Original article

The effect of peracetic acid on the corrosion and hemodialysis adequacy in reused polyethersulfone (PES) dialyzer

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Abstract:

A peracetic acid (PAA) disinfectant of commercial polyethersulfone (PES) dialyzer reuse is increasingly utilized in hemodialysis (HD) of renal replacement therapy. However, a certain numbers of dialyzer reprocessing have not yet been determined as a standard guideline. Thus, we verified the physical and chemical characteristics of the membranes within dialyzers that were performed on end- stage renal disease. These dialyzers were allocated into the following two groups as 1) three of new dialyzers (the reuse number is 0) and 2) reuse of dialyzers undergo the number of reuses increases as 1st, 5th, 10th, and 15th times (three dialyzer for each sub-group), respectively. The results of this study showed that no significant difference of the hemodialysis adequacy between two groups of the patients. However, upon the number of times for dialyzers reusable raise up to 10th and 15th times were corroded by PAA which was founded in the membrane leakages and significantly high of sulfur atoms in the inner surface areas with the increasing number of dialyzer reuse. Moreover, the outer surface areas of membranes had a smaller membrane pore sizes because the PAA-dialyzer membrane interaction activated the negatively charged ion absorption. These results were successfully completed by using scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS) techniques. Consequently, the number of PES dialyzer reuse can be performed for 10th times.

Keywords: ● *Peracetic acid* ● *Dialyzer reuse* ● *Corrosion*

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นิพนธ์ต้นฉบับ

ผลของกรดเปอร์อะซิติกต่อการกัดกร่อนและความเพียงพอของการฟอกเลือดในตัวกรองเลือดที่ใช้ซ้ำชนิด polyethersulfone (PES)

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บทคัดย่อ

การนำตัวกรองเลือดชนิดเยื่อกรองฟอกเลือดสังเคราะห์ polyethersulfone (PES) กลับมาใช้ซ้ำโดยผ่านการกำจัดจุลชีพด้วยกรดเปอร์อะซิติกเป็นวิธีที่ได้รับความนิยมสำหรับการฟอกเลือดด้วยเครื่องไตเทียม แต่กลับพบว่ายังไม่มีการกำหนดจำนวนครั้งในการใช้ซ้ำ ผู้วิจัยจึงศึกษาลักษณะทางกายภาพและเคมีของเยื่อกรองฟอกเลือดโดยใช้ตัวกรองเลือดกับผู้ป่วยโรคไตวายเรื้อรังระยะสุดท้าย โดยแบ่งตัวกรองเลือดออกเป็น 2 กลุ่มคือ 1) กลุ่มของตัวกรองเลือดใหม่ และ 2) กลุ่มของตัวกรองเลือดที่ใช้ซ้ำในครั้งที่ 1, 5, 10, และ 15 (จำนวน 3 ตัวสำหรับแต่ละกลุ่มย่อย) ผลการทดลองพบว่า ตัวแปรค่าความเพียงพอของการฟอกเลือด (hemodialysis adequacy) ทั้ง 2 กลุ่มไม่มีความแตกต่างกันอย่างมีนัยสำคัญ ขณะที่โครงสร้างของเยื่อกรองฟอกเลือดในตัวกรองเลือดที่ใช้ซ้ำครั้งที่ 10 และ 15 กลับถูกกัดกร่อนด้วยกรดเปอร์อะซิติกโดยพบรอยฉีกขาดและการเพิ่มขึ้นของธาตุซัลเฟอร์ที่ผิวด้านในอย่างมีนัยสำคัญตามจำนวนการใช้ซ้ำ และพบขนาดของรูพรุนที่เล็กลงที่ผิวด้านนอกจากการดูดซับสารที่มีประจุลบ ทราบได้จากเทคนิค scanning electron microscope และ energy dispersive X-ray spectroscopy ดังนั้นจำนวนครั้งที่เหมาะสมในการนำตัวกรองเลือดชนิด PES มาใช้ซ้ำคือจำนวน 10 ครั้ง

คำสำคัญ: *● กรดเปอร์อะซิติก ● ตัวกรองเลือดที่ใช้ซ้ำ ● การกัดกร่อน*

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Introduction

The dialyzer reuse is the most worldwide popular for the HD patients with end-stage renal disease (ESRD) because it can decrease not only the cost and medical wastes but also the incidence of first use syndrome from either chemical substances or materials of new dialyzer. A large number of the synthetic polymer HD membranes within dialyzer have been utilized with HD patients due to the fact that it has higher membrane performance for HD procedure than the others[1,2]. The questionnaires from the HD units in Thailand indicated that this high flux dialyzer is reused approximately 15-25 times depending on each HD unit policy. However, there is no study to determine the maximum number of dialyzer reuse which its efficiency remains sustainability and suitability for HD patients.

A synthetic dialysis membrane has been developed to improve a deficient kidney clearance in hemodialysis patients for many years. Specifically, the polyethersulfone (PES) membrane is one type of dialyzers that required in the dialyzer market due to its most effective in term of uremic toxin clearance capacity such as urea, uric acid, albumin, creatinine, and β2-microglobulin. The PES membrane is also achieved in the hemocompatibility profile in the dialyzer because their features can decrease harmful reactions between blood constituents and the membrane[3]. The reason is the PES membrane dialyzer was modified in a hydrophilic agent that can reduce the accumulation of adsorbed proteins at the membrane surface[4]. Therefore, the efficiency of reused PES dialyzer after dialyzer reprocessing is remain unclear. The PAA has been used as disinfectant for many medical materials because of its oxidizing agent property. For dialyzer reprocessing procedure, the higher-level concentration of PAA is also used in order to get rid of any microorganisms and pathogens. In the beginning step, the peracetic acid mixture (PAM) was diluted with purified reverse osmosis (RO) water to a concentration of PAA of 0.12-0.16 %. Prior to take it for reusing with the patients, the HD membrane must be then incubated with PAA for 11 h. Because the entire microorganisms were finally eliminated by the oxidation reaction from hydrogen peroxide (H_2O_2) which is the product from PAA. The equation is as the follow:

$$\text{Peracetic acid} + H_2O \dashrightarrow \text{Acetic acid} + H_2O_2$$

Although the PAA is a good disinfectant, it can corrode and enhance the damage to both metallic and non-metallic materials[5,6]. The previous study has shown that the alteration structures of synthetic polymer HD membrane by PAA. The deposit of protein molecules into this membrane affects to the reduction of HD efficiency[7]. The study of Matos JP, et al., found that the PAA induced the detriment to HD membrane making and impact on the waste disposal reduction[8]. In addition, H_2O_2 is another oxidative agent generated by PAA that can reduce the number of dialyzer reuse by deterioration of the HD membrane[9,10]. The current hypothesis is that the greater number of the dialyzer reuse, the greater destroy of HD membrane can be occurred. Obviously, the retrospective study found that the ability of high-efficiency HD membranes for the waste product removing have a reducing effect on the incidence of morbidity and mortality rates[11], in particular, cardiac arrhythmias[12]. From our mention, the objective is to determine the optimal number of synthetic polymer HD membrane built in reused dialyzer corroded by PAA, we conducted the study in a novel high efficiency HD membrane, polyethersulfone (PES). However, the formation of membrane damage by PAA remains unclear. Therefore, another objective is to examine the corrosion effects of PAA on the reused HD membrane. The interesting parameters for the effectiveness of HD membrane is investigated as follow; 1) HD adequacy, 2) urea elimination to drainage system in term of urea filtration rate 3) HD membrane microstructure, and 4) analysis of HD membrane elements. The evidence base results of the study can be documented to determine the clinical guideline practice in term of the suitable numbers for PES HD membrane.

Materials and Methods

This is the analytic study with one group self-controlled design. The study protocol approved by the Nopparat rajathanee hospital human subject committee (IRB/IEC reference number 5/2021) was informed to the human subjects. Then, the written consent forms were obtained. There were 3 ESRD female patients aged 50-65 years with hemodialysis time at least 5 years enrolled in the study with three times per week of HD session using dialyzer with PES membrane.

The characteristics of PES HD membrane is 1) surface area = 2.0 square meter (m^2), 2) priming volume = 116 milliliters (mL), 3) ultrafiltration coefficient (Kuf) = 26 milliliters/ hour/millimeter of mercury (mL/h/mmHg), 4) mass transfer area coefficient (KoAurea) = 319 millimeters/ minute (mL/min), 5) membrane thickness = 35 micrometers, 6) diameter of micro-capillary tube = 20 micrometers, and 7) maximum transmembrane pressure (TMP) = 600 mmHg. The total of 15 dialyzers were categorized into two groups; the first group was the three of new dialyzers and the second group was divided into four subgroups depending on the number of dialyzer reuse. Each subgroup of three dialyzers received the 0.16 % PAA as disinfectant was 1) 1^{st} time reuse, 2) 5^{th} time reuse, 3) 10^{th} time reuse, and 4) 15^{th} time reuse. All dialyzers of both groups were evaluated for HD adequacy, the filtration rate of urea eliminated via dialysis port out to the drainage system, and the physical characters of HD membrane including microstructure and elements. The details of each method was;

1. HD adequacy parameters by URR, Kt/V, and nPCR methods

The concentration of blood urea nitrogen (BUN) was evaluated from each patient at pre and post HD procedure. Then, the URR, Kt/V, and nPCR were calculated by the equations below:

1.1 Urea reduction rate (URR) = [100] [1- Ureapost HD/Ureapre HD]

Ureapost HD = BUN post-HD procedure

Ureapre HD = BUN pre-HD procedure

1.2 Dialysis efficiency (Kt/V) = -Ln (R-0.008 x t) + (4-3.5 R) x UF/W

Ln = national logarithm

R = ratio of Ureapost HD/Ureapre HD

t = hemodialysis duration (hour)

UF = water removal from blood (ultrafiltration) (Liter)

W = patient body weight (kilogram)

1.3 nPCR (normalized protein catabolic rate)

nPCR (g/kg/day) = 0.22+(0.036 x IDrise in BUNmidweek x 24)/ID interval (h)

ID = inter-hemodialysis session

2. The urea elimination to drainage system

The patient's blood urea, which is the main waste product from HD process was determined by ultraviolet visible spectroscopy technique. For the study, urea eliminated from the patient's blood to the outlet of dialysis fluid port was collected for urea filtration rate calculation at before and during HD procedure including 30, 60, 90, 120, 150, 180, 210, and 240 min, respectively.

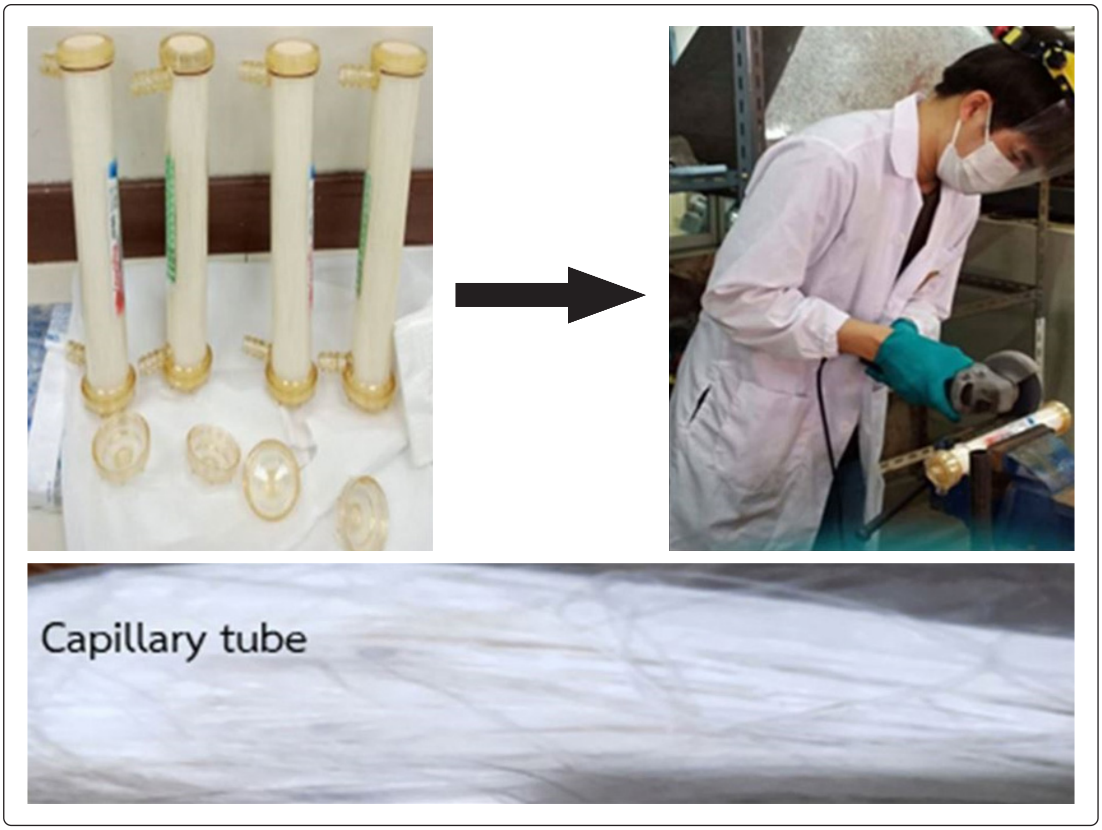


Figure 1 The preparation of micro-capillary tube (HD membrane) within dialyzer housing after washing out of PAA by purified water

3. The alterations of HD membrane microstructure by SEM technique

Both the outer and the inner microstructure surface of HD membrane were imaged and recorded by SEM (Philips XL30, England). Starting with the housing of new and reused dialyzers were split out which was shown in Figure 1. The micro-capillary tubes (HD membrane) were removed and then dissected into appropriated sizes of the outer and the inners by microtome. Each HD membrane was placed on the stub adhered with carbon tabs followed by gold element coating in order to get rid of the charges during the image processing. Owing to a large number of pores at outer surface, the twenty pores were additionally randomized and calculated for the average pore size using image J program[13]. The data were presented as mean and standard deviation (SD).

4. The elemental analysis of HD membrane by EDS technique

The main element compositions and average amounts of the inner and outer HD membranes were determined by EDS technique[14]. The weight percentage of each constituent element was then calculated after the full-time exposure upon with or without PAA. The theory of EDS is as follow. When the sample or HD membrane receives high-energy electrons from the X-ray radiation, the exciting electrons are escaped from their outer shells. Then, the higher energy electron is transferred from the inner shell to lower energy at outer shell which is a hole for electron vacancy. The transferring electron then releases energy in form of the X-ray radiation which can be called characteristic X-ray. Each energy characteristic and intensity of radiating X-ray is measured by silicon drift detectors (SSD). The elemental types and compositions of HD membranes can be estimated.

5. Statistical analysis

The data included 1) the URR, Kt/V, and nPCR, 2) The filtration rate of urea from the patient's blood to dialysis fluid, 3) the average pore size of outer HD membrane, and 4) the elemental compositions of both outer and inner HD membrane shown as mean±SD. The mean values of all these parameters between new and reused dialyzers at 1st, 5th, 10th, and 15th times, respectively were analyzed using one-way analysis of variance (ANOVA) with Duncan's multiple range test. The p-value < 0.05 was accepted as statistical significance. For the equal number of dialyzer reuse, the comparing of the filtration rate of urea from the patient's blood to dialysis fluid between before and during HD procedure at various durations as 0, 30, 60, 90, 120, 150, 180, 210, and 240 min, respectively were analyzed by one-way analysis of variance with post-hoc Tukey's HSD (Honestly Significant Difference). The p-value < 0.05 was accepted as statistical significance. In addition, the microstructure of outer and the inner of HD membrane were presented as images.

Results

1. HD adequacy parameters by URR, Kt/V, and nPCR methods

The URR, Kt/V, and nPCR of the patients who hemodialysed with either the new dialyzers or the various times of reused dialyzers were shown in Table 1. All data had not any significant difference when compared between the new dialyzer and various times of the reused dialyzers.

2. The filtration rate of urea from the patient's blood to drainage system

In the Figure 2, when comparing the filtration rate of urea from the patient's blood to dialysis fluid of new and various times of reused dialyzers (1, 5, 10, and 15, respectively) at the similar HD duration had not shown the significant difference. For the same numbers of the reused dialyzers, the results showed that the filtration rate of urea from the patient's blood to dialysis fluid of the 30 and 60 min had significantly higher than that at 0 min. In addition to the new and the 5th times of reused dialyzers, the filtration rate of urea from the patient's blood to dialysis fluid at 90 and 120 min had significantly higher than that at 0 min as well. However, insignificant differences of the filtration rate of urea from the patient's blood to dialysis fluid of new and all numbers of reused dialyzers at 150, 180, 210, and 240 min compared to 0 min were found.

3. The alterations of HD membrane microstructure using SEM technique

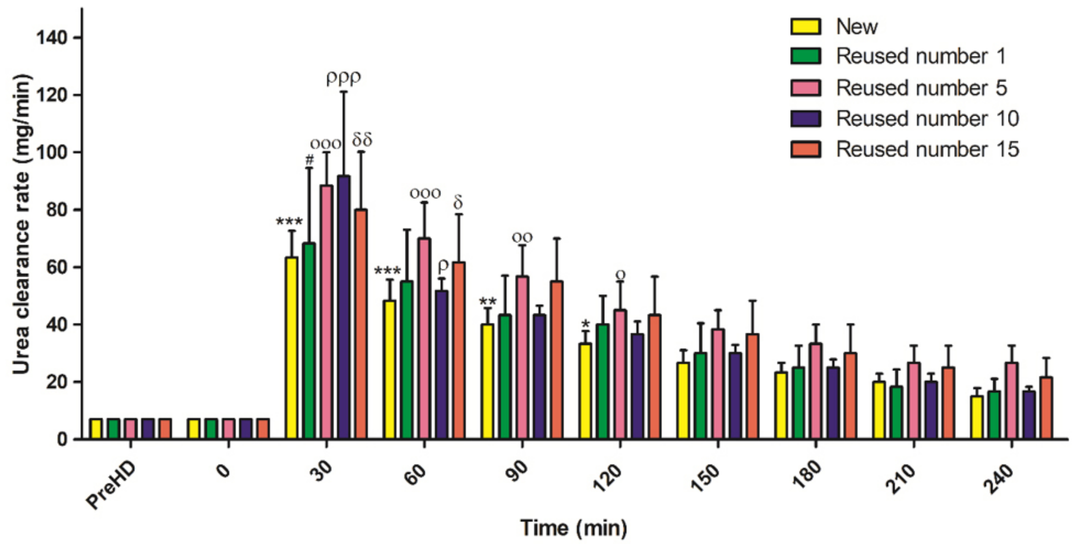
The inner and outer microstructure images of HD membranes studied by SEM technique had shown in the Figure 3. The inner microstructure of new HD membrane displayed the smooth surface which had almost similar to those of the 1st, and 5th times of reused

Table 1 The HD adequacy parameters of the new and various times of reused dialyzers

Adequacy parameters	Number of dialyzer reuse				
	0 (New)	1	5	10	15
URR	0.82±0.01	0.79±0.03	0.82±0.04	0.79±0.04	0.79±0.02
Kt/V	2.07±0.08	1.89±0.19	2.12±0.20	1.9±0.23	1.88±0.10
nPCR	0.91±0.11	1.01±0.32	1.23±0.06	0.9±0.11	1.08±0.13

URR, urea reduction rate; Kt/V, dialysis efficiency; nPCR, normalized protein catabolic rate

Data are presented as mean±SD. All adequacy parameters of each dialyzer reuse group shown no significant difference.



$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$ when compare the filtration rate of urea from the patient's blood to dialysis fluid of new dialyzers between at various times and 0 min

$^{\#}p < 0.05$ when compare the filtration rate of urea from the patient's blood to dialysis fluid of 1st reused dialyzers between at various times and 0 min

$^{o}p < 0.05$, $^{oo}p < 0.01$, $^{ooo}p < 0.001$ when compare the filtration rate of urea from the patient's blood to dialysis fluid of 5th reused dialyzers between at various times and 0 min

$^{\rho}p < 0.05$, $^{\rho\rho\rho}p < 0.001$ when compare the filtration rate of urea from the patient's blood to dialysis fluid of 10th reused dialyzers between at various times and 0 min

$^{\delta}p < 0.05$, $^{\delta\delta}p < 0.05$ when compare the filtration rate of urea from the patient's blood to dialysis fluid of 15th reused dialyzers between at various times and 0 min

Figure 2 The comparisons of the filtration rate of urea (urea clearance rate) from the patient's blood to dialysis fluid at various times (preHD, 0, 30, 60, 90, 120, 150, 180, 210, and 240 min) of reused dialyzers.

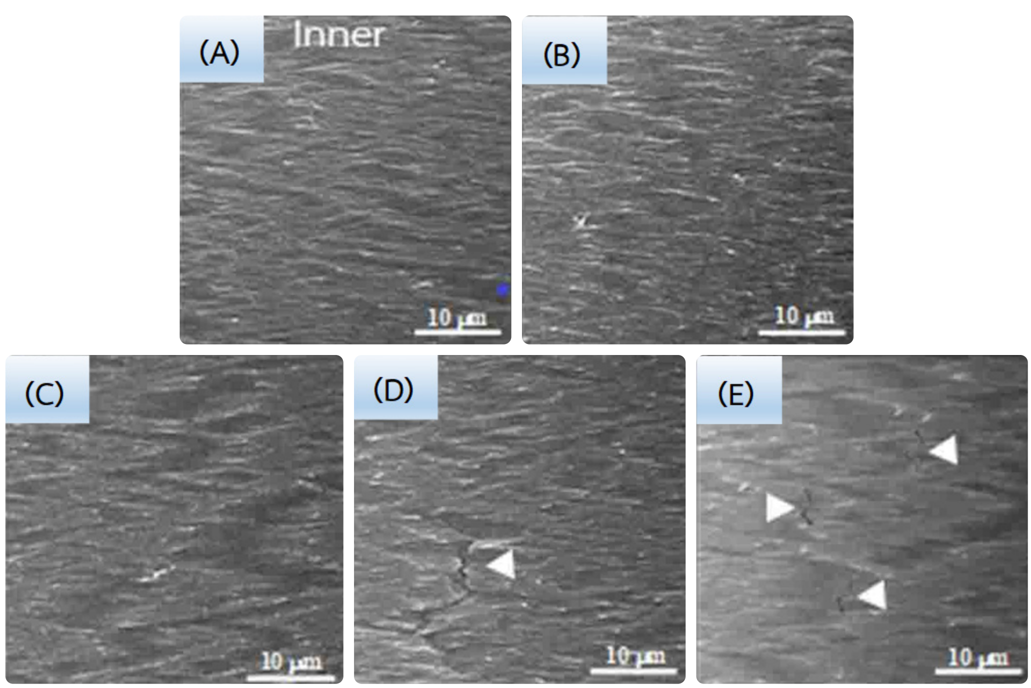


Figure 3 A-E Images of inner microstructure of HD membrane using SEM technique

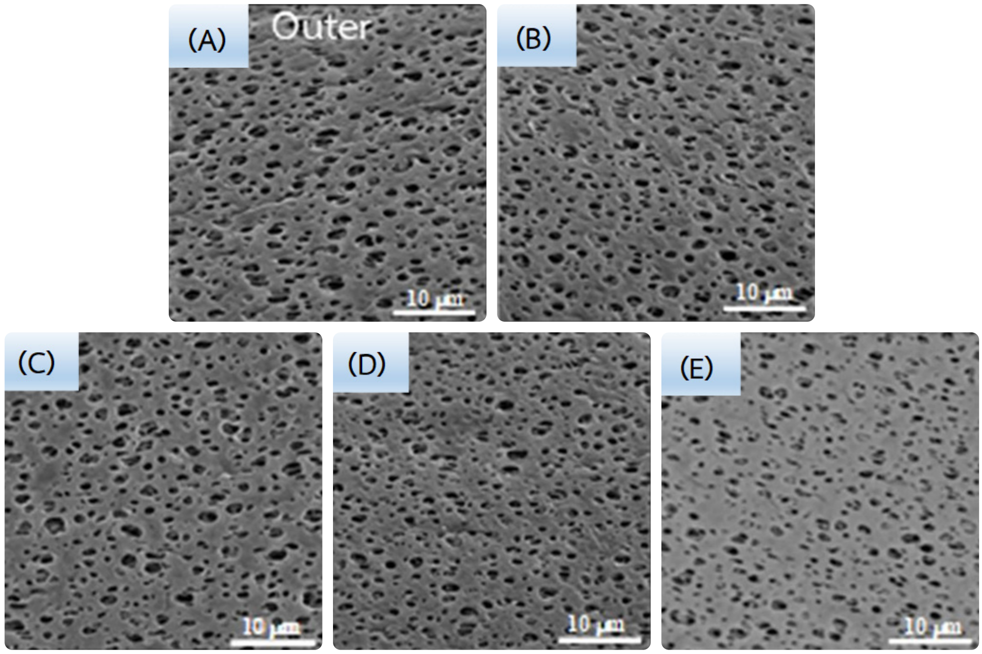


Figure 4 A-E Images of outer microstructure and its pore size of HD membrane using SEM technique

Table 2 The average pore size of outer HD

Outer surface of HD membrane	Average pore size diameter (micrometer)
New dialyzer	0.997±0.163
1st dialyzer reuse	0.797±0.174
5th dialyzer reuse	0.774±0.177
10th dialyzer reuse	0.656±0.135*
15th dialyzer reuse	0.605±0.133**

*$p < 0.05$, **$p < 0.01$ when the pore size diameters of outer surface HD membranes were compared between new and reused dialyzers.

dialyzers (Figure 3A-C) whereas it was torn for the 10th and 15th times of reused dialyzers shown in Figure 3D and 3E (white arrow points). For the outer surface of HD membrane, there were rough appearances with a lot of pores shown in Figure 4. These pore sizes were completely magnified by the image J program. The randomized twenty pores of outer surface were calculated in form of average pore size diameter (micrometer). The data in Table 2 indicated the average pore size was inversely related to the number of the dialyzer reuse. When compare the pore size diameters of HD membrane between 10th or 15th times of reused and new dialyzers showed significant difference as (0.656±0.135 vs 0.997±0.163; p-value < 0.05) and (0.605±0.133 vs 0.997±0.163; p-value < 0.01), respectively. However, there were not shown any significant difference of the pore size between 1st and 5th times of reused and new dialyzers.

4. The elemental analysis of HD membrane using EDS technique

The new and various times of reused dialyzers were quantified by EDS technique. There were three main elements in HD membrane as carbon (C), oxygen (O), and sulfur (S). The higher amount of C whereas the lower amount of O, and S were found of the inner surfaces of HD membranes. In the Table 3, the inner surface

Table 3 The analytical results for three elements of the inner and outer surfaces of HD membranes by EDS technique

Hemodialysis membrane	Element quantity of inner membrane (%weight)			Element quantity of outer membrane (%weight)		
	C	O	S	C	O	S
New dialyzer	77.46±7.33	11.50±3.94	11.05±4.41	50.65±6.65	7.60±3.92	41.75±8.12
1st dialyzer reuse	61.83±7.51	14.78±4.10	23.39±5.56**	44.75±5.94	5.81±4.13	49.44±9.08
5th dialyzer reuse	60.84±6.72	11.98±3.88	27.19±5.98**	50.37±5.21	7.61±3.44	42.03±10.45
10th dialyzer reuse	58.18±6.96	9.82±3.67	32.00±10.12**	59.72±7.89	10.82±4.25	29.46±12.58
15th dialyzer reuse	64.26±7.47	14.65±4.54	21.09±4.45*	57.42±6.87	12.44±5.04	30.14±12.99

*$p < 0.05$, **$p < 0.01$ the element contents were compared between inner surface of new and reused HD membrane.

of new and 1st, 5th, 10th, and 15th times of reused HD membrane were compared. The data revealed that the significant higher amount of sulfur of all reused dialyzers were found (23.39±5.56 vs 11.05±4.41; p-value < 0.01, 27.19±5.98 vs 11.05±4.41; p-value < 0.01, 32.00±10.12 vs 11.05±4.41; p-value < 0.01, 21.09±4.45 vs 11.05±4.41; p-value < 0.05, respectively. On the outer surface, no significant differences for these three elements were observed among all groups.

Discussion

In the present study, we interested to investigate the efficiency of PES HD membrane causing this membrane had been modified which higher of the water osmosis property[15], its strength, and its high temperature stabilization[16] than the PS HD membrane. Although this PES HD membrane may be grown up the usage in the future, there have been a few studies on the corroded effect of PAA on the HD membrane. According to the standard guideline for the reusing of the dialyzer, it has stated that the total cell volume (TCV) should not less than 80 percent of the priming volume due to the dialysis insufficiency for the patient usage. From our empirical study, this dialyzer volume capacity had the maximum number of the reusing at 15 times which was the limitation of this study. Because its TCV is less than the permitted volume.

When the standard parameters for HD adequacy including URR, Kt/V, and nPCR were considered. There were no significant differences when comparing HD membranes of new and those of reused dialyzers at 1st, 5th, 10th, and 15th times, respectively. These three parameter results indicated that the PES HD membranes could be reused up to 15 times. Due to the fact that all parameters use the urea concentration for the calculation and urea molecule is a small waste substance (molecular weight 0.06 kilodalton; kDa). Consequently, it can continuously easy diffuse and eliminate from the patient's blood. This study has been supported by the experimental results shown in Figure 2. The comparison between new and various numbers of the reused dialyzers at the similar durations (0, 30, 60, 90, 120, 150, 180, 210, and 240 min), explored no significant differences of the urea elimination to dialysis fluid. However, when the clearance of the urea from the patient's blood to the dialysis fluid of each reused dialyzer group was compared between the various durations during HD session and at 0 min. The data demonstrated that the maximum urea elimination was achieved at 30 min and the urea elimination inversely relates when the HD durations increase. The current investigation was advocated by a study of Olesberg TJ, et al[17], 2004.

Because the diffusion is the major process for urea removal from the patient's blood trough HD membrane into the drainage system. The main affecting factor for urea diffusion is the gradient between higher urea concentration in the patient's blood and free of urea in dialysis fluid. For the early stage of the HD process, high level of urea removal can be enhanced. However, when the longer of HD durations will originate the decrease of urea concentration difference between the patient's blood and the dialysis fluid. Therefore, the removal of urea from the patient's blood into the dialysis fluid was reduced. Although there is an increase of the simultaneously urea allocation from cells throughout the body into the bloodstream, its gradient concentration remained unchanged[18]. In accordance with this mention, the elevation of urea removal from the patient's blood was unrelated with the increasing of HD durations at 150, 180, 210, and 240 min, respectively. Therefore, if only the urea removal from the patient's blood is considered as an index of PAA corrosion to HD membranes, it was found that the HD membrane can be reused up to 15 times with the maximum urea removal duration was 30 min.

The alterations of the HD membranes corroded by PAA were further investigated by SEM technique. The images showed that the inner surface of the HD membrane was smooth. On the other hand, its outer had rough surface with a lot of pores. Unsurprisingly, these are the characteristics of PES HD membrane[19,20]. When comparing the inner surface of the new with reused HD membranes, the images of 10th and 15th times displayed the tear points. This may be due to the effect of PAA which has been used for the elimination of microorganisms during dialyzer reprocessing. The PAA is the initiating source of oxidative reaction and it enhances the carbon- sulfur cleavage reaction (breaking the bonds between carbon and sulfur atoms) of HD membrane. The oxygen atom from PAA then reacts with the sulfur atom (reactive site) to form sulfuroxide (SOx)[21] which may destruct to the strength of HD membrane.

In addition, Ussawawongaraya, et al., 2016 showed that the residues of PAA were found in HD membrane of the reused dialyzer[22]. Although it was removed with 0.9% normal saline as the standard protocol of dialyzer reprocessing process. The PAA residues remain as the oxygen atom donation to the sulfur atom in the patient's blood who is being the HD session[6,21,23]. The source of blood sulfur for oxidative reaction may be the cysteine in form of the sulfur-containing amino acids. The cysteine is more prone to oxidation because it has nucleophillic property[24]. Subsequently, the elevation of sulfur oxide anchored to the inner surface of PES HD membrane calls sulfonation reaction and it then becomes sulfonated polyethersulfone. This was the reason for the increasing the sulfur atoms of PES HD membrane as shown in Table 3. Moreover, the study of Sahebi S, et al., 2021 demonstrated that the sulfonation reaction on PES HD membrane (Figure 5) caused the decreasing of thickness, modulus, strength and finally tears of its inner surfaces[25]. As shown in Figure 3, the rupture points of the 15th times (Figure 3E) had greater than that of 10th times of the reused HD membranes (Figure 3D).

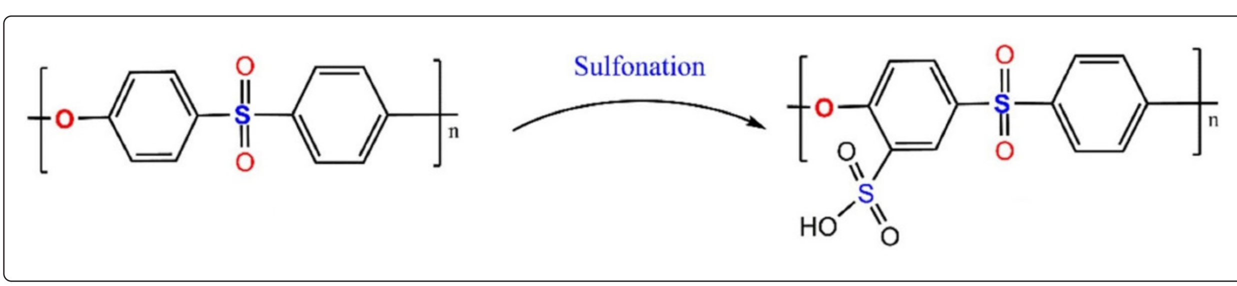


Figure 5 The sulfonation of polyethersulfone (left) to sulfonated polyethersulfone (right)

The considering for 10th and 15th times of reused HD membranes after the interaction with PAA, the outer surface showed the decreasing of its pore size diameter as shown in Figure 4. This phenomenon had been supported by the study of Shou J, et. al., 2007[5]. It stated that the positive charges of PS HD membrane will absorb the proteins having negative charges. Moreover, the expanding of clogged HD membrane pores may be due to the vacuum force from ultrafiltration pump of HD machine. The other negatively charged substances are then pulled and stuck on HD membrane. Therefore, the impediments into the HD membrane of the outer surface pores were taken place for this study. Indeed researchers found that the diffusions of vitamin B12, (1.35 kD) and 10 KDa dextran into dialysis fluid were decreased by 20 and 70 %, respectively. In addition, the damaging effect of PAA impacts on the attenuation of ultrafiltration coefficient for 50%[5].

Although some chemical characters of PES differs from PS membrane, the positively charged similar to PS membrane remains to be discovered. Therefore, it should has the clogging effect same as PS[26]. Furthermore, the positively charged of PES was able to bind with the negatively charged of endotoxin[26] and platelets[27]. For the standard protocol of the dialyzer reprocessing as mention above, the dialyzers were not reused greater than 15th times. Because the TCV had less than 80% of priming volume. This data can exactly insist that the HD membrane pores were occluded by molecules of negatively charged either proteins or other substances.

These sophisticated data can be proposed that if we evaluate the dialyzer efficacy by only URR, Kt/V, and nPCR, the 15th times of dialyzer can be reused. However, when the augmentation of microstructures and compositions of HD membrane are considered. It should be suggested to be reused for only 10 times as a result of its deformation structure corroded by PAA. Consequently, these procedures should be the new guideline for reused HD membrane in order to improvement the standard treatment of the patient's quality of life. Nevertheless, these may be further developed for the evaluation of the other HD membranes including celluloses, substitute celluloses, and synthetic polymers.

Conclusion

This preliminary study concluded that the PES HD membrane is corroded by PAA from dialyzer reprocessing procedure. Therefore, this membrane is recommended to be approximately reused 10 times because its efficiency remains as new HD membrane. However, this study lacks the data concerning the removal capacity of the waste products having middle molecules such as parathyroid hormone (9.5 kDa) and beta-2 microglobulin (11.0 kDa). Consequently, our further study will investigate the disposal of these wastes instead of urea coupled with physical and chemical characteristics of reused HD membrane.

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Conflict of ingterest

The authors declare no conflict of interest.

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