Should renal nurses be aware of water quality?

KEY WORDS

Water, Osmosis, Quality, Testing, Biofilm

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ABSTRACT

Although traditionally considered the domain of the renal technologist, many units do not have technicians or may only have part time access to one. In these cases, it often falls to nursing staff to ensure that patients are dialysed safely. However, water quality is an area in which some nurses do not feel confident. This article is aimed at providing information about the importance of appropriate water treatment, water testing and monitoring and the implications to the patient if the water is not checked appropriately in accordance with the guidelines.

INTRODUCTION

Water has an important function in the provision of haemodialysis. It is the major component of dialysis fluid and, if not of a high enough quality, can have a detrimental effect on patients undergoing haemodialysis therapy (Thomas 1997). Traditionally, the responsibility of the provision of water of suitable quality has been with the renal technologist. However, many dialysis units do not employ technologists, or have only limited access to their services. In these circumstances it falls to the nursing staff to undertake routine testing and monitoring of the water treatment system. However, water treatment technology and water quality is an area in which some nurses are not familiar. Although nurses may not be servicing the water treatment system, they are responsible for understanding all the clinical ramifications of water treatment for haemodialysis patient's (Amato 2001). This can increase the nurses' ability to provide treatment with added confidence and through this knowledge some factors appertaining to better treatments may be possible.

Selecting the water treatment system most appropriate for the needs of the unit is important. A series of logical steps are required that identify the uses to which the purified water will be put; to arriving at a configuration for the final system. Knowledge in this area is not intended to make renal nurses into water treatment engineers. However, it should enable nurses to develop an understanding of the system, including the purification processes and their sequence in the system. Importantly an understanding of the testing and monitoring procedures is required to maintain quality standards.

WATER SUPPLY - RISKS AND HAZARDS

The provision and maintenance of water supplies which are free from pathogenic organisms is an important factor in the protection of public health. The recommendations of the World Health Organisation (WHO 1992) and European Commission (EC Council 1980) relating to potable water aim to provide water that is physically, bacteriologically and chemically safe to be used for drinking.

To achieve these standards, the water supplied to our homes undergoes several stages of treatment. This treatment often involves the addition of chemicals to facilitate the removal of suspended compounds and other constituents. In addition, chemicals are added as disinfection agents to control bacteriological contaminants. Whilst these standards usually ensure a safe drinking water supply, the average dialysis patient is exposed to more water in one year than the average person drinks in a lifetime, which means even low levels of bacteriological or chemical contaminants could represent a health risk (Anon 1996).

The medical literature contains reports of patient injury or death associated with inadequately treated or monitored dialysis water supplies (Perez-Garcia and Rodriquez-Benitez 2000). Dialysis nurses should be aware that patient reactions caused by chemicals or their residuals that may contaminate the dialysis water

exhibit a wide range of symptoms including headache, hypotension, osteoporosis, haemolysis, organ failure or even death (Thomas 1997).

With Because aluminium sulphate is used to treat municipal supplies, reports of severe bone disease and fatal dialysis encephalopathy have been associated with high levels of aluminium in the water supply (Platts, 1977; Ganzi, 1984; Serrano-Arias, 1995); Ismail, 1996). In 1993, 25 patients in southern Portugal died from severe encephalopathy linked to aluminium intoxication (Stragier 1994). Bone disease is a serious aspect of renal replacement therapy (RRT) and any measures which are able to prevent or delay this would be beneficial for the patient.

Chlorine and chloramines are used as bactericidal agents in public supplies and by the 1970's chlorine along with aluminium, fluoride and copper were noted to be toxic to haemodialysis patients (Henderson and Thuma 1998). Even low levels of these contaminants can cause dementia, osteomalacia, nausea and vomiting, so the water used to create dialysate needs to contain low levels of the contaminants (Alfrey, LeGendre and Kaehny 1976; Ward 2007). Contaminant exposure to blood can cause de-naturing of haemoglobin. In Madrid due to water treatment system failure 66 patients were affected by severe haemolysis with 15 requiring blood transfusions (Lorenzo et al 1996). In 1996 also, 60 haemodialysis patients died due to cyanobacteria (blue-green algae) in the water treatment supplies (Pouria et al 1998). Adverse effects related to chemical contaminants also result from nitrates, copper, calcium and potassium, fluoride and sodium azide (Arduino et al 1989).

DIALYSIS WATER SYSTEM

Water for haemodialysis requires additional treatment to remove contaminants that may be present in drinking water (Hoenich and Levin 2003). The typical water treatment system for dialysis will depend upon the quality of the incoming

supply. Different contaminants require different treatment processes for their removal. The desired end quality will have a bearing upon the design of the system, with higher quality necessitating further treatment processes.

WATER QUALITY GUIDELINES

Various bodies and associations, such as the Association for the Advancement of Medical Instrumentation (AAMI) and EDTNA/ERCA have produced standards and guidelines for haemodialysis systems which include water used to prepare dialysate. The AAMI standards have represented a worldwide reference since 1980 and have been recently updated (AAMI, 2001; 2004). In Europe most standards are defined by the European Pharmacopoeia (EP) (2001, 2002) or suggested by national guidelines.

All nurses should have access to these publications as this knowledge impacts on treatment outcomes. These publications state the permitted contaminant levels and additionally some applications impose additional water purity criteria. These additional criteria mainly relate to microbiological contamination and are necessary due to the developments in therapy that have taken place over the years.

Compliance with the general standard is adequate for water used in the preparation of dialysate with conventional low permeability membranes. The use of highly permeable membranes and ultrafiltration control systems may result in transfer of dissociated endotoxins and endotoxin fragments from dialysate to blood (Hoenich and Levin 2003). Therefore the water used to prepare dialysate for high-efficiency haemodialysis, needs to have a lower level of microbiological contamination than is suggested for general use as high flux membranes may have a higher absorption capacity for endotoxins than a low flux cellulosic membrane. On-line Haemodiafiltration (HDF) requires a higher standard as large volumes of infusate are infused directly into the blood supply.

EVALUATING THE QUALITY OF THE WATER

The public water supplier should be contacted to determine the characteristics and seasonal variations of water leaving the water treatment plant supplying the dialysis unit. Nurses need to be aware that the supply can vary widely by both region and nature of the water source. Due to seasonal variations and water treatment practices haemodialysis units need to be aware of this information and be advised by the water supplier of major changes in the supply quality or adverse incidents.

Ground water is usually less contaminated with organic substances, but may be high in ionic contaminants. Surface water can be contaminated with organic compounds, both naturally occurring as well as man-made pollutants. Ground water is generally less subject to seasonal variations than surface water. However suppliers may alternate between surface and ground water sources.

Public water suppliers generally use free chlorine or chloramines to suppress bacterial growth. Free chlorine or chloramines in the water supply to the haemodialysis facility must be removed because of their haemolytic effects and susceptibility of certain types of reverse osmosis membranes to damage by free chlorine (AAMI, 2004).

A number of clarification techniques are used, some which are detrimental to haemodialysis water quality and could have adverse effects on treatment outcomes. If the supplier uses ferric chloride flocculation, iron oxide may precipitate and pose a problem as a foulant. If the water treatment plant uses alum, the aluminium concentration of the water supply may be high enough to require extensive treatment to bring it to safe levels. Peak concentration data should be requested from the water supplier for contaminants listed in the standards.

THE DIALYSIS WATER SYSTEM

Purified water for dialysis must meet the requirements for ionic and organic chemical purity and must be protected from microbial proliferation. It is usually prepared using drinking or potable water as feed water and purified using operations that may include ion-exchange, reverse osmosis, filtration, or other suitable procedures. Figure 1 is a basic water treatment system for dialysis use. The raw water tank provides a buffer from the supply and allows pressure booster pumps to be used to give a constant supply.

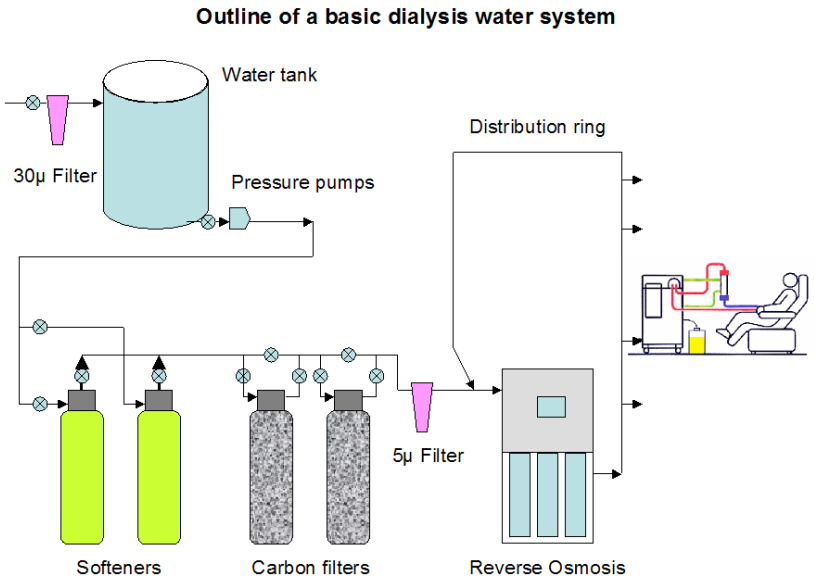


Figure 1: Basic Direct Feed water treatment system

Filtration

Filtration is generally achieved by what is basically an ultra-fine sieve capable of removing fluid borne particles larger than the pore size of the filter membrane. There are two general types of cartridge filter which are routinely used: ‘depth filters’ and ‘membrane filters’. With depth type filters the water flows through the thick wall of the filter, where the particles are trapped throughout the media. The most important factor in determining effectiveness is the porosity throughout the media. Filters with a graded density, i.e. lower on the outside and increasingly higher toward the inside, have a higher dirt holding capacity than single density filters. The effect of grading is to trap larger particles toward the outside and finer

particles toward the inside. This type of filter is usually employed as coarse filters (typical rating 5 - 30 micron) in the incoming water stream to remove larger particulate matter.

Absolute or membrane particle filters typically use a flat sheet media, membrane or specially treated non-woven material to trap the particles. The media is usually pleated to provide a larger surface area. These filters are usually positioned after all the pretreatment components and immediately before the RO pump and membranes. These are coarse filters to protect the RO and prevent fouling of softeners and carbon beds with larger bits of debris.

Activated Carbon

The main purpose of using activated carbon is to remove chlorine and chloramines from the water. The term ‘activated’ refers to the process by which the carbon is processed in order to enlarge its pore structure. Granular Activated Carbon (GAC) is commonly used. The ability of activated carbon to remove contaminants is determined not by its weight or volume, but its adsorption capacity. Carbon is often rated in terms of iodine numbers for absorbency, the higher the number, the more chlorine and chloramines will be adsorbed.

Ion exchange

Ion exchange can be defined as the reversible interchange of ions between a solution and an ion exchanging material. In water treatment, the principle of ion exchange is used to remove unwanted ionic impurities, and the main use to which ion exchange is put to is in the softening of water. This is achieved by passing hard water containing calcium and magnesium ions through a vessel containing an exchange resin of the sodium form. The calcium and magnesium ions are exchanged for sodium ions, and it is the sodium ions which give the water its ‘softness’.

The resin is ion specific so only calcium and magnesium ions are removed and replaced by sodium (Figure 2). Once all of the sodium ions have been exchanged, the softening process ceases. The resin then needs to be regenerated by flushing with a strong brine solution containing large amounts of sodium chloride, enabling the reverse exchange to occur. The calcium and magnesium are disposed of by flushing to drain.

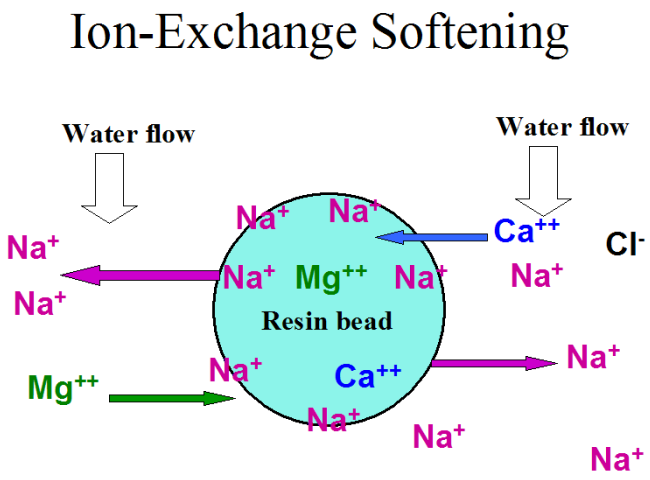


Figure 2. The ion exchange process

The point of exhaustion of the exchange resin will depend upon the levels of calcium and magnesium in the feedwater. The hardness of the feedwater is usually ascertained by testing and is often quoted in degrees of hardness or parts per million $CaCO_3$. Most dialysis units have a water softener, incorporating a brine tank and control head that automatically executes the regeneration cycle. The water needs to be softened as the “harder” the water the more ionic impurities that will exist within the water supply system which can have negative effects on patient outcome. The calcium and magnesium salts may cause a scale to form on the reverse osmosis membrane if they are not removed before the water enters the reverse osmosis unit. Basically the majority of pre-RO water treatment is to protect the membrane of the RO, the exception being the carbon

filters for removing chlorine. This knowledge has significance for treatment outcomes.

Reverse Osmosis

Reverse osmosis was originally developed for removal of inorganic salts. It involves the transport of water through a membrane which acts as barrier to the constituents to be removed from solution. Water is forced across a semi-permeable membrane at high pressure to filter the water and rejects approximately 90-95% of ionic and non-ionic impurities as well as microbiological contaminants (Thomas 1997; Al-Khader and Al-Jondeby 2002).

Reverse osmosis will generally remove any molecular compounds smaller in size than water molecules. Such compounds include salt, manganese, iron, fluoride, lead, and calcium (Binnie et al, 2002). To achieve this, feed water under pressure is pumped into a module containing a semi-permeable membrane. Provided the applied pressure exceeds the natural osmotic pressure of the impure water, a proportion of the feed will pass through the membrane, which rejects most of the contaminants, to form the “permeate.” The contaminants accumulate in the residual “concentrate” stream, which is discharged to drain.

Thin-film composite RO membranes can remove up to 99.5% of the inorganic ions from the feed water, together with virtually all the colloids, micro organisms, pyrogens, and other organic macromolecules. Thus, water purified by reverse osmosis will be essentially free from endotoxins and from inorganic toxins, such as aluminium, irrespective of their chemical form (Cross, 1997). RO membrane performance is measured by percent rejection. Final product water quality is measured by either conductivity in micro-siemens/cm (µS/cm) or total dissolved solids (TDS) displayed as mg/L or parts per million (PPM). The RO membrane removes contaminants that would otherwise cause a potential health risk to the patient. Renal patients are already immunocompromised to some degree and are therefore at more risk of infections, which can lead to an increase in mortality. Any aspect of their RRT care that increases their infection risk needs to be dealt

with effectively, this demonstrates again that nursing knowledge with regards to water quality is important.

Distribution pipe work

The final element in the system is the distribution pipe work, which design should minimises dead space and be assembled from non-toxic materials and able to be disinfected regularly by a suitable method. The distribution pipe work is usually constructed in a loop, allowing surplus water to be returned to the input side of the RO and the dialysis machine connection points are designed to have minimum dead space. As water treatment systems are susceptible to microbial contaminations, periodical disinfection is mandatory to obtain levels expected by international water quality standards (Cappelli et al 2006).

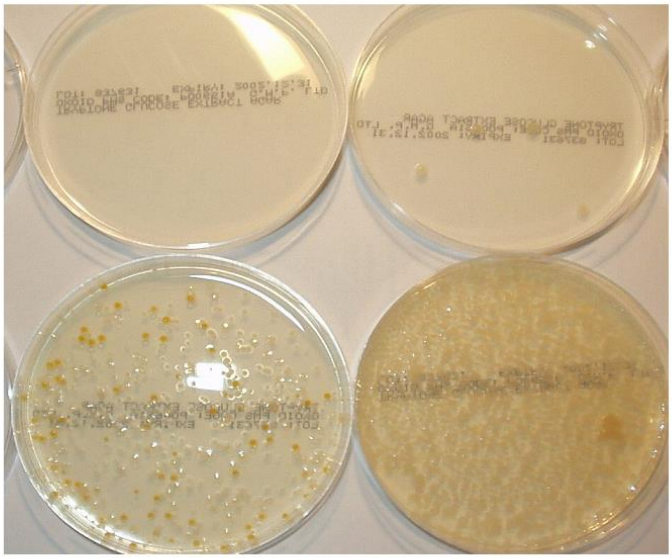
Developments in materials and design of the distribution system allow different disinfection methods. Nurses may be unaware that the level of microbiological contamination can increase due to biofilm being present in the water system. Bacterial fragments from the biofilm can cross the dialysis membrane and simulate an inflammatory patient response, which has been implicated in the mortality and morbidity of haemodialysis patients (Hoenich and Levin 2003).

MONITORING THE HAEMODIALYSIS WATER QUALITY

Numerous guidelines can be followed and most concur on the majority of issues. Routine testing should form part of unit policy and the frequency of testing should not be less than monthly, and be sufficiently frequent to detect trends. Guidelines suggest samples for microbiological and endotoxin analysis should be taken from the water treatment outlet plant and points expected to have the highest bacterial load, normally where the flow is at its lowest. (EDTNA/ERCA, 2002) Samples should be taken from the machine connection points as these can harbour bacteria that are not detected at other sample points, potentially leading to a false impression of quality (James, 2006). Current guidelines also suggest that samples for microbiological analysis should be cultured using a low nutrient

media but vary in recommending temperature and time. A commonly accepted method of culturing samples is at 22°C for 7 days (ERA-ERCA, EDTNA-ERCA), and provides for a greater recovery rate than at other temperatures and times (James, 2007).

Endotoxin analysis is usually carried out using the Limulus Amoebocyte Lysate (LAL) assay.



Testing for bacteria using 1ml spread plates

Figure 3 Cell culture plates.

Routine monitoring of the feed water and permeate is the best way to ensure a water system is operating under optimal conditions. Variables such as hardness levels, chlorine, conductivity, flow rates and operating pressures should be monitored. These can effect treatment outcomes thus could endanger the person undergoing treatment

Each renal unit should have a designated person, whether this is the technician, nurse or patient in the case of home haemodialysis who is responsible for developing a monitoring plan, including testing frequency, to keep the microbial

and endotoxin levels within the standard. Operational data should be recorded frequently, and can be used to spot trends in operating conditions and alert to impending maintenance issues such as membrane replacement or cleaning. It is important that the nurse manager is involved in this process so that he/she is aware of any potential issues as soon as is possible.

Chemical Testing

A hardness test using an ethylenediaminetetracetic acid (EDTA) titration test, or dip and read test strips on the effluent softened water should be done at least once at the end of the day and recorded (AAMI, 2004). Testing at the end of the day proves the softener performed adequately all day in removing hardness. The salt level in the brine tank should be inspected daily and be at least half-full with salt (AAMI, 2004). It is recommended to test for total chlorine which identifies both free chlorine and chloramines, and never free chlorine alone, in order to protect the patients from injury. In some units the renal technician has responsibility for this, yet it is within the role of a nurse to ensure patient safety prior to RRT and this part of the routine testing, so, by definition nurses should be doing the monitoring when no technician is available. This role could be designated to one nurse per shift or day to ensure that the water is tested to ensure that it is softened and that there is an appropriate amount of salt available in the brine tank (if this type of tank is used). Again this is another nursing role that cannot be over looked and someone whether it is a nurse or technician needs to be allocated this role to ensure stability.

With a standard DPD (N, N-diethyl-p-phenylenediamine) test, the difference between the "free" chlorine and "total chlorine" is considered the chloramine content, since there is no test that isolates chloramine. When total chlorine tests are used as a single analysis (e.g., test strips), the maximum level for both chlorine and chloramine should not exceed 0.1 mg/L. Since there is no distinction between chlorine and chloramine, this safely assumes that all chlorine present is chloramine. An AAMI chemical analysis (see Table 1) or equivalent should be

carried out at least once a year to validate contaminant removal by the water treatment system.

Microbiological Testing

The establishment of quantitative microbiological water guidelines for dialysis purposes is necessary because guidelines help establish procedures to be implemented in the event that significant excursions beyond these limits occur. The purpose of establishing any action limit or level is to assure that the water system is under control. The AAMI recommendation for bacteria is less than 200 CFU/ml for all water used in dialysis, including the water in the distribution system, with an action level of 50 CFU/ml. If 50 CFU/ml is reported, then action should be taken to disinfect the RO and/or loop and re-sample. For endotoxins, the AAMI recommendation is less than 2.0 IU/ml with an action level of 1.0 IU/ml. The European recommendations are more stringent. The EP suggests a limit of 100 CFU/ml for bacteria and 0.25 IU/ml for endotoxins, with an action level of 25 CFU/ml. Although none is given, an action level of 0.125 IU/ml would seem prudent.

Nurses and other dialysis professionals should understand the above-mentioned bacteria testing measures may underestimate the bacterial burden in the water system due to the nature of biofilm (AAMI, 2001). The required testing methods may not show all organisms that can grow in the system because testing measures for planktonic (free-floating) bacteria and not sessile (attached) bacteria. Since most currently recommended microbiological techniques available require at least 5 days to obtain definitive results, the water from which the sample was taken has already been used. Therefore, it is highly recommended to disinfect routinely and not just when unacceptable microbial samples dictate. Where systems have a large amount of downtime (system off) or poor flow through the system, biofilm can be present even with samples indicating no growth. If the standards are not achieved, then microbiological contamination can occur in the dialysate due to biofilm being present in the water

distribution network or dialysis machine. Bacterial fragments that are produced due to this can cross the dialysis membrane and stimulate an inflammatory patient response (Hoenich and Levin, 2003). Biofilm is the cause of chronic, sub clinical inflammation due to repeated macrophage stimulation (Cappelli, Tetta and Canaud, 2005).

DIALYSIS FLUID and ULTRAPURE DIALYSIS FLUID

Dialysis fluid is a solution intended to exchange solutes and/or water with blood during haemodialysis or haemodiafiltration (definition from IEC 60601-2-16 2.107). Dialysis fluid is generally made up of three components – water, 'A' concentrate and 'B' concentrate. The water originates as drinking water but via several processes becomes usable for haemodialysis (Hoenich, Ronco and Levin, 2006). The 'A' concentrate contains some acid in the form of acetate, which is why it is sometimes referred to as the 'acid bath'. "B" is the bicarbonate concentrate and it is the dilution of the 'A' and 'B' concentrates in water that gives the conductivity of the dialysis fluid. Bicarbonate is the body's major buffer and as such is required in the dialysis fluid to help resolve the acidosis from which the RRT patient suffers.

With the increasing use of high flux dialysers, there is increased risk of backfiltration and so the fluid used in therapy needs to have stricter levels of acceptable microbes as contamination can lead to septicaemia, headache or malnutrition. High flux dialysers are more porous than lo flux membranes and can facilitate the passage of specific organisms – endotoxins, aluminium and water borne bacteria - into the blood stream (Al-Khader and Al-Jondeby 2002)..

Ultrapure water still has the same mechanisms for water treatment as for usual dialysis water, but additionally passes through other filters which ensure that no bacteria or bacterial toxins occur in the dialysis fluid. This is imperative with online haemodiafiltration as the filtered dialysate is infused into the patient's blood stream (Brunet and Berland 2000). The presence of even small amounts

of bacterial toxins can provoke inflammatory responses in the blood which can lead to pyrexia, anaemia, cerebrovascular disease (Al-Khader and Al-Jondeby 2002).

Conclusion

Nurses need to be aware of the methods and concepts of purifying the water used in haemodialysis. The desire to improve treatment outcomes has led to stringent standards for microbiologic purity of the dialysis fluid (Hoenich and Levin 2003). Ultrapure dialysis fluid is highly purified dialysis fluid that can be used in place of conventional dialysis fluid. The definition of ultrapure fluid varies, but the recommendation used in the ERA/EDTA Guidelines is <0.1 cfu/ml and <0.03 IU/ml. These standards are usually achieved by point of use filtration of the water and dialysis fluid at the dialysis machine. Most current systems pass the water and final dialysis fluid through at least two ultrafilters. Ultrapure dialysis fluid may be further purified to produce on-line substitution fluid for haemodiafiltration.

Renal nurses are involved in total patient care and as such should be aware of water quality as the patient's bloodstream is exposed to large amounts of water each treatment, which places them at risk of reactions that at their worst could lead to their death. Water quality guidelines exist which should be followed which incorporate what to test for, how to test and how often to test it. Nurses should be aware there are numerous different water purification systems available which overall incorporate similar features. Understanding how these features work is important for nurses to understand, even if testing of the dialysis water is not a routine nursing task in your unit. Nurses need to know how and why the water purification system works without the details of the system, as it can have a bearing on treatment outcomes. Moreover it is not sensible or safe practice to be a passive participant in a life saving treatment. All additional knowledge which can assist in better treatment outcomes is beneficial for the nurses and patients.

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