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Estimated influence of a novel biocompatible dialysis membrane on vascular events in dialysis patients with diabetic nephropathy: a prospective randomized controlled pilot study

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Abstract

Background: Polysulfone (PS) dialyzers are most frequently used worldwide for chronic renal failure patients and they are produced by several manufacturers. Despite using the same materials, differences in biocompatibility among PS dialyzers have been reported. TORAYLIGHT NV (NV) is a PS dialyzer that was reported to have superior biocompatibility compared with other PS membranes (conventional PS membranes). Therefore, we examined whether biocompatibility of PS membranes would affect the occurrence of cardiovascular events in hemodialysis patients with diabetic nephropathy (DN).

Methods: Fifty hemodialysis patients with DN were enrolled. They were randomly divided into NV and PS groups and then followed up for 3 years. The number of patients who developed cardiovascular events and clinical data including laboratory tests and blood pressure was recorded.

Results: There were 13 and 14 patients who developed cardiovascular events during the 3-year follow-up of the NV and PS groups, respectively. There was no significant difference between the groups. There were no significant differences in most of the clinical data between the two groups. However, serum pentosidine concentrations in the PS group significantly increased throughout this study, while those in the NV group did not change. Additionally, the width of the systolic blood pressure drop, which was shown to be the difference between before and after dialysis session, in the PS group showed no change, while that in the NV group tended to decrease.

Conclusions: The superiority of using NV membrane compared with conventional PS membranes in reducing cardiovascular events in hemodialysis patients with DN remains unclear. However, our results suggested that PS membranes with superior biocompatibility would slow the progression of atherosclerosis and reduce the occurrence of intradialytic hypotension.

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Trial registration: This study was retrospectively registered with the Clinical Trials Registry at the University Hospital Medical Information Network (UMIN-CTR) on March 17, 2017 (registration ID, UMIN 000026339). <https://upload.umin.ac.jp/cgi-open-bin/ctr/ctr.cgi?function=brows&action=brows&recptno=R000030259&type=summary&language=J>

Keywords: Diabetic nephropathy, Cardiovascular Events, Pentosidine, Atherosclerosis, Biocompatibility, Polysulfone dialyzer, Randomized controlled study

Background

Many patients with chronic renal failure (CRF) undergo hemodialysis using hollow fiber-type dialyzers. There are many types of dialyzers that are constructed with different membrane materials. Polysulfone (PS) dialyzers are most frequently used for CRF patients worldwide, and they are produced by several manufacturers. Dialyzer manufacturers have continuously improved the removal performance or biocompatibility of their products. Despite using the same material, differences in biocompatibility among PS dialyzers have been reported [1, 2].

It is well-known that the conditions of the inner surface of the hollow fiber membrane are related to the biocompatibility of hemodialyzers because blood cells including white blood cells (WBCs), red blood cells, and platelets (PLTs) contact the hollow fiber membrane. TORAYLIGHT NV (NV) is a PS dialyzer that uses a new hydrophilic polymer on the inner surface of the hollow fiber to improve biocompatibility [3]. There are some reports of low PLT activation [2, 4, 5], which possibly reduces the occurrence of intradialytic hypotension (IDH) [6] and the dose of erythrocyte stimulating agents (ESAs) [7, 8] in NV compared with other PS dialyzers (conventional PS dialyzers).

In accordance with the annual survey of the Japanese Society for Dialysis Therapy Renal Data Registry (JRDR) [9], the most common primary disease among incident dialysis patients at the end of 2017 was diabetic nephropathy (DN), and the number of dialysis patients with diabetic mellitus (DM) is increasing. Vascular events in patients with DM are well-known to occur frequently compared with other patients because DM patients' vascular diseases progress more quickly [10]. We can predict that the frequency of vascular event occurrence might be higher in dialysis patients with DN because their blood cells would be activated by dialysis therapy. Thus, we investigated whether biocompatibility of PS dialyzers would affect the occurrence of vascular events in hemodialysis patients with DN.

We planned and conducted a multicenter prospective randomized controlled trial in hemodialysis patients with DN. In this article, we report the results of this clinical trial.

Methods

Subjects

Patients who met the following entry criteria were enrolled. The inclusion criteria were as follows: patients

whose original disease was DN and who received hemodialysis with a conventional PS dialyzer except for TORAYLIGHT NV (NV, Toray Inc., Tokyo, Japan), three times per week at one of the eight participating dialysis centers. The exclusion criteria were as follows: patients over 80 years of age, who had a dialysis duration of less than 1 year, or who had cerebrovascular or cardiovascular events within 3 months before the beginning of this study.

Study design

This is a prospective randomized controlled 3-year clinical trial, and patients who met all the inclusion and none of the exclusion criteria were enrolled after providing written informed consent. The study period was set for 3 years referring the past articles reporting estimation of prognosis and cardiovascular events on hemodialysis patients [11, 12]. The enrolled patients were randomly allocated into the following two groups: PS group and NV group. In the PS group, patients did not change from using PS dialyzers, while in NV group, patients who were using PS dialyzers were changed to the NV dialyzer. We collected the following 12 items from the patients' medical records: sex, age, dialysis duration, body weight after the dialysis session, effective surface area, hemoglobin (Hb) concentration, serum albumin concentration, hemoglobin A1c (HbA1c), DN duration, insulin administration, dipeptidyl peptidase-4 (DPP-4) inhibitor administration, and antihypertensive agent administration. Evaluation items for primary and secondary endpoints were collected each year. The primary endpoint was the number of patients who developed cardiovascular events. Secondary endpoints were other evaluation items that are described above.

Dialysis conditions including dialysis time, membrane surface area, anticoagulant, and dialysate were maintained throughout the study period.

Trial registration

This study was approved by the Tokatsu Dialysis Hospital's institutional review board and all patients provided written informed consent. This study was registered with the University Hospital Medical Information Network (UMIN) (registration ID: UMIN000026339). This study was retrospectively registered with UMIN-CTR because

the first patient had been enrolled on February 23, 2015. The reason why this study was retrospectively registered was a lack of awareness of the prospective registration requirement.

Cardiovascular events

The number of patients who developed vascular events was collected each year for 3 years. As a reference, the number of patients who developed vascular events within the 3 years before the onset of this trial was collected from the patients’ medical records.

Clinical data

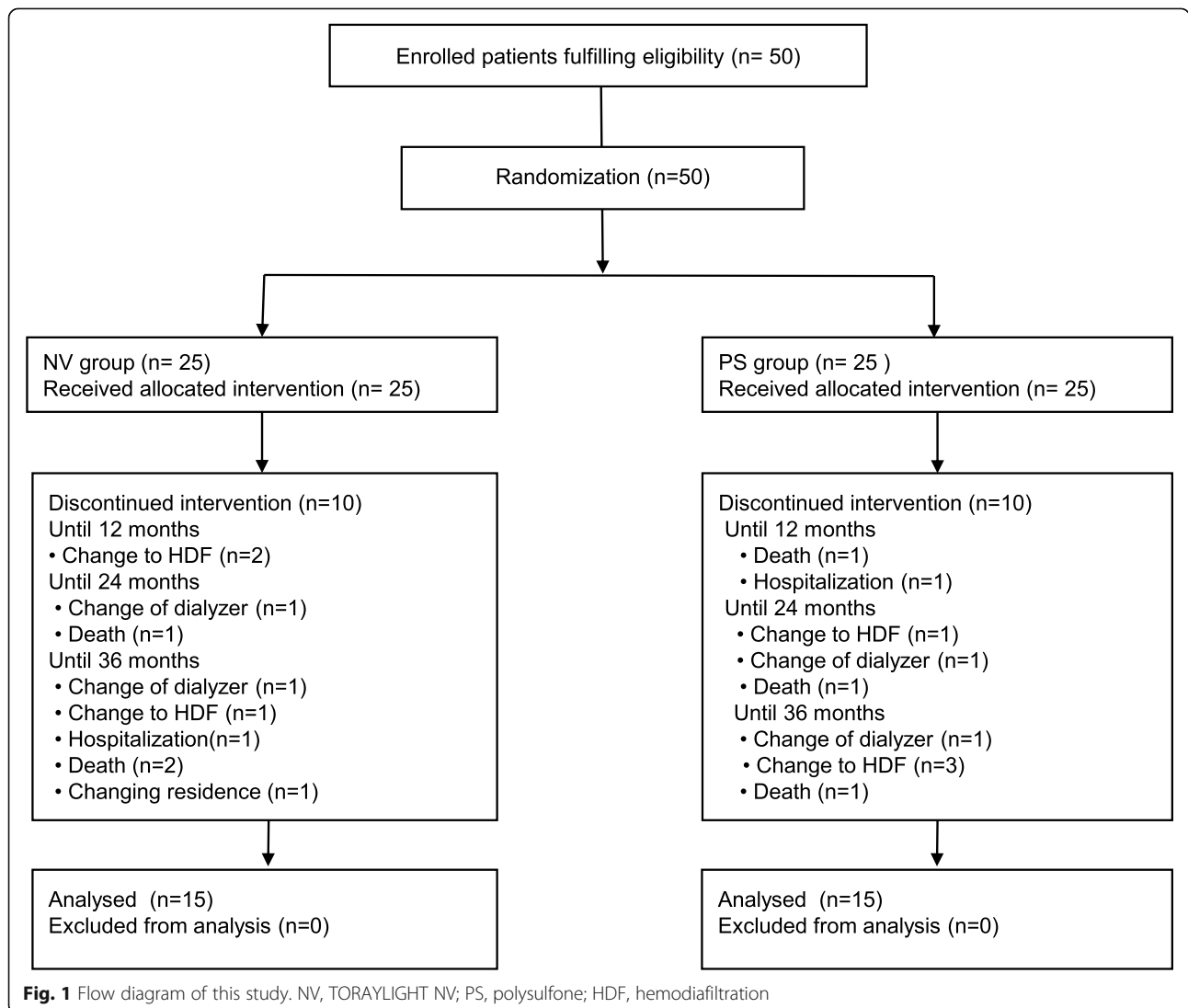
The following clinical data were collected each year for 3 years: serum pentosidine, soluble-E-selectin or endothelial leukocyte adhesion molecule-1 (ELAM-1), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), Hb, and albumin levels; WBC and

PLT counts; systolic blood pressure (SBP) and diastolic blood pressure (DBP); the ankle brachial index (ABI) and cardio-ankle vascular index (CAVI); and body weight, body mass index (BMI), and the Geriatric Nutritional Risk Index (GNRI). Pre-study values were collected from medical records before the beginning of this trial.

Blood samples were taken before each dialysis session, and pentosidine and ELAM-1 were measured by a medical laboratory (SRL Inc., Tokyo, Japan). SBP and DBP were measured before and after each dialysis session. In this study, we calculated the width of the blood pressure drop using SBP before and after each dialysis session. The ABI and CAVI were measured using a VaSera VS-3000A or VS-3000E (Fukuda Denshi Co. Ltd., Tokyo, Japan).

Drug administration

The ESA and iron doses were collected each year.



Data and statistical analysis

Data analysis did not include data from withdrawn patients. Statistical testing was performed using the chi-square test of independence, the Mann–Whitney *U* test, the Friedman test, and an analysis of variance (ANOVA), with a significance level of $P < 0.05$. Statcel 4 (OMS Publishing Inc., Saitama, Japan) statistical processing software was used for all statistical analyses.

Results

Overview

A flow diagram of this study is shown in Fig. 1. We enrolled 50 patients who met the criteria for this study and randomized 25 patients into each of the following groups: the NV and PS groups. There was no significant difference in the patient characteristics between the groups (Table 1). There were ten patients in each group who were withdrawn, and thus, each group had 15 patients. The reasons for withdrawal were death, changing to hemodiafiltration (HDF), change of dialyzer, hospitalization, and change of residence. In the NV and PS groups, the reasons for withdrawal were, respectively, as follows: three and three patients died, three and four patients changed to HDF, two and two patients had a change of dialyzer, one and one patient was hospitalized, and one patient in only the NV group had a change of residence. There were no significant differences in the reasons for withdrawal between two groups. Data analysis did not include the data from withdrawn patients. There was no significant difference in characteristics of analyzed patients between the groups (Table 2).

Vascular events

Patients developing cardiovascular events were counted each year for 3 years before and after the start of this

study. The number of patients who developed vascular events in a year did not drastically change for 3 years after the start of the study compared with before the study. There were more vascular events before the study in the NV group compared with the PS group. However, the overall number of vascular events in the NV and PS groups was almost the same after 3 years (Table 3).

Change of systolic blood pressure during this study

During this study, there was no significant difference in SBP before and after dialysis sessions between the two groups. Additionally, SBP before and after dialysis was not different between the groups. SBP after dialysis sessions tended to decrease in the PS group but it tended to increase in the NV group (Fig. 2a, b). There was no significant difference in the width of the SBP drop between the groups in this study, but the width of the SBP drop in the NV group tended to be smaller compared with the PS group (Fig. 2c). During this study, the number of patients with a width of the SBP drop that was more than 20 mmHg tended to show a decrease in the NV group, but there was no change in the PS group (Fig. 3).

Clinical data

There were no significant differences in pentosidine and ELAM-1 levels between the two groups during this study. Pentosidine levels in the NV group did not change (Fig. 4c), but in PS group, the pentosidine levels significantly increased during the study (Fig. 4d). No statistically significant differences were observed between the NV and PS groups for LDL-C, HDL-C, ABI, and CAVI. There were no significant differences in nutritional indicators such as serum albumin, body weight, BMI, and GNRI. There were no significant differences in the WBC

Table 1 Characteristics of enrolled patients

	NV group	PS group	<i>P</i> value
Number of patients	25	25	–
Sex (male/female)	17/8	18/7	0.76
Age (years)	64.8 ± 9.0	63.9 ± 10.2	0.59
Duration of dialysis (years)	6.5 ± 3.6	6.6 ± 5.1	0.69
Insulin administration (Y/N)	10/15	10/15	1.00
Duration of diabetic nephropathy (years)	19.1 ± 13.0	13.9 ± 10.9	0.13
Administration of DPP-4 inhibitors (Y/N)	16/9	13/12	0.39
Administration of antihypertensive agents (Y/N)	16/9	17/8	0.76
Body weight (kg)	60.8 ± 12.1	58.7 ± 11.7	0.75
HbA1c (%)	6.2 ± 1.0	6.2 ± 0.8	0.96
Hb (g/dL)	10.3 ± 0.7	10.5 ± 0.6	0.89
Serum albumin (g/dL)	3.9 ± 0.4	3.9 ± 0.3	0.74
Surface area of dialyzer (m ²)	1.8 ± 0.4	1.8 ± 0.4	0.53

Results of parameters were evaluated in enrolled patients and are presented as the mean ± standard deviation

Table 2 Characteristics of study patients

	NV group	PS group	P value
Number of patients	15	15	–
Sex (male/female)	10/5	13/2	0.39
Age (years)	69.5 ± 7.8	67.6 ± 10.5	0.49
Duration of dialysis (years)	9.2 ± 3.9	9.1 ± 3.7	0.95
Insulin administration (Y/N)	6/9	7/8	0.71
Duration of diabetic nephropathy (years)	19.5 ± 10.7	16.5 ± 7.7	0.59
Administration of DPP-4 inhibitors (Y/N)	12/3	10/5	0.68
Administration of antihypertensive agents (Y/N)	13/2	11/4	0.65
Body weight (kg)	65.2 ± 12.9	62.6 ± 10.2	0.77
HbA1c (%)	6.2 ± 0.9	6.3 ± 0.9	0.88
Hb (g/dL)	10.4 ± 0.7	10.2 ± 0.5	0.55
Serum albumin (g/dL)	4.0 ± 0.4	3.9 ± 0.4	0.38
Surface area of dialyzer (m ²)	1.9 ± 0.3	1.8 ± 0.4	0.34

Results of parameters were evaluated in enrolled patients and are presented as the mean ± standard deviation

and PLT counts. Hb levels were transiently low in the PS group after 1 year. There were no significant differences in WBC and PLT counts as indicators of biocompatibility throughout the study (Table 4).

Drug administration

The ESA dose before the study was significantly lower in the NV group compared with the PS group (Table 5). The ESA dose did not change in either of the two groups in this study. These clinical findings were observed during the study. The iron dose was not significantly different between the two groups from before the study up to year 2. However, in year 3, the dose of iron in the NV group was significantly lower compared with the PS group (Table 5).

Discussion

In this multicenter prospective randomized controlled study, we examined whether the dialyzer that was reported to have superior biocompatibility would affect the occurrence of cardiovascular events in hemodialysis patients with DN.

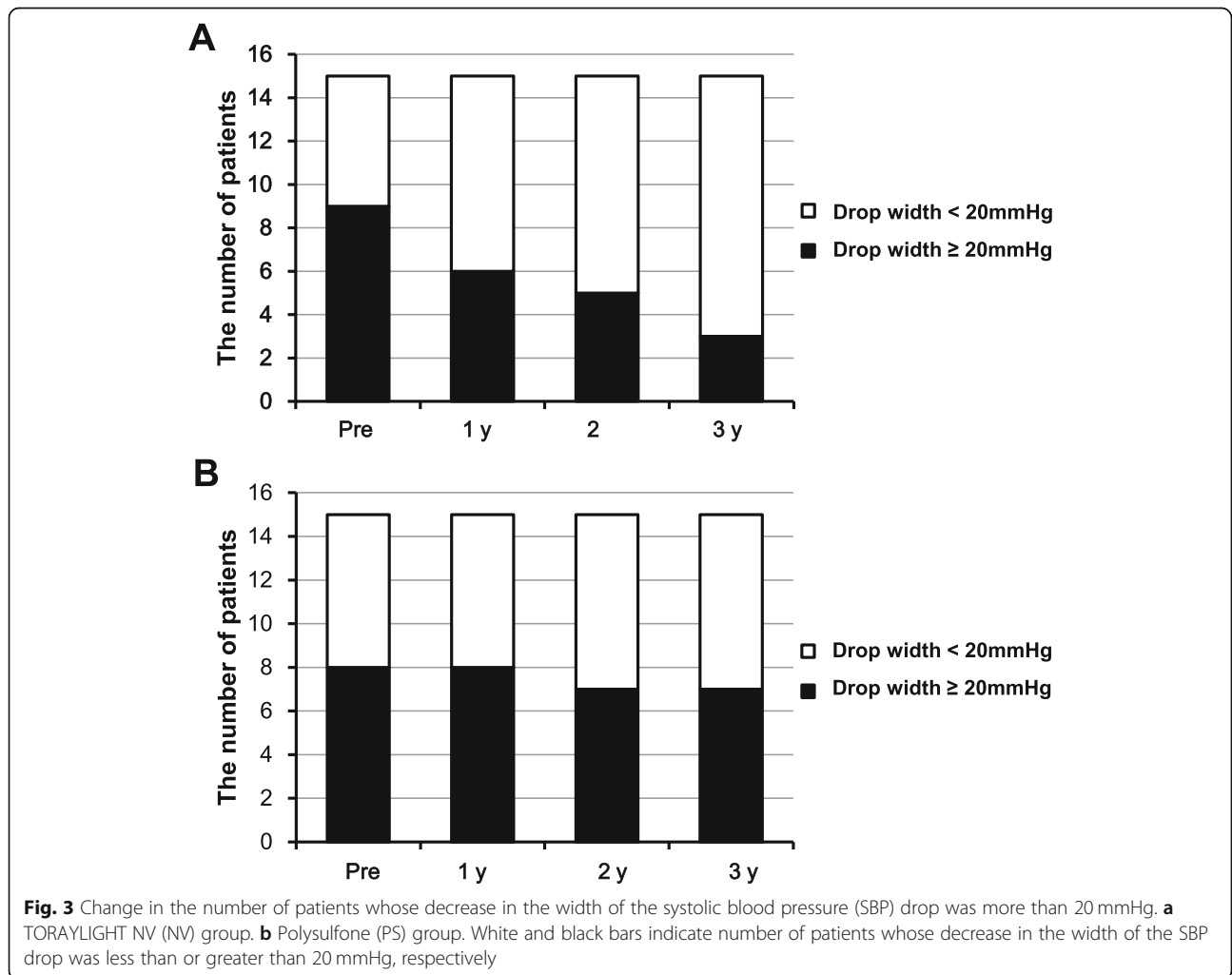
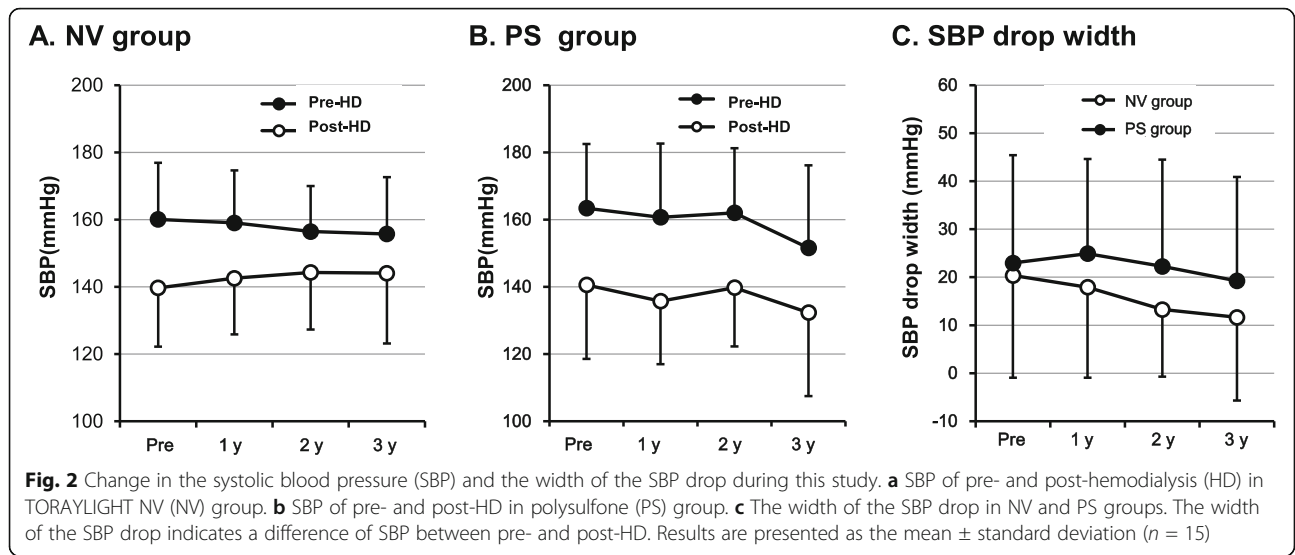
The number of patients developing cardiovascular events during the 3-year study period was the primary endpoint, which was not significantly different between the NV and PS groups (Table 3). Additionally, there was no significant difference in the number of patients who developed cardiovascular events before or after the study. This finding suggests that changing the dialyzers did not affect the primary endpoint.

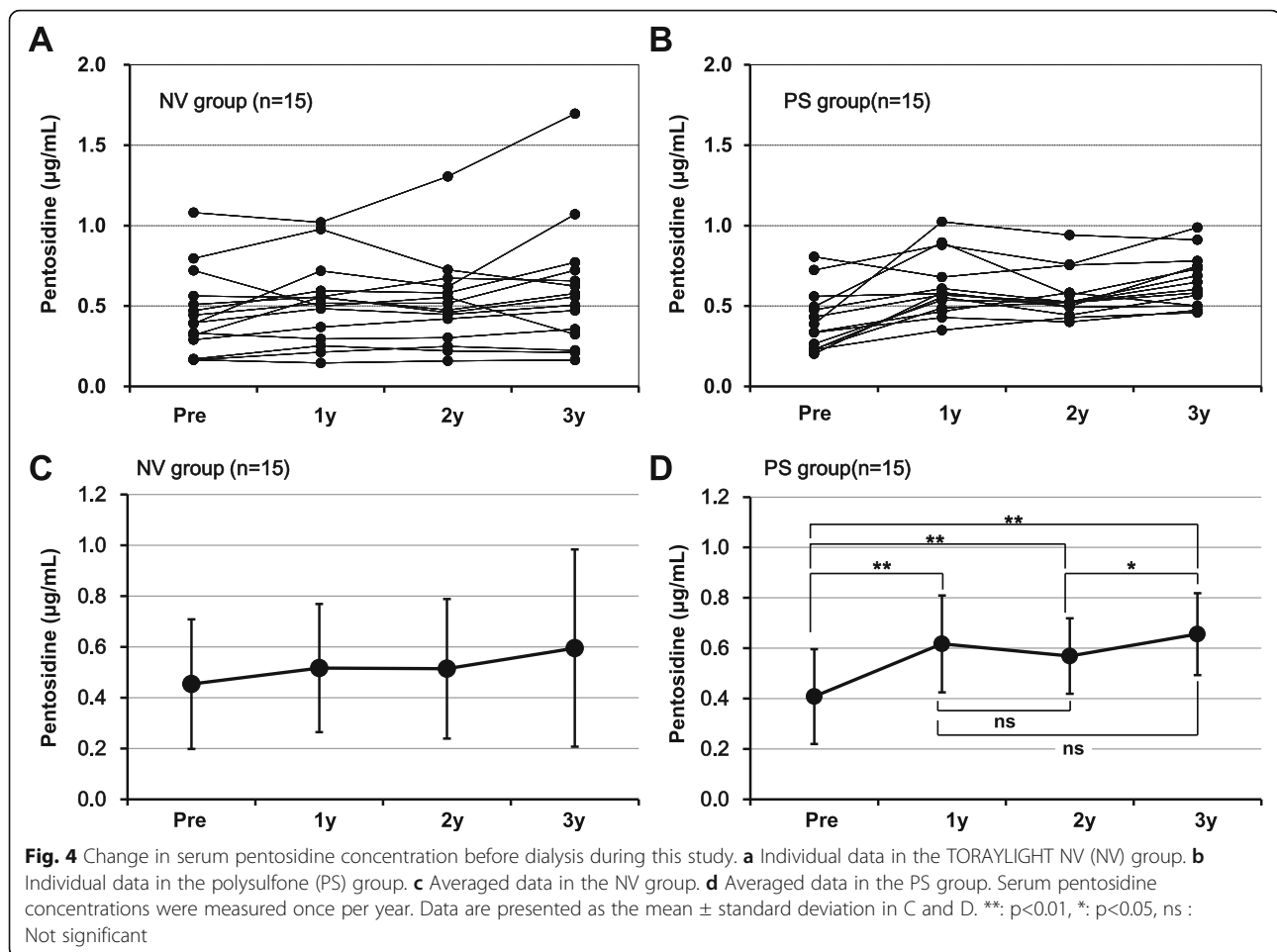
There was no significant difference between most of the clinical data in both groups. However, serum pentosidine concentrations significantly increased in the PS group over time, but did not change in the NV group. Pentosidine, which is an advanced glycation end product (AGE), is known to develop in response to oxidative stress [13, 14]. There were some reports showing that the hemodialysis membrane type influenced the pentosidine plasma levels [15, 16]. In NV, which showed low blood cell activation [2, 4, 17], it is presumed that the occurrence of oxidative stress derived from blood cells had decreased in these patients. We suggest that this is the reason for the differences found in serum pentosidine concentrations between the groups. Because pentosidine is related to the

Table 3 Number of patients who developed cardiovascular events for 3 years before and after the beginning of the study

Group		– 3 to – 2 year	– 2 to – 1 year	– 1 to 0 year	0 to 1 year	1 to 2 years	2 to 3 years	Total (0 to 3 years)
NV group	<i>n</i>	15	15	15	15	15	15	45
	Yes	4	5	3	4	4	5	13
	No	11	10	12	11	11	10	32
PS group	<i>n</i>	15	15	15	15	15	15	45
	Yes	1	4	3	5	4	5	14
	No	14	11	12	10	11	10	31

Yes, number of patients who developed cardiovascular events; no, number of patients who did not develop cardiovascular events





progression of atherosclerosis [18, 19], we can expect that the progression of atherosclerosis is suppressed by long-term use of PS dialyzers with superior biocompatibility. However, in this study, there was no significant difference in ABI and CABI, which are indexes for atherosclerosis, between the two groups. Thus, we suggest that there were no differences between the two groups because atherosclerosis might have already progressed substantially in patients who were enrolled into this study. We consider that different results would be obtained for atherosclerosis progression between conventional and superior biocompatible PS membranes if we would enroll patients who are incident dialysis patients or who had less atherosclerosis progression.

PLT activation is an index for evaluating the biocompatibility of the dialysis membrane [1, 20, 21], and PLT activation by NV was reported to be lower compared with that of conventional PS membranes [2, 4, 5, 18]. Tsuchida and his co-workers previously reported that NV with low PLT activation could reduce the occurrence of IDH in patients with DN and a frequent occurrence of IDH [6]. In hemodialysis therapy, it is important to suppress the occurrence of IDH because

IDH is known to affect mortality [22, 23]. Because the aim of our study was not an examination of IDH, we did not collect data about the width of the blood pressure drop. However, we estimated the width of the blood pressure drop by calculating the change in blood pressure before and after dialysis as a representation of the width of IDH. Compared with the PS groups, the width of the blood pressure drop in the NV group before and after dialysis tended to be smaller compared with that in the PS group. The number of patients whose decrease in the blood pressure width was more than 20 mmHg did not change in PS group, while that in NV group tended to decrease. Similar to Tsuchida et al.'s report [6], we suggest that these results showed that the PS membrane with the low platelet activation properties such as NV could reduce the occurrence of IDH. Additionally, Tsuchida et al.'s report [6] also suggests that the PS membrane has low PLT activation, NV can reduce the occurrence of IDH.

In this 3-year study, ten patients in each of the NV and PS groups withdrew. The reasons for withdrawal were death, changing to HDF, change of dialyzer, hospitalization, and change of residence. The reasons that may have been related to dialyzers were death and

Table 4 Clinical data in analyzed patients

	Pre	1 year	2 years	3 years
Number of patients				
NV group	15	15	15	15
PS group	15	15	15	15
Pentosidine ($\mu\text{g/mL}$)				
NV group	0.45 \pm 0.26	0.52 \pm 0.25	0.51 \pm 0.27	0.60 \pm 0.39
PS group	0.41 \pm 0.19	0.62 \pm 0.19	0.57 \pm 0.15	0.66 \pm 0.16
ELAM-1 (ng/mL)				
NV group	43.4 \pm 19.1	42.1 \pm 18.0	47.3 \pm 18.5	48.8 \pm 17.6
PS group	37.8 \pm 17.8	43.2 \pm 21.9	38.7 \pm 20.3	39.6 \pm 18.3
LDL-C (mg/dL)				
NV group	83 \pm 25	83 \pm 25	88 \pm 31	87 \pm 30
PS group	77 \pm 19	76 \pm 22	75 \pm 20	78 \pm 23
HDL-C (mg/dL)				
NV group	49 \pm 14	47 \pm 14	46 \pm 14	47 \pm 15
PS group	47 \pm 24	47 \pm 24	47 \pm 24	78 \pm 23
ABI (right)				
NV group	1.04 \pm 0.14	0.98 \pm 0.15	1.00 \pm 0.17	0.92 \pm 0.16
PS group	1.00 \pm 0.26	0.95 \pm 0.21	0.95 \pm 0.22	0.91 \pm 0.24
ABI (left)				
NV group	1.00 \pm 0.12	0.96 \pm 0.12	0.98 \pm 0.12	0.92 \pm 0.16
PS group	1.03 \pm 0.11	1.00 \pm 0.13	0.99 \pm 0.15	0.98 \pm 0.17
CAVI (right)				
NV group	8.9 \pm 1.1	9.2 \pm 1.4	9.5 \pm 1.3	9.5 \pm 1.4
PS group	9.1 \pm 1.5	9.4 \pm 1.8	9.0 \pm 1.4	9.1 \pm 1.4
CAVI (left)				
NV group	8.9 \pm 1.3	9.3 \pm 1.5	9.3 \pm 1.2	9.5 \pm 1.0
PS group	8.2 \pm 0.8	8.7 \pm 1.0	8.7 \pm 1.4	8.9 \pm 0.7
Serum albumin (g/dL)				
NV group	4.0 \pm 0.6	4.0 \pm 0.2	3.9 \pm 0.3	3.9 \pm 0.2
PS group	4.0 \pm 0.2	3.9 \pm 0.3	3.8 \pm 0.4	3.8 \pm 0.6
Body weight (kg)				
NV group	64.7 \pm 11.1	63.8 \pm 11.8	64.1 \pm 11.9	62.9 \pm 11.3
PS group	61.8 \pm 10.5	62.2 \pm 11.5	61.8 \pm 11.2	61.4 \pm 11.0
BMI (kg/m^2)				
NV group	24.4 \pm 3.6	24.3 \pm 4.0	24.5 \pm 4.0	24.1 \pm 3.8
PS group	23.6 \pm 3.1	24.0 \pm 2.9	23.8 \pm 2.7	23.7 \pm 2.7
GNRI				
NV group	100.0 \pm 8/9	100.2 \pm 3.9	99.6 \pm 5.2	99.0 \pm 4.0
PS group	99.7 \pm 4.4	98.8 \pm 5.1	97.2 \pm 6.5	96.9 \pm 9.5

Table 4 Clinical data in analyzed patients (Continued)

	Pre	1 year	2 years	3 years
Hemoglobin (g/dL)				
NV group	10.6 ± 0.6	10.5 ± 0.4*	10.5 ± 0.7	10.6 ± 0.8
PS group	10.3 ± 0.4	10.2 ± 0.5	10.4 ± 0.7	10.2 ± 0.7
WBC (cells/μL)				
NV group	6154 ± 1293	6181 ± 1151	6856 ± 2047	6726 ± 2513
PS group	5791 ± 711	6147 ± 1175	6078 ± 1016	6017 ± 882
Platelet (× 10 ⁴ cells/μL)				
NV group	20.7 ± 8.9	21.7 ± 8.0	21.4 ± 8.3	19.9 ± 11.1
PS group	18.8 ± 6.4	18.3 ± 5.8	18.5 ± 5.7	17.8 ± 5.1

Results are presented as the mean ± standard deviation

NV TORAYLIGHT NV, PS polysulfone, ELAM endothelial leukocyte adhesion molecule-1, LDL-C low-density lipoprotein cholesterol, HDL-C high-density lipoprotein cholesterol, ABI ankle brachial index, CAVI cardio-ankle vascular index, BMI body mass index, GNRI geriatric nutritional risk index, WBC white blood cell

*P < 0.05 vs. PS group

change of dialyzer. Because the number of patients withdrawn for each reason was the same in the two groups, we considered that dialyzers were not related to these patient withdrawals.

Conclusion

We examined whether PS membranes that were reported to have superior biocompatibility would reduce the occurrence of cardiovascular events in hemodialysis patients with DN compared with a normal PS membrane. However, there were no significant differences in the number of patients who developed cardiovascular events between the two groups. We showed that PS membranes with superior biocompatibility would reduce the serum pentosidine concentration and decrease the width of the blood pressure drop during dialysis. Use of PS membranes with superior biocompatibility might lead to a reduction in atherosclerosis progression and IDH occurrence. To confirm these clinical findings, we need to plan and conduct a prospective randomized

controlled trial that will enroll a higher number of patients and that will have a different primary endpoint.

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Authors' contributions

MK, RN, KA, YT, KK, KK, YM, SH, KI, and NA performed the clinical study. MK was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this article.

Ethics approval and consent to participate

This clinical study was approved by the ethics committee of Tokatsu Dialysis Hospital and written informed consent was obtained from each study participant.

Consent for publication

Not applicable.

Competing interests

Not applicable.

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Table 5 Change in drug administration during this study

	Pre	1 year	2 years	3 years
Number of patients				
NV group	15	15	15	15
PS group	15	15	15	15
Dose of ESA (IU/week)				
NV group	2115 ± 1691*	2591 ± 1541	2760 ± 2095*	2267 ± 2492*
PS group	4611 ± 3218	5236 ± 3459	5346 ± 4093	5156 ± 4101
Dose of iron drug (mg/week)				
NV group	18 ± 20	11 ± 13	15 ± 18	5 ± 10*
PS group	23 ± 18	15 ± 10	15 ± 13	18 ± 20

Results are presented as the mean ± standard deviation

NV TORAYLIGHT NV, PS polysulfone, ESA erythropoiesis stimulating agent

*P < 0.05 vs. PS group

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