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Evaluation of Nanostructure in Reused Cuprophane and Polysulfone Dialysis Membranes

Badanie nanostruktury reutylizowanych kuprofanowych i polisulfonowych błon dializacyjnych

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Abstract

Background. Internal surface roughness, chemical profile, overall mass transfer (KoA), and ultrafiltration coefficients (K_{ufr}) of dialysis membranes are the main determinants of the biocompatibility and functional profile of every dialyzer.
Objectives. The aim of the study was to compare the surface nanostructures of cuprophane (CUP) and polysulfone (PS) dialysis membranes and their changes depending on the number of dialyzer reutilizations with peracetic acid (Renalin®), which is commonly used in dialysis units for this purpose.
Material and Methods. Surface roughness parameters (RMS, BR20%; BR80%) were measured by atomic force microscopy (AFM) for new CUP and after 1, 2, 3, 4, and 5 reutilizations and for new PS dialysis membranes and after 1, 3, 5, 7, and 10 reutilizations. Biocompatibility of the CUP and PS membranes was evaluated by measuring interleukin-6 and TNF-α serum concentrations measured in each of the studied hemodialysis sessions. HD sessions were performed in 10 chronically dialyzed subjects in whom dialyzer reuse was accepted.
Results. Internal and external surface roughness of the membranes disclosed an asymmetrical nanostructure of PS and a symmetrical of CUP. The increase in serum IL-6 concentration during the HD sessions with new CUP dialyzers and after 1, 2, 3, 4, and 5 reutilizations was statistically significant ($p < 0.05$) in each HD session while the increases of IL-6 concentration during the HD session with new PS dialyzers and after 1, 3, 5, 7, and 10 reutilizations was not statistically significant in any HD session. Increases in TNF-α concentration during HD session with new CUP dialyzers and after 1, 2, 3, 4, and 5 reutilizations and with new PS dialyzers and after 1, 3, 5, 7, and 10 reutilizations were not statistically significant in any HD session.
Conclusions. Reuse of dialysis membranes with peracetic acid does not affect their surface nanostructure. No correlation between the dialysis membrane surface roughness and biocompatibility was found (**Adv Clin Exp Med 2008, 17, 2, 172–182**).

Key words: cuprophane dialysis membrane, polysulfone dialysis membrane, nanostructure, dialyzer reuse, biocompatibility.

Streszczenie

Wprowadzenie. Szorstkość wewnętrznej powierzchni, skład chemiczny tworzywa, współczynnik przepuszczalności błonowej (KoA) i współczynnik ultrafiltracji (K_{ufr}) błon dializacyjnych można uznać za główne wskaźniki biozgodności i charakterystyki czynnościowej dializatorów.
Cel pracy. Porównanie nanostruktury błon kuprofanowych (CUP) i polisulfonowych (PS) oraz ocena wpływu wielokrotnej reutylizacji kwasem nadoctowym (Renalin®) dializatorów z nich wykonanych.
Materiał i metody. Wykorzystując mikroskop sił atomowych, oceniono wskaźniki charakterystyki powierzchni, tzw. wskaźnik szorstkości RMS oraz tzw. proporcję pokrycia (BR – *bearing ratio*) dla 20 i 80%. Badania wykonano dla błon pozyskanych z nowych dializatorów oraz reutylizowanych, odpowiednio: kuprofanu 1-, 2-, 3-, 4-, 5-

process was performed with Renalin® (Renal Systems, Minneapolis, USA) [4]. The LAL test was used to control the bacteriological cleanliness of the reverse osmosis water for rinsing the dialyzer. During the reuse process a post-priming volume (PPV) was defined for each dialyzer. A PPV value lower than 80% of the FBV (fiber bundle volume) disqualified a dialyzer from further clinical use, according to Gotch's guidelines [5].

Membrane Surface Nanostructure Evaluation with AFM

The dialysis membranes' surface roughness parameters were measured by atomic force microscopy (AFM) using new dialyzers and after subsequent reuse (1, 2, 3, 4, and 5 times for CUP and 1, 3, 5, 7, and 10 times for PS). Evaluation of the dialysis membranes' nanostructures was performed with an atomic force microscope (Thermo-microscopes Autoprobe CP). Seven fibers were randomly selected in each dialyzer on which 14 surface images were performed (7 of the internal and 7 of the external surfaces). These images of the CUP fibers were collected using the contact AFM mode. Images of the internal surfaces of the PS fibers were collected with contact AFM mode and those of the external surfaces with the non-contact AFM mode. Altogether, 420 surface images were collected (210 images of the internal and 210 of the external surface) of the CUP and PS capillaries. Cumulatively, 840 AFM images of capillaries' were obtained.
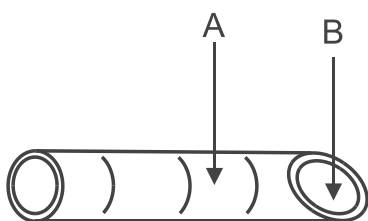
Fig. 1. Schematic presentation of a single capillary section to show its internal and external surface available to the AFM cantilever tip: A – external capillary surface, B – internal capillary surface

Ryc. 1. Schematyczny obraz przecięcia pojedynczej kapilary w celu udostępnienia powierzchni wewnętrznej dla ostrza mikroskopu sił atomowych: A – powierzchnia zewnętrzna, B – powierzchnia wewnętrzna

Surface Roughness Parameter Analysis

Evaluation of the characteristic features of the dialysis membranes with AFM consisted of mea-

suring and comparing the parameters describing the surface properties recorded as an AFM image [6]. In the present study, these were the RMS (root mean square) values corresponding to surface roughness and the bearing ratio (BR, the height over the plane defined by the *x* and *y* coordinates in three-dimensional space for which the given percentage of all pixels in the AFM image have values greater than or equal to that value), described by the equation:

$$\text{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z - \overline{z})^2}$$

z_i – the *i-th* observation within the sample,
$\overline{z}$ – sample mean,
n – number of observations within the sample,
n – 1 – degrees of freedom (the number of independent observations that may be used to calculate the given statistics).

Variable Coefficient and Dynamic Changes Coefficients

A variable coefficient and dynamic change coefficients were applied to obtain a detailed estimation of the changeability in the membranes' surface roughness.

Variable coefficient – the ratio of the standard deviation of the roughness parameter (RMS, BR 20%, BR 80%) to its arithmetic mean value, i.e. V% = SD/mean × 100.

Dynamic changes coefficients:
– *change rate* – the ratio of the absolute increase (AI) in the RMS observed in the consecutive dialyzer reutilizations to the values observed for the new membrane (N), i.e. CR% = AI/N × 100%,

– *fixed base index* – the ratio of the RMS values observed in the consecutive dialyzer reutilizations (R) to the values observed for the new membrane (N), i.e. FBI% = R/N × 100%.

Dialysis Membrane Biocompatibility Assessment

Blood samples of 1.5 ml each were drawn from the arterial lines before staring the HD session to assess both IL-6 and TNF-α levels and then after 90 and 120 minutes of HD. IL-6 concentrations were determined with an immunoradiometric assay (IRMA) using an Interleukin-6-IRMA kit (Biosource International) [7]. The radioactivity measurements were performed using a Wallac

1470 WIZARD® automatic scintillation gamma counter (PerkinElmer, USA). TNF-α concentrations were determined with an immunoenzymatic assay (ELISA) using a Tumor Necrosis Factor-α CB ELISA (TNF-α CB) kit (Biosource International) [8]. Sample absorbance measurements were performed with a single-wave method using a 650-nm filter in a Universal Microplate Reader El$_x$800$_{NB}$ automatic microplate reader (BIO-TEK Instruments, Inc.).

Statistical Analysis

The results of the two studied dialyzers groups, CUP and PS, were analyzed for small samples with equal variances with Student's t test. Differences in IL-6 and TNF-α concentrations during dialysis on new cuprophane dialyzers and after 1, 2, 3, 4, and 5 reutilizations and on new polysulfone dialyzers and after 1, 3, 5, 7, and 10 reutilizations were analyzed with Student's t test for small dependent samples. Comparison of the internal surface roughness parameters of the CUP and PS membranes with IL-6 and TNF-α concentrations obtained from consecutive dialyzer use are presented as Pearson's correlation coefficient. The level of statistical significance for each calculation was $p < 0.05$. Statistical analysis was performed with STATSDIRECT STATISTICAL SOFTWARE v. 2.3.8.

Results

The symmetrical external and internal surfaces of the single CUP capillary are presented in Figs.
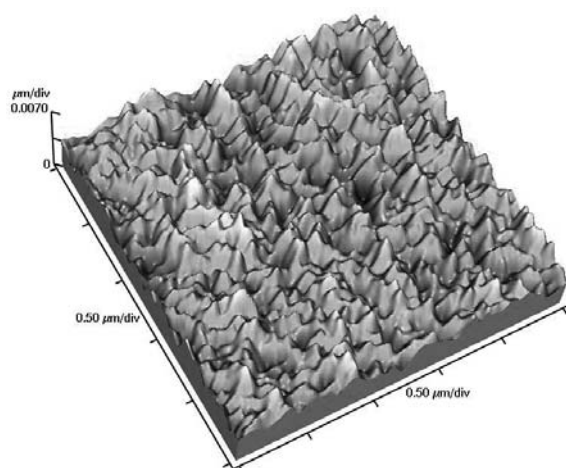
2a and 2b. The symmetrical structures of the PS capillary are shown in Figs. 3a and 3b. The AFM technique allows spectacular viewing of the differences.

Dialysis Membrane Nanostructure Evaluation – Roughness Parameters (RMS, BR 20%, BR 80%)

Analysis of the RMS, BR 20%, and BR 80% values of the CUP and PS membranes' internal and external surfaces (Figs. 4–7) shows that, except for dispersion of significant results and after eliminating the extreme values, there were no crucial changes in roughness of the two membranes after consecutive dialyzer utilizations and that there was a very close correlation of all the evaluated parameters (RMS, BR 20%, and BR 80%).

The roughness parameters of the PS internal surface (mean RMS: 8.7 nm) demonstrated greater roughness than those of the internal CUP surface (mean RMS: 4.1 nm). Analysis of the external surface roughness parameters of the CUP and PS membranes shows much greater roughness (porosity) of the PS membrane (mean RMS of the external surface: 36.8 nm) than of the CUP membrane (mean RMS of the external surface: 3.4 nm; Figs. 8, 9).

Variable Coefficient (V%)

The mean RMS value of the CUP membrane's internal surface was 4.2 nm, (range: 1.1–12.5 nm). There was very high diversity in the
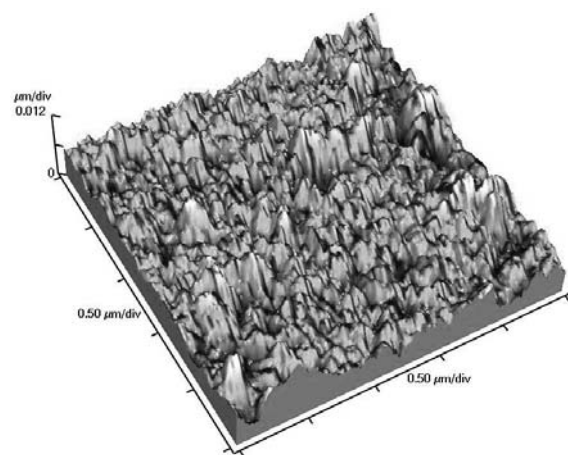
Fig. 2. CUP: **a –** symmetrical membrane, internal surface (AFM), **b** – external surface (AFM), authors' ownership

Ryc. 2. Kuprofan, przykład błony symetrycznej: **a–** obraz powierzchni wewnętrznej, **b** – obraz powierzchni zewnętrznej (badania własne autorów)

a)

b)
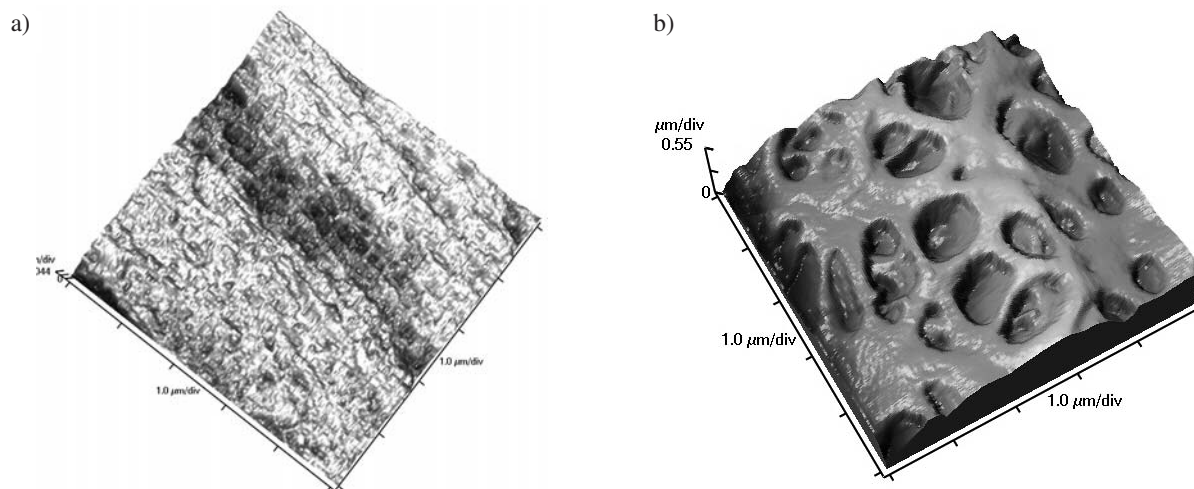
Fig. 3. PS: a – asymmetrical membrane, internal surface (AFM), b – external surface (AFM), authors' ownership

Ryc. 3. Polisulfon, przykład błony asymetrycznej: a – obraz powierzchni wewnętrznej, b – obraz powierzchni zewnętrznej (badania własne autorów)

	N	1	2	3	4	5
☐ RMS int.	4.23	3.52	2.97	2.94	6.86	4.32
■ BR 20 int.	27.9	15.1	17.5	23.6	35.1	21.7
☐ BR 80 int.	21.3	11.9	12.9	20.6	24.4	16.4

reuse

Fig. 4. CUP, mean values of RMS, BR20%, and BR80% of the internal surface

Ryc. 4. Kuprofan, średnie wartości RMS, BR 20%, BR 80% – powierzchnia wewnętrzna

	N	1	3	5	7	10
☐ RMS int.	7.26	9.84	7.93	8.08	10.69	8.42
■ BR 20 int.	34.54	54.4	37.77	40.56	56.55	45.25
☐ BR 80 int.	22.96	36.16	25.88	27.95	39.2	30.86

reuse

Fig. 6. PS, mean values of RMS, BR 20%, and BR80% of the internal surface

Ryc. 6. Polisulfon – średnie wartości RMS, BR 20%, BR 80% – powierzchnia wewnętrzna

	N	1	2	3	4	5
☐ RMS ext.	2.04	5.38	2.34	3.6	3.89	3.06
■ BR 20 ext.	14.45	44.96	14.83	19.82	19.55	20.8
☐ BR 80 ext.	11.32	22.79	9.66	17.12	12.24	16.59

reuse

Fig. 5. CUP, mean values of RMS, BR20%, and BR 80% of the external surface

Ryc. 5. Kuprofan, średnie wartości RMS, BR 20%, BR 80% – powierzchnia zewnętrzna

	N	1	3	5	7	10
☐ RMS ext.	29.4	48.3	39.5	33	31.3	39.3
■ BR 20 ext.	115	260	222	208	169	233
☐ BR 80 ext.	94.2	188	155	155	122	163

reuse

Ryc. 7. PS, mean values of RMS, BR20%, and BR 80% of the external surface

Ryc. 7. Polisulfon, średnie wartości RMS, BR 20%, BR 80% – powierzchnia zewnętrzna
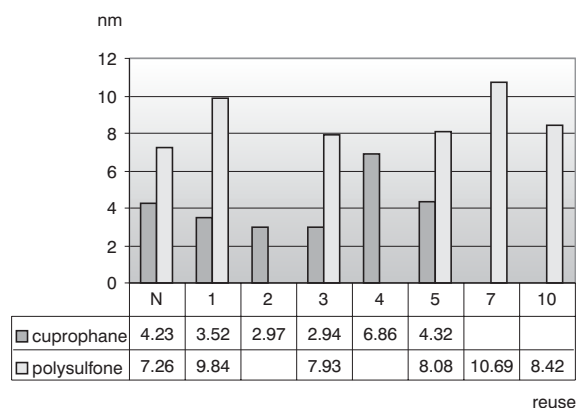
Fig. 8. CUP and PS, comparison of mean RMS values of the internal surfaces

Ryc. 8. Kuprofan i polisulfon, porównanie średniej wartości RMS dla powierzchni wewnętrznej

Fig. 10. CUP, V% for RMS, BR 20%, and BR 80% of the internal surface

Ryc. 10. Kuprofan, wartość V% dla BR 20% i BR 80% dla powierzchni wewnętrznej

Fig. 9. CUP and PS, comparison of mean RMS values of the external surfaces

Ryc. 9. Kuprofan i polisulfon, porównanie średniej wartości RMS dla powierzchni zewnętrznej
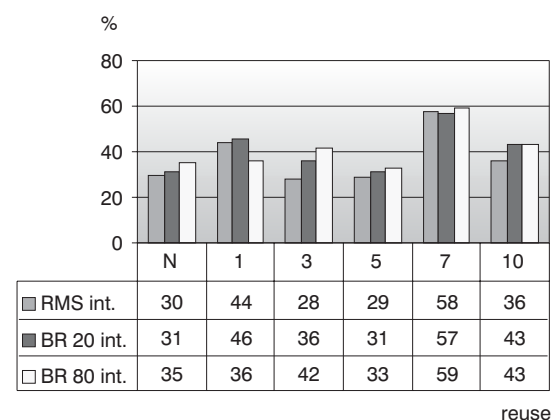
Fig. 11. PS, V% for RMS, BR 20%, and BR 80% of the external surface

Ryc. 11. Polisulfon, wartość V% dla BR 20% i BR 80% dla powierzchni zewnętrznej

initial RMS parameters of the CUP membranes' internal surfaces, the variable coefficient being as much as 111%. After consecutive reuse, the CUP membrane's internal surface RMS was very unstable, which was reflected by the variable coefficient, which ranged from 11 to 112% after 5 reutilizations. The RMS values of new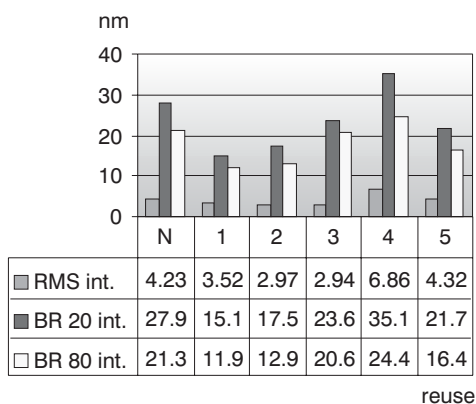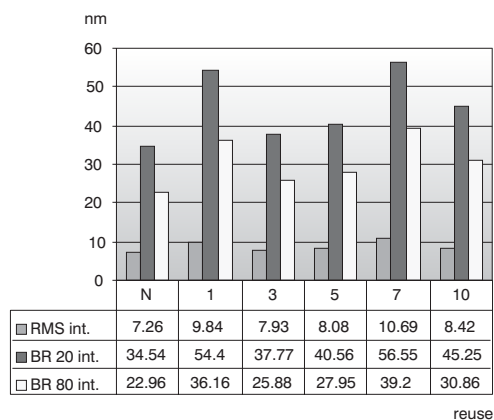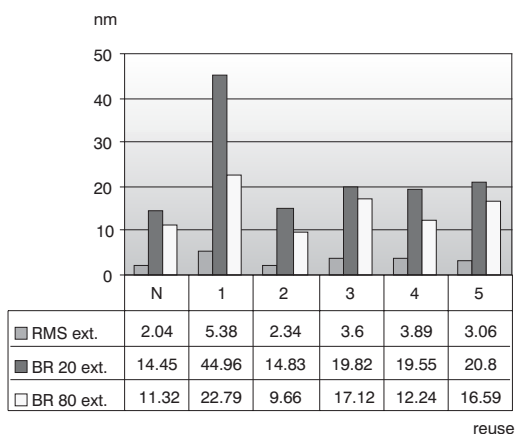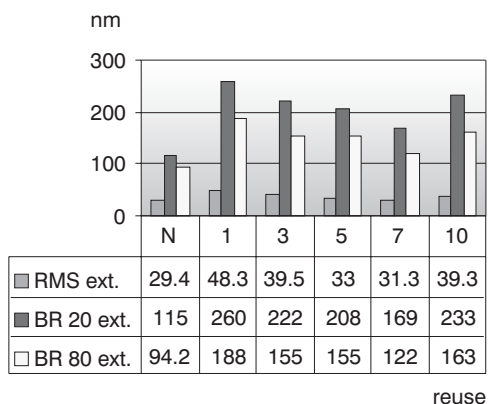 PS membrane's internal surface were stable, ranging from 4.6 nm to 10.6 nm. The variable coefficient (V%) for this membrane was 30%. The maximal variable coefficient for the RMS of the internal PS membrane was 58% and the minimal 28% (Figs. 10, 11).

The data in Table 1 indicate that the mean variable coefficient (V%) for the RMS of the internal PS surface was 37.5% and that for the internal CUP surface was as much as 53.8%. Values of the variable coefficient for the RMS of the external surfaces of the studied membranes were analo-

gous, with that for the external PS surface being 25% and for the external CUP surface as much as 36.2% (Tab. 1, Figs. 12, 13).

Dynamic Changes Coefficients

Values of the change rate (CR%) after consecutive reutilizations for all the observed roughness parameters (RMS, BR20%, and BR 80%) for the PS membrane were stable and predictable (mean CR% for the RMS of the internal surface: 31.4%, of the external surface: 31.5%), which confirms the great resistance of PS polymer to external clinical working conditions. For the CUP membrane the change rate was variable, unstable, and after consecutive reutilizations characterized by large ups and downs (mean CR% for the RMS of the internal surface: 99.9%, of the external surface: 91.3%), which confirms the lack of durability and
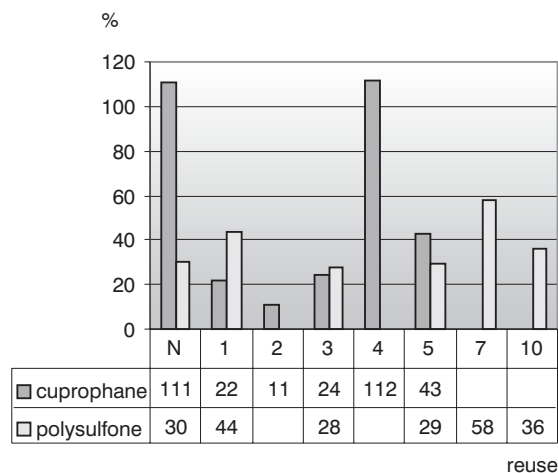
Fig. 12. Comparison of V% for RMS of CUP and PS membranes, internal surfaces

Ryc. 12. Porównanie wartości V% dla RMS błon kuprofanowych i polisulfonowych, powierzchnia wewnętrzna
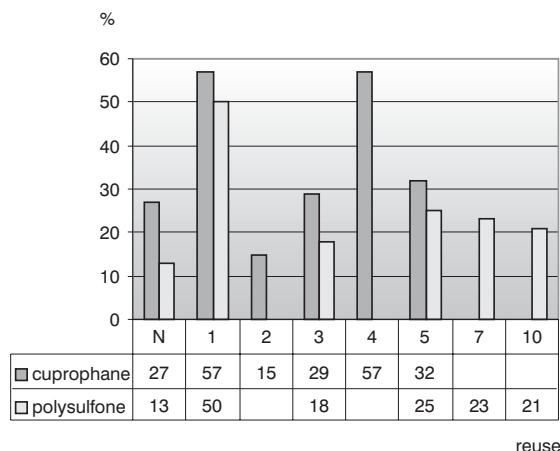
Fig. 13. Comparison of V% for RMS of CUP and PS membranes, external surfaces

Ryc. 13. Porównanie wartości V% dla RMS błon kuprofanowych i polisulfonowych, powierzchnia wewnętrzna

resistance of cellulose to the external clinical working conditions of these dialyzers (Tab. 2). Comparison of the fixed based index in relation to those observed for new membranes also confirms the great stability and homogeneity of the PS membrane's roughness parameters (mean FBI% for the RMS of the internal surface: 131.4%, of the external surface: 131.5%) and the lack of these features in the CUP membrane (mean FBI% for the RMS of the internal surface: 199.9%, of the external surface: 191.3%).

Assessment of Biocompatibility Reactions

Interleukin 6 (IL-6)

The increase in IL-6 concentration during HD sessions with a new CUP dialyzer and after 1, 2, 3, 4, and 5 reutilizations was statistically significant ($p < 0.05$) in each HD session. while that with a new PS dialyzer and after 1, 3, 5, 7, and 10 reutilizations was not statistically significant in any HD session (Tables 3, 4).

Tumor Necrosis Factor-alpha (TNF-α)

The increases in TNF-α concentration during HD sessions with a new CUP dialyzer and after 1, 2, 3, 4, and 5 reutilizations and with a new PS dialyzer and after 1, 3, 5, 7, and 10 reutilizations were not statistically significant in any HD session (Tables 5, 6).

Correlation of Membrane Roughness Parameters and Biocompatibility Marker Values

As expected, no correlation between surface roughness parameters (RMS) of the internal CUP and PS membranes in subsequent dialyzer reuti-

Table 1. Comparison of mean surface roughness parameters' values (RMS, BR 20%, BR 80%) and the variable coefficient (V%) for RMS of the PS and CUP membranes

Tabela 1. Porównanie średnich wartości wskaźników szorstkości powierzchni (RMS BR 20%, BR 80%) i współczynnika zmienności RMS (V%) dla błon kuprofanowych i polisulfonowych

	Cuprophane membrane (Błona kuprofanowa)				Polysulfone membrane (Błona polisulfanowa)			
	RMS	BR 20%	BR 80%	V% RMS	RMS	BR 20%	BR 80%	V% RMS
Internal surface (Powierzchnia wewnętrzna)	4.1	23.5	17.9	53.8%	8.7	44.9	30.5	37.5%
External surface (Powierzchnia zewnętrzna)	3.4	22.4	15	36.2%	36.8	201.1	146.1	25%

Table 2. PS and CUP membranes: mean values of CR% and FBI% for the calculated RMS

Tabela 2. Błony polisulfonowe i kuprofanowe, porównanie średnich wartości CR% and FBI% dla wyliczonych wartości wskaźników RMS

	Polysulfone membrane (Błona polisulfanowa)		Cuprophane membrane (Błona kuprofanowa)	
	internal surface %	external surface %	internal surface %	external surface %
CR% RMS	31.36	31.50	99.86	91.27
FBI% RMS	131.36	131.50	199.86	191.30

Table 3. CUP dialyzers. IL-6 levels during HD sessions with new dialyzers and after 1, 2, 3, 4, and 5 reutilizations

Tabela 3. Dializatory kuprofanowe, zestawienie średnich wartości stężeń IL-6 podczas sesji hemodializacyjnych wykonywanych na nowych i reutylizowanych, odpowiednio: 1, 2, 3, 4 i 5-krotnie, dializatorach

Cuprophane dialyzers (Dializatory kuprofanowe)	t_0	SD	t_{120}	SD	p	delta
N	5.77	1.92	14.62	4.53	0.019	8.84
1	5.27	2.91	14.58	9.09	0.048	9.31
2	9.29	5.93	18.54	7.26	0.010	9.25
3	5.17	2.07	17.24	6.38	0.012	12.07
4	7.89	3.78	16.36	5.93	0.008	8.47
5	6.77	5.48	16.59	6.36	0.011	9.82

Tabela 4. Dializatory polisulfonowe. Zestawienie średnich wartości stężeń IL-6 w czasie sesji hemodializacyjnych wykonywanych na nowych i reutylizowanych odpowiednio 1, 3, 5, 7 i 10-krotnie dializatorach

Table 4. PS dialyzers, IL-6 levels during HD sessions with new dialyzers and after 1, 3, 5, 7, and 10

Polysulfone dialyzers (Dializatory polisulfonowe)	t_0	SD	t_{120}	SD	p	delta
N	19.82	12.94	19.76	13.23	ns.	–0.06
1	17.04	5.55	18.88	5.55	ns.	1.84
3	19.48	12.66	20.42	12.23	ns.	0.94
5	16.54	12.42	16.12	8.59	ns.	–0.42
7	18.54	13.73	17.74	11.36	ns.	–0.80
10	16.00	9.94	17.2	10.01	ns.	1.20

Table 5. CUP dialyzers. TNF-α concentrations during HD sessions with new dialyzers and after 1, 2, 3, 4, and 5 reutilizations

Tabela 5. Dializatory kuprofanowe, zestawienie średnich wartości stężeń TNF-α podczas sesji hemodializacyjnych wykonywanych na nowych i reutylizowanych, odpowiednio: 1, 2, 3, 4 i 5-krotnie, dializatorach

Cuprophane dialyzers (Dializatory kuprofanowe)	t_0	SD	t_{90}	SD	p	delta
N	3.66	1.59	3.70	1.48	ns.	0.04
1	4.16	1.78	3.48	2.03	ns.	–0.68
2	3.42	1.54	3.00	1.12	ns.	–0.42
3	3.32	1.08	3.80	0.81	ns.	0.48
4	3.40	0.83	3.52	1.65	ns.	0.12
5	2.88	0.29	3.26	0.51	ns.	0.38

Table 6. PS dialyzers. TNF-α concentrations during HD sessions with new dialyzers and after 1, 3, 5, 7, and 10 reutilizations

Tabela 6. Dializatory polisulfonowe, zestawienie średnich wartości stężeń TNF-α podczas sesji hemodializacyjnych wykonywanych na nowych i reutylizowanych, odpowiednio: 1, 3, 5, 7 i 10-krotnie, dializatorach

Polysulfone dialyzers (Dializatory polisulfonowe)	t_0	SD	t_{90}	SD	p	delta
N	4.78	1.25	4.60	1.42	ns.	–0.18
1	4.96	2.00	5.58	1.79	ns.	0.62
3	5.00	1.51	4.76	1.03	ns.	–0.24
5	5.24	0.94	5.10	1.33	ns.	–0.14
7	4.72	0.99	4.96	1.61	ns.	0.24
10	5.24	1.81	4.60	1.32	ns.	–0.64

lizations and IL-6 or TNF-α secretion profiles in the patients' serum was found. Based on the results presented above, the following conclusion can be drawn: dialyzer reuse with peracetic acid does not significantly affects the surface nanostructure of the studied membranes nor has an influence on their degree of biocompatibility assessed by IL-6 and TNF-α concentration monitoring.

Discussion

The character of the biochemical interactions which take place when a patient's blood comes in contact with a dialyzer's capillaries is determined by several properties of the dialysis membrane. The internal surface roughness, chemical profile, molecular mass transfer (KoA), and ultrafiltration coefficients (K_{ufr}) of the dialysis membrane are the main determinants of biocompatibility and functional profile of every dialyzer. The adhesion of cells (mainly thrombocytes and leukocytes) and several proteins on the dialysis membrane's surface is a result of both physical and chemical reactions [9]. Tsunoda et al. evaluated the effect of five types of surface roughness of cellulosic dialysis membranes (by the AFM technique) on the degree of thrombocyte adhesion [2]. They found that in membranes with higher surface roughness the degree of thrombocyte adhesion was more intense and the biocompatibility of these membranes was lower, while the capillaries with lower surface roughness contributed to much less intense thrombogenesis and were characterized by a higher degree of biocompatibility.

The present study demonstrated that the internal surface roughness of the PS membrane (mean RMS: 8.7 nm) was higher than that of the CUP membrane (mean RMS: 4.1 nm). With reference to Tsunoda's results, false conclusions might be drawn about a higher degree of biocompatibility for the CUP membrane [4]. The results of this study naturally cannot confirm such a correlation because the decisive factor in the degree of a dialysis membrane's biocompatibility is first and foremost the chemical compound of the internal surface which is in direct contact with the patient's blood. The significance of the roughness of this surface is very important; however, with RMS values ranging from 8.7 nm to 4.1 nm, this parameter is not so crucial as to affect the degree of a membrane biocompatibility. A much higher external roughness (in other words, porosity) of the PS membrane (mean RMS of the external surface: 36.8 nm) than of the CUP membrane (mean RMS of the external surface: 3.4 nm) was noted.

However, this finding may have another explanation. The higher the RMS value, the greater the surface area of the membrane, which might explain the excellent bacterial endotoxin adsorption from a dialysate on an external PS membrane surface and lack of such capability in the case of the CUP membrane. Furthermore, comparing the RMS values of the PS membrane (RMS of the internal surface: 8.7 nm and of the external surface: 36.8 nm), it would clearly appear that its asymmetrical nanostructure cannot be ascertained by analyzing the analogous values of the symmetrical CUP membrane (RMS of the internal surface: 4.1 nm and of the external surface: 3.4 nm).

The lack of any trend in changes in surface roughness of the evaluated dialysis membranes after consecutive reutilizations might be explained by the fact that dialyzer reuse was performed using peracetic acid, which, in contrast to bleach's removal of PVP from PS polymer and destroying the structure of CUP membranes (chemical reaction between cellulose and alkali), did not impair the chemical structure of the studied dialysis membranes. The variable coefficient values for the new CUP internal surface (V%: 111%) obtained in this study and the considerable diversity of this parameter after consecutive reuse of the dialyzer (from 11 to 112%) might show lack of both nanostructure homogeneity and reusability of this membrane, which were assessed by the capillaries' roughness and their great receptivity to external factors caused by the dialyzers' working conditions (TMP, Q_B, Q_D) and the reuse process itself. This may have an impact on changes in the characteristics of CUP membrane parameters, which not only leads to delivering an insufficient dialysis dose to the patient, but decreases the safety and biocompatibility of the hemodialysis session as well. In contrast, the stable internal surface variable coefficients of new (V%: 30%) and reused (28–58%) PS membranes may demonstrate greater homogeneity and reusability of this membrane and its lower receptivity to external factors related to the clinical working conditions of these dialyzers. The stable variable coefficient values of PS membrane provide more predictable and homogenous conditions of hemodialysis sessions, which contributes to delivering the desired dialysis dose to the patients as well as safety and maximal procedure biocompatibility.

The concept of multiple and simultaneously safe use of dialyzers prompted the creation of the PS membrane. However, no correlation was found between CUP and PS internal surface roughness parameters (RMS, BR20%, BR80%) after their times of consecutive reuse and IL-6 or TNF-α secretion profiles determined in hemodialyzed patients' serum. On the basis of the results quoted

in this article it can be concluded that dialyzer reuse with peracetic acid neither affects significantly the surface nanostructure of evaluated dialysis membranes nor influences considerably their degree of biocompatibility evaluated by monitoring IL-6 and TNF-α levels. Matsuda et al., who comprehensively studied the problems of structural and functional characteristics of dialysis membranes and dialyzer biocompatibility showed, that there was no one selected and independent factor describing the surface which comes in contact with the patient's blood and which would be decisive for the total biocompatibility profile of the given device [10]. In other words, there is currently no biomaterial or polymer which would fully cover all the biocompatibility criteria concerning all the biological parameters which might be considered as biocompatibility markers in the human body. PS polymer is characterized by numerous advantages essential in current dialysis therapy which are not covered even partially by cellulosic membranes or other synthetic polymers. PS dialysis membranes, owing to their high degree of biocompatibility and excellent functional parameters, were considered to

be a the "gold standard" among synthetic dialysis membranes [11]. The results obtained in the present study values for the variable coefficient (V%), change rate parameter (T%), and fixed based index (FBI %) entirely confirm this thesis.

The authors conclude that the internal and external surface roughness of the studied membranes (expressed as the mean RMS value) disclosed an asymmetrical nanostructure of the PS and symmetrical nanostructure of the CUP membrane. Mean values of the variable coefficient (V%) for the RMS of both the internal and external surfaces of the studied dialysis membranes showed greater nanostructure stability of new and reused PS membranes in comparison with CUP ones. The reuse of dialysis membranes with peracetic acid does not affect significantly the surface nanostructures of the studied dialysis membranes. No correlation between dialysis membrane surface roughness (RMS) and degree of biocompatibility (IL-6 and TNF-α) was found in this study, which takes note of the importance of the chemical composition of the material the capillaries are made of as a decisive factor in determining and influencing dialyzer biocompatibility.

References

[1] **Puka J, Rutkowski B, Lichodziejewska-Niemirko M et al.:** Raport o stanie leczenia nerkozastępczego w Polsce – 2003. MAKmedia, Gdańsk 2004.

[2] **Tsunoda N, Kokubo K, Sakai K et al.:** Surface roughness of cellulose hollow fiber dialysis membranes and platelet adhesion. ASAIO 1999, 45, 418-423.

[3] Renal Systems Inc.: Renatron. Dialyzer reprocessing system. Model RS 8300. Instruction Manual. Minneapolis 1983.

[4] Renal Systems Inc.: Renalin. Dialyzer reprocessing concentrate. Instruction for use and technical notes. Minneapolis 1983.

[5] Fresenius Medical Care. ESRD patients in 2006. A Global perspective. Bad Hamburg 2007.

[6] **Rumian R, Krawentek L, Pietrzyk JA:** Zastosowanie techniki atomowego mikroskopu siłowego (AFM) do badań nad strukturą i biozgodnością błon dializacyjnych. Sprawozdanie z realizacji projektu badawczego KBN nr 4T11E 024 22. Kraków 2004.

[7] Biosource International: Interleukin 6 IRMA (IL-6). Diagnostic Catalog 2002–2003, 98.

[8] Biosource International: Tumor Necrosis Factor-α CB ELISA (TNF-α CB). Diagnostic catalog 2002-2003, 104.

[9] **Bowry SK, Ronco C:** Surface topography and surface elemental composition analysis of Helixone®, a new high-flux polysulfone dialysis membrane. Int J Artif Org 2001, 24, 757-765.

[10] **Matsuda T:** Biological response at non-physiological interfaces and molecular design of biocompatible surfaces. Nephrol Dial Transplant 1989, 4, 60-66.

[11] **Bowry SK:** Dialysis membranes today. Int J Artif Org 2002, 5, 447-460.

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