Peritoneal Dialysis during Active War

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Summary: Armed conflict jeopardizes patient care through shortages in vital medical supplies. When health care resources are both scarce and not secure, ethically justified principles of action are required to continue the treatment of patients. Although literature exists on the allocation and treatment decisions for military health care workers and warfighters, scarce literature exist for the use of available resources for civilians living within war zones. Chronic or acute kidney disease patients requiring replacement therapies are among the most vulnerable patient population in this regard. In this article, we discuss the use of peritoneal dialysis treatment for both acute and chronic kidney disease patients during war times.
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The majority of modern armed conflicts are internal sectarian and/or civil in nature, compared with the international conflicts that defined the early 20th century. In 2009, 15% of the world's nations were believed to be involved in internal armed conflicts.[1]

Worldwide, an estimated 172 million people are affected by armed conflicts and a prediction suggests that the proportion of countries with internal armed conflict will be 7% in 2050.[1] In addition to these manmade crises, 175 million people also are affected by natural disasters each year.[2] With advances in health care keeping patients alive and well, the impact of conflicts is definitely more complex on the civilian population than in previous years, and now a population of patients exists whose continued health or even existence depends on the availability and ethical distribution of medical treatment.[3]

Peritoneal dialysis (PD) is a life-saving procedure that successfully has treated patients with acute kidney injury (AKI) in war, disaster, and conflict settings since its invention. These instances include the Korean War, the Vietnam War, transcontinental disaster incidents, modern combat operations in Iraq and Afghanistan, and countless other conflicts and disasters worldwide.[4−9] If PD infrastructure is in place, standard equipment and techniques may be used. Improvised or modified PD also can be initiated in war and conflict settings where medical supplies are limited.[10]

The hallmarks of PD include ease of initiation, ease of use, and efficacy, which enable the therapy to be used across the geopolitical spectrum by an estimated 196,000 patients worldwide.[11] Even with hemodialysis (HD) available, PD may be a safe alternative for treating AKI.[12,13] In addition, for neonatal and pediatric patients with AKI, including AKI secondary to sepsis, severe diarrheal illness, or hemolytic uremic syndrome, PD is the preferred means of renal replacement therapy (RRT).[14] The infrastructure burden for PD is lower than for HD, and given the prevalence of AKI in conflict settings, PD capabilities can be vital. A range of procedure-capable providers using readily available medical supplies in disaster scenarios, military conflicts, and resource-limited settings have initiated PD.[5,6,15] Programs can be modeled from template programs including those in Brazil, India, and the Saving Young Lives Program in sub-Saharan Africa and Southeast Asia.[12,14,16,17] The International Society of Peritoneal Dialysis (ISPD) guidelines are also a core resource for the provision of high-quality PD care in these settings.[18] Overall, renal care including infrastructure to support PD is an important resource in settings of conflict and disaster, with the precise dialysis capabilities varying with the regional medical resources (Table 1).

Major disasters may destroy dialysis facilities, leaving patients without life-saving therapy in their local environment. This was a major challenge after natural disasters such as Hurricane Katrina, Cyclone Yasi, the Kobe and Marmara earthquakes, and the recent Tohuku earthquake and tsunami. End-stage kidney disease (ESKD) patients on PD were, in general, able to continue PD; however, some HD patients were transferred to temporary PD. Thus, PD played a major role in the renal care response in these events.

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Table 1. General Overview of PD and Associated Renal Treatment Capabilities in War or Disaster

Capability	Example	PD Catheter Placement Techniques	Useful Adjuncts (if Available)	Catheters	Dialysate
Basic medical	Immediate Conflict Response	Percutaneous	US, radiography, laboratory, medical evacuation	Improvised (eg, nasogastric tube, chest drain)	Improvised
Basic surgical	Military Forward Resuscitative Surgical team	Open surgical, percutaneous	US, radiography, laboratory, medical evacuation	Improvised	Improvised
Interventional nephrology	Coordinated recovery phase of conflict	Percutaneous, peritoneoscopic	PD automation, HD	PD catheters	Commercial solutions
Advanced multidisciplinary care	Tertiary care center near affected region	Open surgical, laparoscopic, percutaneous	Any including HD	PD catheters	Commercial solutions

If available, HD may be a destination therapy for a subset of patients requiring PD during a conflict, or HD may be used if PD fails. The Forward Resuscitative Surgical Team is a mobile trauma surgical and resuscitation team often deployed to forward settings in war zones. Laboratory capabilities in conflict regions may range from limited point-of-care electrolyte panels to advanced laboratory analysis, microbiology, and blood banks.
HD, hemodialysis; PD, peritoneal dialysis; US, ultrasound.

INDICATIONS

PD in AKI

In conflict settings, common indications for PD in AKI include rhabdomyolysis, severe acidosis, hyperkalemia, and uremia. For each of these indications, a functional peritoneal membrane is a requirement for the initiation of PD.[19] Key clinical data to be tracked include general clinical features such as volume status and urine output, and, if available, in a resource-limited environment, appropriate laboratory data to guide the initiation and maintenance of RRT.[20] Indications for urgent-start PD include severe acidosis, hyperkalemic emergency, hypervolemic respiratory failure, uremia, and life-threatening toxin exposure.

Myoglobinuric AKI secondary to rhabdomyolysis is a common indication for emergent RRT when crush injuries occur during military conflicts or natural disasters such as earthquakes.[21] Initial resuscitation involves electrolyte management and volume repletion to maintain a urine output goal of 2 to 3 mL/kg/h.[22] Rhabdomyolysis can lead to anuric AKI with secondary multiorgan dysfunction, acidosis, and hyperkalemia within hours. Emergent RRT may be life saving.

Sepsis and hypovolemic shock secondary to traumatic injuries or diarrheal illnesses may cause AKI, requiring an urgent start of PD during times of combat.[5,6] Resuscitation may focus on damage control interventions such as volume repletion and source control, but progressive renal dysfunction still may occur. Oliguric and anuric AKI secondary to acute tubular necrosis may cause severe and refractory acidosis, hyperkalemia, and, in some cases, postresuscitation hypervolemia. These complications alone or in concert may meet the threshold for RRT in resource-abundant and resource-limited conflict settings.

Less-common indications for urgent-start PD in combat or conflict scenarios include isolated hypervolemia and toxin clearance. In hypervolemic patients with AKI, high-dextrose dialysate can be used to remove volume. There is a significant gap in toxin clearance and overall efficacy relative to HD, but PD can be attempted as the primary means of RRT, or as an improvised bridge to HD for toxic exposures, including toxic alcohols.[23] Toxins or medications cleared with less efficacy by PD are primarily large or extensively plasma protein-bound molecules such as sulfonylureas or amatoxins.[24] Because the efficacy of PD may be considerably less for these indications relative to HD, medical therapies must be optimized simultaneously in all cases.

PD in ESKD

Conflicts and disasters lead to mass movement of populations within or across countries. Some researchers have suggested that refugees or internally displaced people are at increased risk of ESKD.[25] This may be owing to siege, poor socioeconomic conditions, infectious diseases, poor diets, and epidemics of noncommunicable diseases.

PD is an attractive alternative to HD because of the simplicity of the system; lack of need for electricity, machinery, and large amounts of water; and elimination of the need for patient transportation to HD centers.[26]

As Kleinpeter[27] suggested, in the face of disasters, PD patients are able to maintain their treatment at alternative locations upon evacuation. If the evacuation is for a prolonged period of time, as was the case with Hurricane Katrina, emergency supplies may be shipped to the appropriate location temporarily or permanently. Hence the utilization of PD for the treatment of ESKD could be encouraged for hurricane- or disaster-prone areas.[27]

CONTRAINDICATIONS

Relative contraindications to the initiation of PD include overlying soft-tissue infection, recent abdominal surgery, known peritoneal adhesions, diaphragmatic injury, and extreme catabolic physiology with severe hyperkalemia.[28] In addition, some patients with respiratory failure may not tolerate intraperitoneal fluid. Benefits must be weighed against the risks, and the clinical team must leverage available expertise to assess the safety and efficacy of the procedure.

ESTABLISHING URGENT-START ACCESS FOR PD

Catheters

Flexible and rigid PD catheters are the primary options for peritoneal access. Flexible catheters generally are preferred.[14] The Tenckhoff catheter, a fenestrated and tunneled flexible catheter, is the gold standard in PD. It enables higher flow rates, long-term viability, and lower rates of complication including infection.[5,29] There are multiple configurations of the Tenckhoff, including single- and double-cuffed designs, with a straight or bent intercuff segment.[30,31] Double-cuffed catheters have an additional anchor point in the preperitoneal space, which act as an added barrier to infection.[5] The Swan-neck catheter facilitates caudad orientation of the catheter tip, and is associated with less-frequent catheter migration and better overall patient satisfaction.[11] Rigid catheters are inserted using a trocar in a nontunneled fashion that allows rapid placement.[29] They are prone to higher rates of complications, including dialysate leakage, impaired drainage, bowel or bladder injury upon insertion, and peritonitis. Although feasible for short-term management, the rigid catheter is used less frequently than its flexible counterpart.

If dedicated PD catheters are not available, clinical teams can use improvised catheters from any sterilized medical tubing. PD has been performed safely and successfully using nasogastric tubes, suprapubic catheters, pediatric chest tubes, central venous catheters, and numerous other devices.[32] Although not designed for long-term use, medical-grade catheter alternatives are reasonable in resource-limited settings. Availability of supplies, body habitus, and anticipated duration of PD may dictate catheter selection. A definitive catheter when available can replace improvised catheters.

Catheter Placement

Locally available resources and expertise determine the safest and best method of placing the PD catheter. Ideally, a location-specific and evidence-based RRT pathway may be drafted by a dedicated PD access team that uses best practices and the latest ISPD guidelines.[31] This will vary with the theater of combat medical response and the network of civilian facilities that still are operational in the region. For example, a mobile military surgical unit near the front lines of conflict may offer open surgical catheter placement for emergent PD with improvised materials when evacuation to a higher level of care is not available. Higher levels of care that receive evacuations and referrals from the front lines may have a proceduralist (eg, surgeon, interventionalist) for urgent and semi-urgent catheter placement alongside dedicated PD catheters and dialysate. Expert consultation always should be obtained for these efforts. Surgeons, interventional radiologists, nephrologists, and procedurally experienced providers commonly place PD catheters worldwide, and a particular theater of combat must create a renal care system using available expertise.[4,6]

Percutaneous, laparoscopic, and open surgical catheter insertion all are viable techniques. Percutaneous needle-guidewire insertion with or without imaging guidance is the most readily available option in austere or conflict settings. Although a sterile technique is required, it does not require specialized surgical equipment or general anesthesia.[33] Analgesia options may include local anesthesia, intravenous analgesia, and moderate sedation if available. Ultrasound or radiographic guidance are recommended adjuncts if available. Prophylactic intravenous antistaphylococcal antibiotics are recommended to minimize the risk of bacterial peritonitis.[14,34] In addition, best practices in patient preparation, including a preprocedural bowel program and bladder decompression, should be followed, alongside the best practices in technical aspects of catheter placement as reviewed in the ISPD guideline update.[31]

A standard procedural variant for flexible PD catheter insertion involves a midline incision 2 cm inferior to the umbilicus, blunt dissection to the linea alba, puncture through the linea alba with a rigid catheter, small-volume infusion of dialysate, guidewire insertion through the catheter, and dilation by the Seldinger technique to the final device.[33] If available, trocars can serve as the

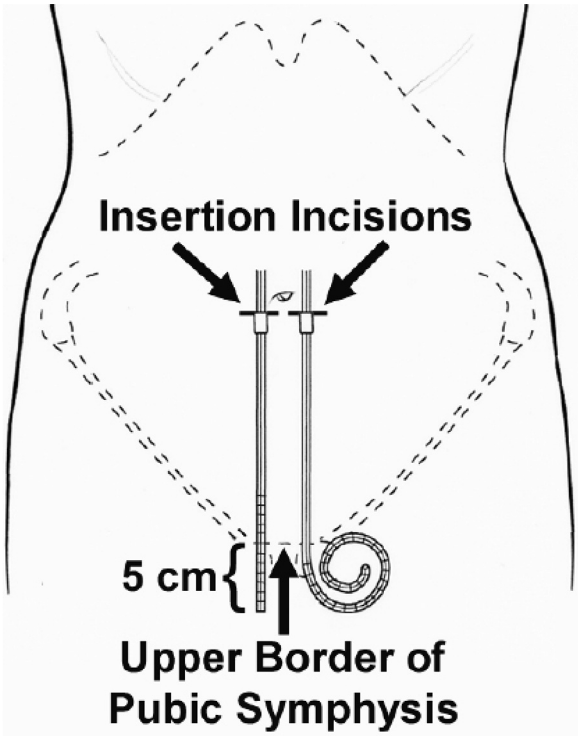

Figure 1. Schematic of a supine patient showing the method in which the catheter insertion site and deep-cuff location are determined to achieve proper pelvic position of the catheter tip. For straight-tip catheters, ideally a design with 15 cm of tubing length beyond the deep cuff, a point 5 cm from the tip of the catheter, is aligned with the pubic symphysis upper border. With coiled-tip catheters, the upper border of the coil is aligned with the upper border of the pubic symphysis. Figure reprinted with permission from Crabtree et al.[31]

rigid catheter to puncture the linea alba. For percutaneous placement of rigid PD catheters, the incisional site is just lateral to the umbilicus, with caudal advancement toward the iliac fossa using a trocar.[18]

When using a dedicated PD catheter, positioning and orientation of the catheter are essential. The upper border of the distal catheter coil should be aligned with the superior border of the pubic symphysis (Fig. 1).[31,35] The catheter is oriented cephalad, approximately 3 cm lateral of midline. The deep- and superficial-cuff points are marked on the anterior abdominal wall. A small skin incision is made at the identified deep-cuff point, and blunt dissection is completed to the rectus sheath. The guidewire, followed by the dilator and peel-away sheath, are advanced into the peritoneal cavity by the Seldinger technique. The catheter then is advanced through the peel-away sheath. The catheter's free end is tunneled via blunt dissection to the superficial-cuff point. At the superficial-cuff point, the catheter exits the abdominal wall and is available for external use, after closure of the skin incisions. The procedure may be assisted by fluoroscopic or ultrasound guidance. Ultrasound enables preprocedural visualization of abdominal structures, real-time tracking of needle advancement, and identification of abdominal wall vasculature.[36] Ultrasound-guided percutaneous catheter placements have shown comparable success rates with the surgical technique in small prospective studies, without any immediate procedure-related complications.[36,37]

Laparoscopic and open surgical placement allow direct visualization of the catheter tip and facilitate the performance of lysis of adhesions and omentopexy to limit catheter tip obstruction or malposition. For example, open surgical placement has been used by forward surgical teams during combat operations, including in Iraq and Afghanistan.[6] After insertion of the catheter at the previously marked deep-cuff point, a subcutaneous tunnel is created toward the superficial-cuff point. At the superficial cuff, the catheter exits the body, the catheter is secured, and the surgical sites are closed. Unfortunately, direct visualization and the option of prophylactic omentopexy do not eliminate the risk of catheter obstruction. Available resources and expertise, alongside patient data including body habitus and surgical history, may guide percutaneous or surgical placement.

DIALYSATE

Dialysate options include premade commercially available solutions, but these may not be available in conflict settings.[38] Alternatively, improvised dialysate may be prepared from intravenous fluids and medications (Table 2).[10,12,14] Peritoneal dialysate typically contains sodium (131-134 mmol/L), chloride (95-105 mmol/L), bicarbonate plus lactate (35-41 mmol/L), and dextrose

Table 2. Four Improvised Dialysate Recipes

	1.45% Dextrose	1.45% Dextrose	1.7% Dextrose	2.5% Dextrose
Lactated Ringers, mL	1,000			
PlasmaLyte (Baxter, Lessines, Belgium) B, mL		1,000		
0.45% NaCl, mL			1,000	
0.9% NaCl, mL				1,000
3% NaCl, mL			60	
5% Dextrose water, mL				1,000
50% Dextrose water, mL	30	30	40	
8.4% $NaHCO_3$, mL			40	100

Using only the medical grade solutions in the left-hand column, ready-to-use 1.45%, 1.7%, and 2.5% dextrose dialysates can be created. The 5% and 50% dextrose water are referred to commonly as D5 and D50, respectively.[10]

(1.5%, 2.5%, or 4.25%). Premade dialysates generally contain zero potassium. Improvised dialysate can be modified from a base solution such as normal saline or 50% normal saline with additives such as sodium bicarbonate, calcium chloride, and dextrose.[39] Lactated Ringer's solution has a comparable electrolyte profile with commercial dialysate but contains 4 mEq/L of potassium. Therefore, the addition of an osmotic agent, such as 50 mL of 50% dextrose per liter of lactated Ringer's solution, will yield an improvised potassium-containing dialysate. If clinically indicated, osmolality adjustments via dextrose additions can augment volume removal. For example, dextrose concentrations increase approximately 1% by adding 20 mL of 50% dextrose per liter of solution. Therefore, clinicians can target the 1.5% to 4.25% dextrose concentrations found in most commercial dialysates. Electrolyte analysis of the serum and the peritoneal effluent can enable optimization of the dialysate (eg, adding potassium to dialysate at serum potassium concentrations <4 mmol/L). Importantly for improvised dialysates, a sterile technique is essential. With each addition to the dialysate, the risk of iatrogenic infection increases, and represents a significant risk to patient safety and outcomes.[40] Antibiotics including aminoglycosides, cephalosporins, and vancomycin can be added to the dialysate for treatment of peritonitis. To decrease the risk of PD catheter obstruction with fibrin, heparin can be added to dialysate, with a typical dose of 500 to 1,000 U/L.[31,39]

DIALYSIS PROCESS

The amount of dialysis to be provided needs to be determined by clinical and laboratory assessments (if available). For patients who are fluid overloaded, catabolic, and/or have a severe metabolic acidosis, aggressive dialysis treatments with frequent PD exchanges may be required. However, for stable ESKD patients, 3 or 4 manual exchanges may well provide acceptable care. For example, Fang et al[41] at Shanghai Jiaotong University School of Medicine, start the majority of their ESKD patients with a 3×2 L/d regimen.[41] Similarly, in Hong Kong, ESKD patients routinely are started on 3×2 L exchanges per day with excellent patient survival rates.[42] Thus, starting PD with a low dose, followed by an incremental increase when needed, might be a useful option in settings where supplies are limited. Standard recommendations from the ISPD suggest targeting a combined urinary and peritoneal Kt/V urea of 1.7 per week or a creatinine clearance of 50 L/wk per 1.73 m^2 for ESKD patients.[43] Achieving these targets may not be manageable during times of crisis. When supplies are scarce, there is a case to be made for ensuring sufficient, albeit suboptimal, care to provide care to the greatest number of patients.[44]

It is important to note that the notion of incremental PD can be an important option for PD patients surviving through conflicts.[45] The definition of *incremental PD* varies between investigators, but the term generally refers to the practice of using residual kidney function to achieve the total desired solute removal, and initially prescribing only a modest dose of PD. Thus, prescribing a smaller total volume of fluid (eg, only one, two, or three continuous ambulatory peritoneal dialysis [CAPD] exchanges/d); or performing PD for fewer than 7 days per week can be used.[45] Kinetic simulation of incremental PD showed that with a glomerular filtration rate as low as 4 to 5 mL/min per 1.73 m^2, patients could be managed successfully.[46]

For patients with AKI treated with PD, the ISPD recommends trying to achieve a weekly combined Kt/V urea of 2.1, although higher doses have been used in some studies.[46] A reasonable starting point for AKI would be 1 to 2 L of dialysate, with 3- to 6-hour dwell times with the patient supine, used three to five times per day.[10] For pediatric cases, 10 to 20 mL/kg of dialysate and shorter dwell times of 30 to 40 minutes may be appropriate. Nonetheless, the guidelines underscore the importance of adjusting the dose based on the clinical circumstances of the patient and the available resources.

COMPLICATIONS

The complication and safety profile of PD is comparable with other commonly performed invasive procedures. Suggested clinical goals regarding complication rates for PD access include visceral injury less than 1%, significant hemorrhage less than 1%, exit-site/tunnel infection less than 5% within 30 days of catheter placement, and peritonitis less than 5% within 30 days of catheter placement.[31] The range of early (ie, within 30 d) and late complications should be reviewed and audited in the local setting. We may hypothesize that complication rates are higher in armed conflicts and in austere settings, but further data are required. Comprehensive reviews of PD complications are essential and cover material beyond the scope of this article.[47-51]

Severe hemorrhage upon catheter placement is a rare complication, and often is contained to the skin or subcutaneous tissues.[52] Special considerations should be made for patients with congenital or acquired coagulopathies. Generally, the overall risk of hemorrhage is mitigated by a more experienced proceduralist, and technical elements such as the use of blunt dissection.[52] Exit site hemorrhage may be managed by direct pressure, suturing, and/or application of local epinephrine.[35] Severe hemorrhage, caused by injury to inferior epigastric arteries or intra-abdominal structures, may require surgical source control or endovascular intervention for embolization.

Visceral injuries (eg, bowel, bladder, or solid organ) are rare but significant early complications. Ultrasonography and radiography can enable the proceduralist to avoid these structures, and assist in the early detection of unintended organ injury.[53] PD access teams must monitor for signs of bowel injury including intraprocedural return of bowel contents or foul-smelling gas, or postprocedural signs of peritonitis.[31]

Intra-abdominal and abdominal wall infections are potential complications of PD catheter placement. Exit-site and tunnel infections often present with stigmata of local cellulitis. Uncomplicated cases can be managed with oral antibiotics.[52] Imaging including ultrasonography may be required to evaluate for abscesses or deep space infections. Severe or refractory cases may require surgical debridement or hardware removal. Peritonitis is the most common late complication in PD, with rates up to 0.24 episodes per patient per year.[50] Prophylactic vancomycin and/or cephalosporins at the time of catheter placement may reduce the rate of secondary bacterial peritonitis. If peritonitis is identified, treatment requires 2 weeks or more of antibiotics, as well documented in ISPD guidelines.[40] Prophylactic antifungal therapy with oral nystatin or fluconazole should be considered during the duration of antibacterial therapy. In hemodynamically stable patients, the antibacterial agents can be delivered via the peritoneal exchanges and PD can be continued.[52] Specific patterns of PD-associated peritonitis or hardware infections may require an algorithm-based approach including medical therapy and/or device replacement.[31]

Dialysate leakage is not an uncommon complication of therapy, particularly when starting therapy sooner than 10 to 14 days after catheter placement, as is often the case in armed conflict, or when using large dialysate volumes.[52] Despite this, certain institutions have had excellent success with urgent-start PD in the nonambulatory setting, with leakage rates as low as 2%.[40,54] These best practices can be translated to war zones. Urgent-start PD may benefit from a low-volume, intermittent dialysis regimen to decrease leakage. PD fluid leakage often is managed conservatively with reduced dialysis frequency or volume, keeping the patient supine, and, rarely, with surgical modifications.[55]

Hydrothorax is an uncommon early and late complication of peritoneal catheter placement. PD leakage into the chest cavity may cause discomfort or respiratory insufficiency in PD patients.[56] A thoracentesis or thoracotomy tube may be indicated for diagnostic or therapeutic purposes. Small-volume PD exchanges may be helpful to minimize accumulation of the effusion. Surgical options such as pleurodesis or thoracotomy with diaphragm repair may be beneficial as well, but generally are unavailable in conflict or austere settings.

Protein loss and hyperglycemia are additional complications of PD.[14] Adequate nutritional protein is important, particularly in prolonged PD therapy. Systemic or dialysate-containing insulin can limit hyperglycemia, improve the osmolar gradient, and improve intraperitoneal ultrafiltration.

Finally, catheter flow dysfunction secondary to catheter tip migration, constipation, bladder distention, and various forms of hardware malfunction may cause discomfort or limit treatment. These may be encountered in war zones, particularly among chronic PD patients. Flow dysfunction typically manifests as outflow obstruction. Constipation and bladder distention should be assessed and, if present, intervention is necessary. If the catheter is partially obstructed during tunneling or improperly secured at the rectus sheath, the catheter tip may be displaced as the device reverts back to its native configuration by its material shape-memory.[55] Omental migration often manifests as decreased dialysate clearance or patient discomfort, and increases the risk of omental trauma from local irritation or forceful attempts at flushing the catheter.[52] If surgical intervention is available, omentectomy or omentopexy may be considered to reduce this complication. Further management of flow dysfunction, leakage, and other procedural complications are reviewed in the ISPD Guideline Update.[31]

CHALLENGES IN DISASTER AND CONFLICT SETTINGS

Supplies

In the initial aftermath of the Kobe earthquake, it was extremely difficult to contact all patients because telephone lines were disconnected and it was challenging to determine where and how to deliver PD fluid to patients. Railway lines and roads were completely damaged. Despite the chaotic situation, emergency delivery still was organized except within the most severely damaged area. Under normal conditions, 18% of the material was transported to the warehouses by ocean containers and 82% by railroad containers. After the earthquake, 35% was transported by ocean containers, 10% by railroad containers, and 55% by ferries and trucks.[57] The specific conditions of the regional conflict or disaster dictate the best mechanism for delivery of materials essential for dialysis.

As a unique example after the Marmara Earthquake, four patients were able to continue on cycling PD using generators, even while living in a tent.[58]

In the instance of Hurricane Katrina, once the enormity of the devastation became evident, arrangements were made for the shipment of additional PD supplies. Emergency protocols were developed to minimize the complications of PD. All patients were advised to use a commercial hypochlorite solution for exit-site care to prevent exit-site infections. Meticulous site care and catheter care were stressed to prevent exit-site infections and peritonitis. For patients with life-threatening cardiovascular, respiratory, or neurologic complaints, immediate referral to an emergency department occurred.[27]

Lack of electricity and tap water during all crisis increases the risk for peritonitis. Social services play a major role in identifying funds to assist patients in obtaining additional support, such as generators. Before the event, education, including reviewing the technique for manual exchanges for those on cycler therapy, and providing patients with a prescription for CAPD if they do not have electric power, is essential. Although some of the patients in Puerto Rico had generators, the shortage of fuel after Hurricane Maria forced most of them to use manual exchanges, resulting in an increased incidence of bacterial peritonitis in the immediate posthurricane period.[59]

Another challenge is the probable lack of clean water. Water safety should be reinforced because as water supplies diminish, people start using natural sources such as rivers, creeks, and lakes for bathing and laundry, increasing the risk of contamination. Patients on PD should be discouraged from using these water sources because they can increase infectious complications.[59]

Sometimes the import of PD solutions becomes a barrier to maintaining treatment. This occurred in Sudan where CAPD was started in 2005. Fluids were supplied by Baxter International (Deerfield, IL) through their local agent in Sudan. However, because of the ongoing crisis in Darfur, Sudan was under a firm economic embargo and Baxter had to obtain an exemption to continue to provide supplies to Sudan.[60]

Operations

As can be seen in many examples, the medical community is not well prepared for disaster and conflict settings. Renal disaster relief strategies should include an advanced plan of measures to be taken after a disaster or during a conflict.[7] This plan should include coordinators of operations, assessment team members, rescuers, and medical personnel. Advanced knowledge is required about the locations, structural and functional features, and capacities of local dialysis facilities, and also referral hospitals for deploying an effective response after any catastrophic event. In addition, educational programs targeting the chronic kidney disease patients including those on PD should be implemented.[7]

In the face of disasters, PD patients should be able to maintain PD at another location upon evacuation. If the evacuation is for a prolonged period of time, as was the case with Hurricane Katrina, emergency supplies need to be shipped to another relocation site temporarily or permanently.[27]

Communication and Telehealth

Disruption of communication is another consequence of these natural disasters. In the Tulane–Dialysis Clinic Inc program, the PD nurse was able to locate nearly all patients within the first 72 hours after the storm via cellular telephone call or text messaging communication.[27] Traditional telephones had tremendous service demands that interrupted basic telephone communication, especially long-distance service. Cellular phones had exponential increases in service demand, disrupting this communication modality as a reliable service. On the other hand, text messaging largely was unaffected, despite increased use of this service.[27]

Communication also was limited significantly after Hurricane Maria. Although it was possible to contact all HD patients within 48 hours, it took 9 days to reach all PD patients who received treatment at the University of Puerto Rico. Internet and social media proved to be invaluable communication tools on the island. Although fragile, it was better than radio or television. Having an organized WhatsApp (Facebook Inc, Menlo Park, CA) group for medical staff made communication easier. The application also was widely used for communication with patients and other health care providers. Analog phone lines are extremely useful and more reliable than mobile cellular telephones because this service was never interrupted after the hurricane.[59]

Syrian American Medical Society Nephrologists visited health care sites in Northern Syria and refugee camps in neighboring countries with the objective of providing a preliminary assessment of the care status of renal patients. Their visits to these sites during the ongoing conflict showed that the care of dialysis patients was severely compromised owing to a lack of access to dialysis units, electricity outage, lack of medications and equipment, destruction of health care facilities, and shortage of medical care providers. The majority of dialysis facilities had no supervising nephrologists. Some regions lacked the existence of any nephrologist.[9] Telehealth therefore became a key intervention during the Syrian conflict. A group of nephrologists involved in the care of kidney patients conducted in-service training for local physicians, nurses, and technicians by maintaining communication and follow-up evaluation through regular telecommunication, Skype (Microsoft, Redmond, WA), and YouTube (Google, San Mateo, CA) videos. Protocols were developed taking into consideration the available local resources. Remote real-time Skype support routinely was made available as well.[9]

Cost

Cost issues are critically important in developing and supporting renal replacement services in times of conflict. For example, although a lack of knowledge and poor penetration of PD were significant factors that favored HD in the Syrian conflict, cost was another barrier to its implementation. Even with three manual exchanges a day at a cost of US $8 per bag (the best price that could be found in Turkey), the monthly cost would be approximately US $750 per patient each month, compared with approximately $500 per patient each month for twice-weekly HD.[26] In developing countries where labor is cheaper, and even after factoring in savings from less transportation and lower erythropoietic agent needs, there was no financial advantage to PD. However, if the cost of PD solutions could be reduced, then PD would be less expensive, particularly if lower doses of PD therapy are targeted.

Similarly, according to health care coverage, the mean cost per session of HD per week is estimated to be 110 Euros (range, 54−250 Euros) or 16,500 Euros (range, 8,100−37,500 Euros) annually; whereas the mean cost of PD per day is 17 Euros (range, 9−27 Euros) or 24,820 Euros (range, 13,140−39,420 Euros) annually in the 10 countries in eastern and central Europe.[61] Another example from a lower-middle-income country such as Egypt shows that the cost of PD was almost five times that of HD, which is attributed to high transport costs and border tariffs incurred by importation of PD solution.[62] However, it is not always clear how the costs of HD actually are calculated. For example, the true cost of HD treatments requires that the cost of machines, the cost of the facility construction, the cost of water, and the cost of electricity, and so forth be taken into account. It is noteworthy that in countries such as India and Mexico, 2-L bags of dialysate can be purchased for a little more than $3 per bag, and lower costs may be available at other sites. Thus, PD in fact may be much less expensive than HD if true costs are calculated and PD supplies are available at a competitive cost.

OUTCOMES

There is inherent variability in the outcomes data reported for PD patients in the aftermath of war or disaster, but valuable lessons can be taken from each experience (Table 3).[63] After the Marmara earthquake, a lack of CAPD solutions and shelter during the first 4 days after the earthquake meant that various medical problems such as hypervolemia, exit-site infection, and peritonitis developed frequently. From the fourth day after the earthquake, teams from CAPD suppliers began to provide medical aid and CAPD solutions for patients living in the earthquake zone. Four patients without shelter of any kind were granted tents where they continued to perform CAPD.[58] Four patients developed peritonitis and were treated successfully without the need for catheter removal. Two patients experienced problems with outflow and were hospitalized because of hypervolemia. After temporary HD therapy, both patients were able to return to their previous CAPD schedule. One CAPD patient experienced a leakage problem and had to be transferred permanently to HD.[58]

The 2011 Japan earthquake and subsequent Fukushima nuclear accident adversely affected dialysis patients not only in the destroyed and radioactively contaminated areas, but also in the adjacent areas.[64] At Kashiwa Hospital, 10 patients maintained on combined PD and HD therapy were forced to stop HD sessions for 2 weeks, however, they continued to perform regular PD without having to travel to a medical facility and they remained medically stable [64]

In the example of Hurricane Maria, 48 of the 52 HD units on the island were able to continue working immediately after the hurricane, although all of them were using generators and water tanks. After a year, three of these units still are closed.[59] In these situations, as well as during conflicts, if possible, dialysis-dependent ESKD patients must be transferred to other dialysis facilities, often in other cities, to continue their dialysis treatment.[65] A good example was seen after Hurricane Maria when more than 600 dialysis patients moved away from Puerto Rico, primarily to Florida.[59]

The outcome of PD patients after the Great Hanshin earthquake (Kobe earthquake) was well documented.[57,66] The Hyogo prefecture region had 265 CAPD patients, accounting for approximately 4% of all dialysis patients. Cyclers were used for 39 patients, none of whom were killed in the disaster, but 3 of whom were injured. Five of the patients' houses totally collapsed, and eight of the patients' houses half-collapsed, but most suffered slight or no damage at all.[66] Treatment was available for most patients at home, although seven patients had to move their equipment to the evacuation area or other sites. The patients who could not use cyclers because of power failures or damage to their houses were switched to CAPD. The outpatient care of

Table 3. Examples of Outcome Measures of PD Programs During Crisis

	PD Patients, n	Outcome	Area Involved
el-Reshaid et al,[67] 1993	27 (7 CAPD, 20 IPD)	All (100%) CAPD patients survived 9 (45%) IPD patients died	Kuwait
Mesic et al,[68] 2018	Unknown	PD program was stopped	Bosnia-Herzegovina
Barbullushi et al,[69] 2000	2	Switched to HD because of peritonitis	Albania
Sakai,[66] 1997	265 PD 39 APD	3 (7.6%) APD patients were injured	Japan
Ozener et al,[58] 2000	42 CAPD	2 (4.7%) patients died under the rubble	Turkey

Abbreviations: APD, automated peritoneal dialysis; CAPD, continuous ambulatory peritoneal dialysis; HD, hemodialysis; IPD, intermittent peritoneal dialysis; PD, peritoneal dialysis.
Data from Ozener et al,[58] Sakai,[66] el-Reshaid et al,[67] Mesic et al,[68] and Barbullushi et al.[69]

the patients became limited because of the severely damaged transport systems and this contributed to some of the patient drop-outs.[66]

Disappointing information about PD patients during a conflict was reported by el-Reshaid et al[67] in which the impact of the invasion of Kuwait on 200 maintenance dialysis patients was analyzed. There were 27 patients on PD, of whom 7 were on CAPD and the rest received intermittent PD (IPD). All seven patients who were originally on CAPD survived. Only one patient required transfer to HD. Nine patients on IPD died during the early weeks of the invasion. All of the remaining IPD patients who were transferred to CAPD died except one.[67] The causes of death of PD patients was summarized as follows: failure to reach the center (four patients), sepsis/peritonitis (nine patients), and myocardial infarction (six patients).

Accurate data on outcomes of dialysis patients during conflicts often are not available. However, many patients are forced to live under difficult circumstances and the mortality rate can be high. For example, at a dialysis center in Tuzla, the largest in Bosnia Herzegovina, the mortality rates of chronic dialysis patients had been 10% to 15% per year before 1992. In 1992, it had increased to 30%, and in 1993 Tuzla lacked sufficient supplies. Patients could be dialyzed no more than 8 hours per week and the mortality rate increased to 41%.[68] The CAPD program, started in 1989, had to be stopped because of a lack of PD solution. Centers in Croatia had a similar experience with their chronic cases.[63]

During the Kosovo War, half a million refugees were admitted to Albania, with a population of 3.5 million. Among the refugees, 75 HD patients presented to the Tirana Dialysis Center. Two PD patients has been switched to HD because of peritoneal infections that developed while travelling to Albania under very difficult conditions.[69]

During the most recent conflicts, a report from Gaziantep, Turkey, provided data about pediatric patients with ESKD.[70] Eighteen children were either on PD (7 patients) or HD (11 patients). Unfortunately, only eight patients continued to visit the hospital regularly despite all free medical support. They presented to the hospital mostly in emergent situations.[70]

Overall, these experiences in times of war and disaster are diverse, but they illustrate the challenges presented in coordinating care for ESKD patients during disasters and conflicts.

CONCLUSIONS

PD is an accessible option for providing life-saving RRT for AKI and EKRD patients in the setting of war and disaster. PD can be improvised from readily available medical supplies, or it can be performed with dedicated equipment including commercially available catheters and dialysate. PD is a safe and effective element of comprehensive renal care during times of war but further research and innovation will be required to continue optimizing PD in these settings. PD may serve as the primary therapy or as a bridge between or to HD. Infrastructure limitations, including supplies and access to renal care providers, will determine the structure of the dialysis network in any specific region of geopolitical conflict. Infrastructure to support PD can be incorporated into medical operations during war and conflict to further enhance care for these vulnerable patients.

REFERENCES

1. Hegre H, Karlsen J, Nygård H, Strand H, Urdal H. Predicting armed conflict, 2010−2050. Int Stud Q. 2013;57:250-70.
2. Samarasekera U, Horton R. Improving evidence for health in humanitarian crises. Lancet. 2017;390:2223-4.
3. Cameron JS. The effect of armed conflict on dialysis patients. Nephrol Dial Transplant. 1993;8:6.
4. Nesbitt I, Almond M. Renal support in military operations. In: Banks DE, ed. Combat anesthesia: the first 24 hours. Vol 1. 1st ed Fort Sam Houston, Texas: Office of the Surgeon General and US Army Medical Department Center and School; 2015:321-6.
5. Yuan CM, Perkins RM. Renal replacement therapy in austere environments. Int J Nephrol. 2011;2011:748053.
6. Pina JS, Moghadam S, Cushner HM, Beilman GJ, McAlister VC. In-theater peritoneal dialysis for combat-related renal failure. J Trauma. 2010;68:1253-6.
7. Sever MS, Lameire N, Van Biesen W, Vanholder R. Disaster nephrology: a new concept for an old problem. Clin Kidney J. 2015;8:300-9.
8. Kumar V, Ramachandran R, Rathi M, Kohli HS, Sakhuja V, Jha V. Peritoneal dialysis: the great savior during disasters. Perit Dial Int. 2013;33:327-9.
9. Al-Makki A, Rifai AO, Murad L, et al. The Syrian National Kidney Foundation: response for the need of kidney patients during the crisis. Avicenna J Med. 2014;4:54-7.
10. Gorbatkin C, Bass J, Finkelstein FO, Gorbatkin SM. Peritoneal dialysis in austere environments: an emergent approach to renal failure management. West J Emerg Med. 2018;19:548-56.
11. Jain AK, Blake P, Cordy P, Garg AX. Global trends in rates of peritoneal dialysis. J Am Soc Nephrol. 2012;23:533-44.
12. Ponce D, Balbi A. Acute kidney injury: risk factors and management challenges in developing countries. Int J Nephrol Renovasc Dis. 2016;9:193-200.
13. Chionh CY, Soni SS, Finkelstein FO, Ronco C, Cruz DN. Use of peritoneal dialysis in AKI: a systematic review. Clin J Am Soc Nephrol. 2013;8:1649-60.
14. Abraham G, Varughese S, Mathew M, Vijayan M. A review of acute and chronic peritoneal dialysis in developing countries. Clin Kidney J. 2015;8:310-7.
15. Ilabaca-Avendaño MB, Yarza-Solorzáno G, Rodriguez-Valenzuela J, et al. Automated peritoneal dialysis as a lifesaving therapy in an emergency room: report of four cases. Kidney Int Suppl. 2008;(108). S173-6.
16. Abdou N, Antwi S, Koffi LA, et al. Peritoneal dialysis to treat patients with acute kidney injury-the saving young lives experience in West Africa: proceedings of the Saving Young Lives Session at the First International Conference of Dialysis in West Africa, Dakar, Senegal, December 2015. Perit Dial Int. 2017;37:155-8.
17. Ponce D, Caramori JT, Barretti P, Balbi AL. Peritoneal dialysis in acute kidney injury: Brazilian experience. Perit Dial Int. 2012;32:242-6.

18. Cullis B, Abdelraheem M, Abrahams G, et al. Peritoneal dialysis for acute kidney injury. Perit Dial Int. 2014;34:494-517.
19. Briggs V, Davies S, Wilkie M. International variations in peritoneal dialysis utilization and implications for practice. Am J Kidney Dis. 2019;74:101-10.
20. Mendu ML, Ciociolo GR, McLaughlin SR, et al. A decision-making algorithm for initiation and discontinuation of RRT in severe AKI. Clin J Am Soc Nephrol. 2017;12:228-36.
21. Vanholder R, Sever MS, Erek E, Lameire N. Acute renal failure related to the crush syndrome: towards an era of seismo-nephrology? Nephrol Dial Transplant. 2000;15:1517-21.
22. Bosch X, Poch E, Grau JM. Rhabdomyolysis and acute kidney injury. N Engl J Med. 2009;361:62-72.
23. Keyvan-Larijarni H, Tannenberg AM. Methanol intoxication. Comparison of peritoneal dialysis and hemodialysis treatment. Arch Intern Med. 1974;134:293-6.
24. Bammens B, Evenepoel P, Verbeke K, Vanrenterghem Y. Removal of middle molecules and protein-bound solutes by peritoneal dialysis and relation with uremic symptoms. Kidney Int. 2003;64:2238-43.
25. Abu-Odah H, Abed Y, El-Khateeb A, Salah M, El-Nems K. End-stage renal disease in the Gaza strip and its relationship to risk factors. J US-China Med Sci. 2016;13:24-34.
26. Sekkarie MA, Zanabli AR, Rifai AO, Murad LB, Al-Makki AA. The Syrian conflict: assessment of the ESRD system and response to hemodialysis needs during a humanitarian and medical crisis. Kidney Int. 2015;87:262-5.
27. Kleinpeter MA. End-stage renal disease use in hurricane-prone areas: should nephrologists increase the utilization of peritoneal dialysis? Adv Chronic Kidney Dis. 2007;14:100-4.
28. Nada D. Peritoneal dialysis in acute kidney injury. BANTAO J. 2010;8:54-8.
29. Wong SN, Geary DF. Comparison of temporary and permanent catheters for acute peritoneal dialysis. Arch Dis Child. 1988; 63:827-31.
30. Abdel-Aal AK, Dybbro P, Hathaway P, Guest S, Neuwirth M, Krishnamurthy V. Best practices consensus protocol for peritoneal dialysis catheter placement by interventional radiologists. Perit Dial Int. 2014;34:481-93.
31. Crabtree JH, Shrestha BM, Chow KM, et al. Creating and maintaining optimal peritoneal dialysis access in the adult patient: 2019 update. Perit Dial Int. 2019;39:414-36.
32. Obiagwu P, Gwarzo G, Akhiwu H, Wada A. Managing acute kidney injury in a child with improvised peritoneal dialysis in Kano, Nigeria. Niger J Basic Clin Sci. 2012;9:84-6.
33. Peppelenbosch A, van Kuijk WH, Bouvy ND, van der Sande FM, Tordoir JH. Peritoneal dialysis catheter placement technique and complications. NDT Plus. 2008;1(Suppl 4):iv23-8.
34. Strippoli GF, Tong A, Johnson D, Schena FP, Craig JC. Antimicrobial agents for preventing peritonitis in peritoneal dialysis patients. Cochrane Database Syst Rev. 2004;(4):CD004679.
35. Crabtree JH, Chow KM. Peritoneal dialysis catheter insertion. Semin Nephrol. 2017;37:17-29.
36. Voss D, Hawkins S, Poole G, Marshall M. Radiological versus surgical implantation of first catheter for peritoneal dialysis: a randomized non-inferiority trial. Nephrol Dial Transplant. 2012;27: 4196-204.
37. Golay V, Trivedi M, Roychowdhary A, et al. Ultrasound-guided CAPD catheter insertion. Perit Dial Int. 2013;33:454-8.
38. McIntyre CW. Update on peritoneal dialysis solutions. Kidney Int. 2007;71:486-90.
39. Teitelbaum I, Burkart J. Peritoneal dialysis. Am J Kidney Dis. 2003;42:1082-96.
40. Li PK, Szeto CC, Piraino B, et al. ISPD peritonitis recommendations: 2016 update on prevention and treatment. Perit Dial Int. 2016;36:481-508.
41. Fang W, Ni Z, Qian J. Key factors for a high-quality peritoneal dialysis program—the role of the PD team and continuous quality improvement. Perit Dial Int. 2014;34(Suppl 2). S35-42.
42. Szeto CC, Lai KN, Yu AW, et al. Dialysis adequacy of Asian patients receiving small volume continuous ambulatory peritoneal dialysis. Int J Artif Organs. 1997;20:428-35.
43. Woodrow G, Fan SL, Reid C, Denning J, Pyrah AN. Renal Association Clinical Practice Guideline on peritoneal dialysis in adults and children. BMC Nephrol. 2017;18:333.
44. Evans NG, Sekkarie MA. Allocating scarce medical resources during armed conflict: ethical issues. Disaster Mil Med. 2017; 3:5.
45. Teitelbaum I. Crafting the prescription for patients starting peritoneal dialysis. Clin J Am Soc Nephrol. 2018;13:483-5.
46. Guest S, Leypoldt JK, Cassin M, Schreiber M. Kinetic modeling of incremental ambulatory peritoneal dialysis exchanges. Perit Dial Int. 2017;37:205-11.
47. Bargman J. Non-infectious complications of peritoneal dialysis. Textbook of peritoneal dialysis. 2nd ed. Dordrecht, Netherlands: Kluwer Academic Publishers; 2000. p.:609-46.
48. Bargman JM. Peritoneal dialysis: introduction. Semin Nephrol. 2011;31:125-6.
49. McCormick BB, Bargman JM. Complications of peritoneal dialysis: implications for patient and technique survival. J Am Soc Nephrol. 2007;18:3023-5.
50. Piraino B, Bernardini J, Brown E, et al. ISPD position statement on reducing the risks of peritoneal dialysis-related infections. Perit Dial Int. 2011;31:614-30.
51. Petrie MC, Traynor JP, Mactier RA. Incidence and outcome of encapsulating peritoneal sclerosis. Clin Kidney J. 2016;9: 624-9.
52. Ratajczak A, Lange-Ratajczak M, Bobkiewicz A, Studniarek A. Surgical management of complications with peritoneal dialysis. Semin Dial. 2017;30:63-8.
53. Abreo K, Sequeira A. Bowel perforation during peritoneal dialysis catheter placement. Am J Kidney Dis. 2016;68:312-5.
54. Jo YI, Shin SK, Lee JH, Song JO, Park JH. Immediate initiation of CAPD following percutaneous catheter placement without break-in procedure. Perit Dial Int. 2007;27:179-83.
55. Crabtree JH. Peritoneal dialysis catheter implantation: avoiding problems and optimizing outcomes. Semin Dial. 2015;28:12-5.
56. Lew SQ. Hydrothorax: pleural effusion associated with peritoneal dialysis. Perit Dial Int. 2010;30:13-8.
57. China S. Management of continuous ambulatory peritoneal dialysis patients in a disaster: the Japanese experience during the Kobe Earthquake. Ren Fail. 1997;19:687-92.
58. Ozener C, Ozdemir D, Bihorac A. The impact of the earthquake in northwestern Turkey on the continuous ambulatory peritoneal dialysis patients who were living in the earthquake zone. Adv Perit Dial. 2000;16:182-5.
59. Bonilla-Félix M, Suárez-Rivera M. Disaster management in a nephrology service: lessons learned from Hurricane Maria. Blood Purif. 2019;47:199-204.
60. Elhassan EA, Kaballo B, Fedail H, et al. Peritoneal dialysis in the Sudan. Perit Dial Int. 2007;27:503-10.
61. Spasovski G, Rroji M, Vazelov E, et al. Nephrology in the Eastern and Central European region: challenges and opportunities. Kidney Int. 2019;96:287-90.
62. Karopadi AN, Mason G, Rettore E, Ronco C. Cost of peritoneal dialysis and haemodialysis across the world. Nephrol Dial Transplant. 2013;28:2553-69.
63. Mesic E, Aleckovic-Halilovic M, Tulumovic D, Trnacevic S. Nephrology in Bosnia and Herzegovina: impact of the 1992-95 war. Clin Kidney J. 2018;11:803-9.
64. Kimura K, Ogura M, Yokoyama K, Hosoya T. A reason for choosing peritoneal dialysis: lessons after the Japan earthquake and the

Fukushima nuclear accident. Am J Kidney Dis. 2012;60:327. author reply 327.
65. Lameire N. Wars, disasters and kidneys. Acta Clin Belg. 2014;69: 418-25.
66. Sakai R. The Japanese experience during the Kobe Earthquake: management of continuous ambulatory peritoneal dialysis patients in a disaster. Ren Fail. 1997;19:693-9.
67. el-Reshaid K, Johny KV, Georgous M, Nampoory MR, al-Hilal N. The impact of Iraqi occupation on end-stage renal disease patients in Kuwait, 1990-1991. Nephrol Dial Transplant. 1993;8:7-10.
68. Mesic E, Resic H, Halilbasic A, et al. Renal replacement therapy in Bosnia and Herzegovina: report of the Society of Nephrology, Dialysis and Transplantation of Bosnia and Herzegovina. Nephrol Dial Transplant. 2003;18:661-3.
69. Barbullushi M, Koroshi A, Tase M. Albanian contribution to the treatment of refugee renal patients from Kosovo. Nephrol Dial Transplant. 2000;15:1261.
70. Akbalik Kara M, Demircioglu Kilic B, Col N, Ozcelik AA, Buyukcelik M, Balat A. Kidney disease profile of Syrian refugee children. Iran J Kidney Dis. 2017;11:109-14.