre, retrospective study	Single, retrospective study	Single, retrospective study	Multi-centre, registry retrospective study	Multi-centre, registry retrospective study	Single centre study	Multi-centre prospective observational study	Retrospective study	Single regional centre, retrospective study	-
No. of participants	N=43	N=171/201	N=279/137	N=42/126	N=3128/6610	N=3128/6610	N=132/80	244 patients with peritonitis	N=667/401	N=1344/811	N=53/80
Age (yrs)	-	58 (mean)	65 (mdn)	63 (mdn)	58.9 (mdn)	58.9 (mdn)	-	54.3 (mdn)	61.7 (mean)	-	-
Sex: Female (%)	-	41	41.2	40.5	44	44	-	34.4	52.1	-	-
Diabetes	-	33	42.3	19.8	38	38	-	43.4	18	-	-
Follow up (months)	-	20	32.5 (mdn)	22 (mdn)	19 (mean)	19 (mean)	12	15.76 (mdn)	-	-	-
Overall peritonitis rate (episodes/ patient yr)	-	0.49	0.76	0.12	0.59	0.59	-	8.9 months from catheter insertion to peritonitis	0.21	5.59 episodes per 100 patient months	-
Climate	Semi-arid, dry climate	Pannonian & mountain Climate	Mediterranean – hot dry summers, mild temperature wet winters	Temperate region	Temperate Regions (N=4236) Tropical Regions (N=411)	Temperate (65%) Subtropical (26%) Tropical (6%)	Tropical	Tropical	Sub-tropical	Sub-tropical	Sub-tropical
Seasonal Weather	-	-	Temperature range: 13-26°C No humidity comment	Temperature range 4-29°C Humidity range 42-85%	Temperature range 12-31°C Humidity range 49-58%	-	-	-	Temperature range 5-23°C Humidity range 59-68%	-	-
Impact of climate on peritonitis rates	No seasonal variation	No seasonal variation	No seasonal variation	No seasonal variation	No seasonal variation	Higher peritonitis rates: Tropical regions (HR 1.15; 95% CI: 1.01-1.31)	Higher peritonitis rates: Hot seasons higher	Higher peritonitis rates: winter vs. summer (21.2 vs 12.9%); monsoon vs post-monsoon period (44.7 vs 27.1%)	No seasonal variation .	Higher peritonitis rates: Summer (OR 1.17, CI 1.03-1.32)	Higher peritonitis rates: Hot humid seasons
Findings	Hot & humid period: Culture-negative organism peritonitis rates higher	High temperatures (Spring & Summer): Gram negative organism peritonitis rates	Spring associated gram positive organism peritonitis rates	No seasonal variation in organism incidence	Spring & summer associated with coagulase negative Staphylococci peritonitis rates Winter associated with Corynebacteria peritonitis rates	Tropical region: higher fungal peritonitis rates			Summer associated with gram negative organism peritonitis rates	Summer associated with gram negative bacilli	Humid months: gram positive organisms higher

USA, United States of America; N, number; yrs, years; mdn, median; °C, degree celcius; HR, hazard ratio; CI, confidence interval; OR, odds ratio; vs, versus.

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