Renal Replacement Therapy

REVIEW

Open Access

Literature review: Combined therapy with peritoneal dialysis and hemodialysis as renal replacement therapy

Hiroaki Io[1,2*], Junichiro Nakata[2], Hiroyuki Inoshita[1,2], Toshiki Kano[1,2], Masanori Ishizaka[1,2], Masahiro Muto[1,2], Yu Sasaki[1,2], Takuya Maeda[2], Haruna Fukuzaki[2], Yuki Shimizu[2] and Yusuke Suzuki[2]

Abstract

Background: Peritoneal dialysis (PD) is the recommended renal replacement therapy for patients with end-stage kidney disease. Complementary hemodialysis (HD) once per week for PD patients can aid in achieving adequate dialysis and extend the duration of PD treatment. In Japan, this therapy is termed "combined therapy with PD and hemodialysis (combPDHD)." CombPDHD represents a treatment option for PD patients for whom adequate dialysis cannot be maintained. CombPDHD has been widely applied in Japanese PD patients; however, it is much less common outside of Japan. Clinical evidence, particularly regarding long-term prognosis and appropriate duration of treatment, remains insufficient.

Summary: CombPDHD will be required as an alternative for increasing the dose of PD under various conditions, such as a loss of residual kidney function (RKF) and peritoneal functional failure. The Japanese regimen for combPDHD involves 5 or 6 days of PD, combined with one weekly session of hemodialysis. According to some reports, the potential benefits of combPDHD are peritoneal rest with improved peritoneal function and delay in membrane deterioration. CombPDHD prevents peritoneal dysfunction and reduces cardiovascular complications by adjusting the fluid volume and improving renal anemia. Increased D/PCr indicates a deterioration in peritoneal function and is an independent risk factor for encapsulating peritoneal sclerosis (EPS). It is previously reported that no significant differences in combPDHD duration were observed between EPS and non-EPS groups. Laparoscopic findings involving patients with combPDHD revealed that there was a difference in abdominal wall degeneration depending on the intra-abdominal cavity of each case. Recently, prospective studies on long-term peritoneal function, survival, and hospitalization in combPDHD have been reported. However, reviews evaluating combPDHD long-term outcomes in multicenter and prospective studies are lacking.

Conclusion: It is difficult to continue PD alone with a declining RKF or when self-management is poor. Hence, combPDHD should be started to adjust the fluid volume, with adequate dialysis dose and peritoneal rest. This therapy is useful from a lifestyle viewpoint during the transition period from PD to HD and should not be continued indefinitely.

Keywords: Combined therapy, Dialysate-to-plasma ratio of creatinine (D/PCr), Fluid overload, Hemodialysis (HD), Inadequate dialysis, Peritoneal dialysis (PD), Renal replacement therapy (RRT), Residual kidney function (RKF)

*Correspondence: hiroaki@juntendo.ac.jp

[1] Department of Nephrology, Juntendo University Nerima Hospital, Takanodai 3-1-10, Nerima-ku, Tokyo 177-8521, Japan
Full list of author information is available at the end of the article

Background

Peritoneal dialysis (PD) is a common kidney replacement therapy for patients with end-stage kidney disease. The benefits of PD treatment include preservation of the residual kidney function (RKF) and high quality of life

[1]. However, adequate solute and fluid removal are difficult to achieve with PD alone, particularly after extensive periods of PD treatment. Therefore, switching to hemodialysis (HD), followed by kidney transplantation or initiating combined therapy with PD and HD (combPDHD), is an option for patients who cannot continue PD alone, or for those who require an increased dosage of PD.

CombPDHD was first introduced in Japan [2, 3] and has subsequently been adopted widely. CombPDHD has been covered by the National Health Care Insurance System in Japan since April 2010. The percentage of patients receiving combPDHD therapy has increased slightly in recent years. In 2018, approximately 1800 patients (~20% of all PD patients) were receiving this therapy in Japan [4]. CombPDHD therapy is indicated as an alternative for increasing the number of dialysis sessions owing to loss of RKF, peritoneal fibrosis, and functional failure induced by a bioincompatible peritoneal dialysate [5]. Generally, the treatment regimen is 5–6 days of PD combined with one session of HD per week. According to some reports [6, 7], the potential benefits of combPDHD include peritoneal rest expecting improved peritoneal function, delay in membrane deterioration, and minimization of HD-related cardiovascular complications. However, Moriishi et al. [8] reported that improvement in peritoneal function with combPDHD cannot be expected in patients with deteriorated peritoneal function. It is well known that long-term PD causes encapsulating peritoneal sclerosis (EPS), a few cases of which have been observed even after PD cessation [9]. Recently, prospective studies on long-term peritoneal function [10], survival [11], and hospitalization [12] in patients treated with combPDHD have been reported. However, multicenter and prospective studies evaluating the long-term effects of combPDHD are lacking (Table 1). Therefore, we aim to review the studies that have reported the outcomes of combPDHD.

Main text

Reports on combined PDHD in previous studies

It is well known that long-term PD is a cause of EPS, with some EPS cases observed even after PD cessation [9]. Improved fluid overload and peritoneal function were clinical status characteristics during short-term combPDHD. Body weight, systolic blood pressure, and left ventricular mass index (LVMI) decreased significantly, and the level of hemoglobin (Hb) increased significantly after combination therapy, suggesting that fluid overload was the primary cause. Previous studies also reported that hydration status significantly improved both in PD therapy [13] and in combPDHD [14]. This therapy could be maintained for over 1 year to improve Hb level and cardiac function by adjusting the body fluid status. CombPDHD should be used in PD patients with fluid overload attributable to ultrafiltration failure, poor self-management of fluid balance, and severe heart failure. The dialysate-to-plasma ratio of creatinine (D/PCr) decreased significantly after short-term combination therapy, which corroborated previous studies [6, 7]. A decline in exposure to the advanced glycosylated end-products, glucose degradation products in the PD fluid, and uremic toxins by combination therapy could prevent the deterioration of the peritoneal membrane [15]. Peritoneal rest could lead to improved peritoneal function and delay in membrane deterioration. However, it is well known that long-term PD therapy is a risk factor for EPS. Previous studies reported that PD could be continued successfully with an acceptably low risk of EPS for at least 8 years; however, greater caution is required for patients receiving PD for long term [9]. According to these reports, the duration of PD might be prolonged by the peritoneal rest provided by combPDHD. However, short-term and long-term combPDHD did not significantly alter the plasma β_2-microglobulin (MG) level (Table 2). CombPDHD should be used in PD patients with sufficient clearance of solutes such as urea, and β_2-MG, which are indexes for small-solute and middle-molecule clearance, respectively. The level of plasma β_2-MG in patients undergoing PD alone should be < 30 mg/L. The level of plasma β_2-MG is associated with increased mortality among HD patients [16] and is a risk factor for EPS [17]. A decline in RKF is another factor. EPS, a rare and serious complication, occurs in patients undergoing long-term PD. Therefore, a high level of plasma β_2-MG and a decline in RKF may lead to a poor outcome. Urine volume was reported in several studies (Table 3). The clinical evidence supporting combPDHD has been steadily accumulating, with several observational studies published to date (Table 1). Notably, most reports were from Japan, and most of them were retrospective single-center studies with small cohorts. Furthermore, all these studies involved before-and-after comparisons but lacked control groups. Recently, multicenter research has been conducted (see Table1). Surprisingly, the total weekly K_t/V ratio [K = clearance dialysis coefficient, t = dialysis duration, and V = body fluid volume] was relatively stable (Table 4). Adequate solute removal is essential in the management of PD, and treatment targets have been defined in several guidelines, including those published by the International Society for Peritoneal Dialysis (ISPD) [18] and the Japanese Society for Dialysis Therapy (JSDT) [19]. The total weekly K_t/V ratio indicates the efficacy of small-molecule uremic toxins removal and is calculated as the sum of renal and peritoneal clearance of urea. The recommend weekly K_t/V ratio is > 1.7 [18, 19]. In contrast, circulating β_2-MG, a marker of middle-molecule

Table 1 Previous reports of combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Country	Study design	Number	Duration of PD at start of combined therapy (years)	Follow-up period (months)	Main outcome
Kawanishi, 1999 [27]	Japan	Single-center retrospective	12	4.1 ± 3.6	3	Increased Kt/V
Hashimoto, 2000 [28]	Japan	Single-center retrospective	6	2.1 ± 0.9	3	Quality of life, medical costs
Kawanishi, 2002 [3]	Japan	Single-center retrospective	31 (12)	(99.4 ± 30.1)	(25.2 ± 18.8)	Dialysis dose and body fluid
Kanno, 2003 [29]	Japan	Single-center retrospective	7	4.3 ± 1.1	6	Solute clearance and symptoms
Agarwal, 2003 [30]	USA	Multicenter retrospective	31	4.3 ± 4.1	6	Solute clearance and symptoms
McIntyre, 2004 [31]	UK	Prospective	8	0 at initiation	12	Blood pressure, left ventricular mass index reduced
Kawanishi, 2006 [32]	Japan	Multicenter retrospective	52	3.6 ± 3.0	24	Adequate solute, fluid removal without PD alone
Hoshi, 2006 [33]	Japan	Single-center retrospective	9	3.6 ± 0.2	36	Clinical status for whom adequate solute
Kawanishi, 2007[5]	Japan	Multicenter (four center) retrospective	52	3.6 ± 3.0	6	Prolonged PD duration
Matsuo, 2010 [6]	Japan	Single-center retrospective	53	4.1 ± 3.2	12	Controlled overhydration and corrected solute removal
Moriishi, 2010 [8]	Japan	Single-center retrospective	76	4.1(mean)	N/A	Retention of peritoneal function
Tanaka, 2011 [34]	Japan	Single-center retrospective	14	3.8 (mean)	9	Left ventricular mass index
Suzuki, 2012 [14]	Japan	Single-center retrospective	10	Within 1 year	72 (Max)	Early start of PDHD prolonged the duration of PD
Maruyama, 2014 [7]	Japan	Multicenter retrospective	104	4.0 ± 3.5	3	Improve overhydration and inadequate dialysis
Kanda, 2017 [10]	Japan	Single-center prospective	30	3.2 ± 1.8	18	D/PCr in long-term, left ventricular mass index
Ueda, 2017 [35]	Japan	Single-center retrospective	13	0 at initiation	30	Preserving both RRF and serum albumin
Banshodani, 2019 [36]	Japan	Single-center retrospective	93 LEF ($n=29$) NEF($n=64$)	LEF:3.6 ± 3.3 NEF:4.5 ± 3.2	36	Hospitalization rate for acute cardiovascular events
Abe, 2019 [37]	Japan	Multicenter prospective	1679	N/A	24	Mortality and cardiovascular events
Tanaka, 2020 [12]	Japan	Multicenter prospective	46	5.8 ± 3.1	46	Dialysis access–related complications
Chung, 2020 [21]	Taiwan	Multicenter retrospective	688	2.5 ± 2.1	2.1 ± 2.0	Cost-effective
Maruyama, 2021 [11]	Japan	Multicenter prospective	47	2.4 (1.4–3.6)	41 (mean)	Survival
Murashima, 2021 [22]	Japan	Multicenter retrospective	608	2.1 (1.0–4.1)	30 (median)	Mortality
Maruyama, 2021 [38]	Japan	Multicenter retrospective	26	4.9	N/A	Fatigue measured by the POMS, VAS
Kawanishi, 2021 [39]	Japan	Multicenter prospective	79	N/A	20 (median)	Mortality, hospitalization
Ueda, 2021 [40]	Japan	Single-center retrospective	4	0 at initiation	24 (mean)	Peritoneal permeability after the short-term peritoneal rest

PD peritoneal dialysis, *N/A* not applicable, *AVF* arteriovenous fistula, *RRF* residual renal function, *POMS* profile of mood states, *VAS* visual analog scale

Table 2 Plasma β_2-microglobulin (MG) levels before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before β_2-MG (mg/L)	After β_2-MG (mg/L)	
Kawanishi, 2006 [32]	35.8 ± 14.3	33.2 ± 7.9	↓
Matsuo, 2010 [6]	35.9 ± 7.5	33.1 ± 7.9	↓
Maruyama, 2014 [7]	34.4 ± 7.2	33.7 ± 7.0	→
Kanda, 2017 [10]	31.9 ± 6.5	31.7 ± 6.9	→
Maruyama, 2021 [11]	29.1 ± 8.2	32.0 ± 7.6	↑

MG microglobulin

uremic toxins, is elevated when combPDHD is initiated. The ISPD or JSDT guidelines do not state an optimal range for β_2-MG; however, higher values are believed to be associated with poorer outcomes. Yokoyama et al. [20] reported that a higher β_2-MG level was an independent risk factor for EPS, which is the most serious complication of PD. Several studies have reported about the D/PCr status at the beginning of combPDHD, which is obtained using the peritoneal equilibration test (Table 5). Increased D/PCr indicates a deterioration in peritoneal function and is an independent risk factor for EPS. Therefore, the JSDT guidelines [19] recommend monitoring of D/PCr and considering cessation of PD if D/PCr is elevated. There was no clinical evidence regarding the deterioration of peritoneal function at the beginning of combPDHD. The observation period ranged from 3 to 72 months; however, the changes in the clinical parameters were similar for all these studies. The patients' body weight (Table 6) and blood pressure (BP) (Table 7) decreased, suggesting an improvement in the fluid overload status. There was also a decrease in creatinine levels (Table 8), indicating an improvement in the adequacy of dialysis. Hb levels increased after initiating combPDHD (Table 9), for which there are two possible explanations. First, dilutional anemia may have improved because of the reduction in excess body fluid, as reflected by the decreased body weight and BP. Second, the improved removal of solutes may have enhanced the response to an erythropoiesis-stimulating agent (ESA). The JSDT guidelines [19] state that a poor response to an ESA for anemia could reflect inadequate dialysis, even if the target solute clearance is achieved. The details of the mechanism involved are unclear; however, the removal of uremic toxins, resolution of peritoneal edema, and peritoneal rest, including the HD treatment time, may improve the function of the peritoneal membrane. Correction of both inadequate dialysis and fluid overload by switching

Table 3 Urine volume before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before urine volume (ml/day)	After urine volume (ml/day)	
Kawanishi, 2006 [32]	438 ± 225 Excludes patients with urine volume ≤ 100 mL/24 h	60 ± 82 Excludes patients with urine volume ≤ 100 mL/24 h	↓
Matsuo, 2010 [6]	253 ± 405	123 ± 331	↓
Tanaka, 2011 [34]	200 (0–900)	150 (0–600)	→
Maruyama, 2014 [7]	150 (0–2000)	75(0–1900)	↓
Kanda, 2017 [10]	0	0	→
Maruyama, 2021 [11]	840 (240–1100)	100 (10–200)	↓
Ueda, 2021 [40]	N/A	N/A	→

N/A not applicable

Table 4 Total weekly K_t/V ratio before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before Kt/V PD	After K_t/V PD + HD	(After K_t/V PD)
Kawanishi, 1999 [27]	1.61	2.06	1.27
Hashimoto, 2000 [28]	1.98 ± 0.28	N/A	N/A
Kawanishi, 2002 [3]	1.64 ± 0.22	2.22 ± 0.25	N/A
Agarwal, 2003 [30]	1.73 ± 0.23	1.67 ± 0.36	1.49 ± 0.32
McIntyre, 2004 [31]	1.00 ± 0.13	2.5 ± 0.14	1.0 ± 0.14
Kawanishi, 2006 [32]	1.86 ± 0.52	2.21 ± 0.25	N/A
Kawanishi, 2007[5]	1.68	2.15	0.8
Tanaka, 2011 [34]	2.20 ± 0.40	N/A	N/A
Maruyama, 2014 [7]	1.80 ± 0.40	N/A	N/A

N/A not applicable

Table 5 Peritoneal equilibration test before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before D/PCr	After D/PCr	
McIntyre, 2004 [31]	N/A	N/A	→
Kawanishi, 2006 [32]	N/A	N/A	→
Matsuo, 2010 [6]	0.65 ± 0.11	0.59 ± 0.13	↓
Maruyama, 2014 [7]	0.67 ± 0.11	0.61 ± 0.13	↓
Kanda, 2017 [10]	0.67 ± 0.09	0.62 ± 0.1	↓ after 18 month ↑
Ueda, 2017 [35]	N/A	N/A	→
Ueda, 2021 [40]	N/A	N/A	→

D/PCr dialysate-to-plasma ratio of creatinine, *N/A* not applicable

Table 6 Body weight before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before BW (kg)	After BW	
McIntyre, 2004 [31]	69.2 ± 5.5	70.4 ± 5.8	→
Kawanishi, 2006 [32]	59.7 ± 10.0	58.0 ± 10.4	↓
Matsuo, 2010 [6]	62.3 ± 11.3	61.1 ± 12.9	↓
Tanaka, 2011 [34]	61.8 ± 7.6	57.8 ± 7.4	↓
Maruyama, 2014 [7]	64.5 ± 14.8	63.4 ± 14.2	↓
Kanda, 2017 [10]	66.3 ± 9.7	62.5 ± 9.0	↓

BW body weight

Table 7 Systolic blood pressure before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before sBP (mmHg)	After sBP	
Kawanishi, 2006 [32]	152 ± 25	139 ± 18	↓
Hoshi, 2006 [33]	141 ± 5	132 ± 5	↓
Matsuo, 2010 [6]	145 ± 22	138 ± 17	↓
Tanaka, 2011 [34]	156 ± 17	139 ± 15	→
Suzuki, 2012 [14]	140.8	132.1	↓
Maruyama, 2014 [7]	144 ± 22	143 ± 20	↓
Kanda, 2017 [10]	153 ± 21	145 ± 21	↓
Maruyama, 2021 [11]	144 ± 16	134 ± 19	↓

sBP systolic blood pressure, *N/A* not applicable

Table 8 Creatinine levels before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before Cr	After Cr	
Kanno, 2003 [29]	N/A	N/A	↓
Kawanishi, 2006 [32]	13.1	12.2	→
Hoshi, 2006 [33]	N/A	N/A	→
Matsuo, 2010 [6]	13.5	12.7	↓
Tanaka, 2011 [34]	12.2	11.1	↓
Maruyama, 2014 [7]	12.9	2.3	↓
Kanda, 2017 [10]	14.2	13.6	↓
Maruyama, 2021 [11]	13.3	13.8	→
Ueda, 2021 [40]	N/A	N/A	→

Cr creatinine, *N/A* not applicable

Table 9 Hemoglobin levels before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before Hb	After Hb	
McIntyre, 2004 [31]	11.3	11.4	→
Hoshi, 2006 [33]	7.7	8.7	↑
Matsuo, 2010 [6]	8.2	10.7	↑
Tanaka, 2011 [34]	8.7	10.8	↑
Suzuki, 2012 [14]	7.7	8.7	↑
Maruyama, 2014 [7]	8.7	10.3	↑
Kanda, 2017 [10]	9.4	10.9	↑
Maruyama, 2021 [11]	10.3	11.2	↑
Ueda, 2021 [40]	N/A	N/A	→

Hb hemoglobin, *N/A* not applicable

Table 10 Left ventricular mass index levels before and after combined therapy with peritoneal dialysis and hemodialysis

First author, year [Ref.]	Before LVMI	After LVMI	
McIntyre, 2004 [31]	194 ± 31	156 ± 21	↓
Tanaka, 2011 [34]	140 ± 31	117 ± 28	↓
Kanda, 2017 [10]	181 ± 71	156 ± 56	↓after 18 month 173 ± 65 ↑
Banshodani, 2019 [36]	189 ± 41	164 ± 47	↓

LVMI left ventricular mass index

to combPDHD could help prevent cardiovascular disease (CVD) and lower the mortality risk in PD patients. LVMI levels were reported in several studies (Table 10). High BP is a strong risk factor for CVD and is observed to decline after switching to combPDHD.

Recent reports on combined PDHD

The management of PD becomes more challenging as RKF declines and peritoneal function deteriorates. Subsequently, inadequate dialysis and/or fluid overload becomes clinically evident. Several guidelines recommend that optimal small-solute clearance, indicated as a K_t/V ratio of > 1.7, and euvolemia should be maintained by monitoring both urine volume and the amount of ultrafiltration achieved [18, 19]. Several reports have demonstrated the clinical utility of combPDHD for the correction of inadequate dialysis and/or fluid overload. However, previous studies assessing patients starting combPDHD compared several clinical parameters before

and after switching to combPDHD. The primary objective of our prospective multicenter observational cohort study was to compare patient hospitalization, mortality, and various clinical parameters between patients who switched from PD monotherapy to combined therapy and those who switched directly to HD (see Table 1).

In a single-center prospective study, Kanda et al. [10] reported that the levels of LVMI (measured using echocardiography) and human atrial natriuretic peptide at 6 months after therapy initiation were significantly lower than those at the start of combPDHD. Moreover, D/PCr levels at 6 months after combined therapy were significantly lower than those at the initiation of combPDHD. Additionally, D/PCr levels at 12 or 18 months after combPDHD were not elevated.

Tanaka et al. [12] reported that the risk of hospitalization was not significantly different between combPDHD and HD alone, although combPDHD patients had a higher risk of dialysis access-related complications than patients receiving HD alone. Because combPDHD requires both a PD catheter and vascular access (VA), combPDHD patients potentially have an increased risk of dialysis access-related complications. Indeed, the hospitalization rate for the sum of PD-related infections and VA complications in combPDHD was threefold than in HD patients.

In a large, multicenter, and retrospective study from Taiwan, Chung et al. [21] reported that combPDHD (two HD sessions per month) is not redundant but a rational and cost-effective treatment, particularly for patients without recent peritonitis. Dialysis staff should therefore be familiar with the advantages and disadvantages of combPDHD, and consider it an essential part of integrated dialysis care. The Taiwanese National Health Insurance (TNHI) system provides services for HD and PD, including the use of icodextrin, nutrineal, and automated PD. The TNHI system has also expanded coverage to combPDHD, but only if the symptoms of uremia and fluid overload cannot be ameliorated by maximizing PD prescription. Patients undergoing PD can decide whether to switch to HD directly or receive combPDHD. Murashima et al. [22] reported that combPDHD was associated with lower all-cause, cardiovascular, and heart failure-related mortalities, but an earlier transition to HD than PD alone might have improved fluid removal. This study aimed to compare the outcomes of combPDHD and PD alone using the Japanese Renal Data Registry database, which is a nationwide cohort of dialysis patients in Japan.

In a multicenter, prospective study, Maruyama et al. [11] first reported the clinical outcomes for patients on PD alone transferred to combPDHD with those for patients directly transferred to HD. No significant differences were observed in the survival outcomes between the two groups. Comparison of patient survival was difficult because of the small number of deaths; however, PD patients with inadequate dialysis and/or volume overload could continue PD therapy safely by switching to combPDHD.

The main limitation of the studies [11, 12, 21, 22] included in this review must be considered. These studies did not evaluate the efficacy of dialysis. The JSDT guidelines [19] recommend that the adequacy of dialysis should be determined using the concept of body fluid clear space in combined therapy [19, 22]; however, established methods to assess the efficacy of combPDHD are lacking. K_t/V ratio was used for the assessment of dialysis adequacy in both PD and HD patients; however, the definitions of these two treatments are completely different [23].

How long can we continue with combPDHD in the future?

It was previously reported that the mean duration of PD was 120.5 ± 42.8 months, and the mean observation period was 211.5 ± 70.1 months in patients with EPS [24]. No significant differences in PD duration, utilization of acidic peritoneal dialysis solution, combPDHD status, combPDHD duration, observation period, and age at death were observed between the EPS and non-EPS groups [24]. Recently, a laparoscopic examination has been used to help diagnose peritoneal degeneration because it facilitates easy observation of the characteristic gross thickening of the peritoneum and increased vascularity of the visceral peritoneal surface [25]. Furthermore, previous studies involving patients with combPDHD have reported on laparoscopic procedures for evaluating angiogenesis, color changes, and plaques in the peritoneum [26]. In each case, there was a difference in abdominal wall degeneration depending on the intra-abdominal cavity. Particularly in the lower abdomen, there was a tendency for stronger degeneration to be more pronounced. Furthermore, there were cases in which no change in the abdominal wall degeneration occurred. Therefore, the timing of PD withdrawal needs to be examined on an individual basis; thus far, there is no clear determining marker. The limitations of the studies included in this review must also be considered. Some degree of selection bias could not be avoided because of the timing of changing modality, and the selection of a new modality type; particularly regarding combPDHD or HD alone selections were at the discretion of the treating physicians.

Conclusions

CombPDHD should be used in PD patients with the fluid overload that is attributable to ultrafiltration failure, poor self-management of fluid balance, and severe heart failure. A previous study revealed that combPDHD might be useful for the long-term maintenance of the peritoneal membrane and cardiac function. However, a high level of plasma β_2-MG with long-term combPDHD can impact patient prognosis. Therefore, we conclude that in cases of declining RKF or when self-management of fluid balance is poor, combPDHD should be initiated to adjust the body fluid status, with a sufficient dialysis dose and peritoneal rest. Further studies are required to evaluate the peritoneal function and determine when PD therapy should be discontinued. Conclusively, combPDHD is useful from a lifestyle perspective for patients during the transition from PD to HD; however, at present, it should not be continued indefinitely.

Abbreviations

CombPDHD: Combined therapy with peritoneal dialysis and hemodialysis; HD: Hemodialysis; PD: Peritoneal dialysis; RKF: Residual kidney function; EPS: Encapsulating peritoneal sclerosis; VA: Vascular access; LVMI: Left ventricular mass index; D/PCr: Dialysate-to-plasma ratio of creatinine; MG: Microglobulin; ISPD: International Society for Peritoneal Dialysis; JSDT: Japanese Society for Dialysis Therapy; BP: Blood pressure; Hb: Hemoglobin; ESA: Erythropoiesis-stimulating agent; CVD: Cardiovascular disease; TNHI: Taiwanese National Health Insurance.

Acknowledgements

We are indebted to the nephrologists and patients at Juntendo University Hospital for their collaboration in our study. We would like to thank Editage (www.editage.com) for English language editing.

Author contributions

HIo compiled the review article; TK, HI, MI, MM, YS, TM, HF, and YS contributed to data acquisition; HIo, JN, and KT contributed to data analysis and interpretation. HI, JN, and YS were the research directors. Each author substantially contributed to important manuscript intellectual content provision during drafting or revision and accepts accountability for the overall work by ensuring that questions pertaining to the accuracy or integrity of any portion of the work are appropriately investigated and resolved. All authors read and approved the final manuscript.

Funding

None.

Availability of data and materials

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Department of Nephrology, Juntendo University Nerima Hospital, Takanodai 3-1-10, Nerima-ku, Tokyo 177-8521, Japan. [2]Department of Nephrology, Faculty of Medicine, Juntendo University, Tokyo, Japan.

Received: 30 March 2022 Accepted: 5 August 2022
Published online: 19 August 2022

References

1. Churchill DN, Thorpe KE, Nolph KD, Keshaviah PR, Oreopoulos DG, Pagé D. Increased peritoneal membrane transport is associated with decreased patient and technique survival for continuous peritoneal dialysis patients. The Canada–USA (CANUSA) peritoneal dialysis study group. J Am Soc Nephrol. 1998;9:1285–92. https://doi.org/10.1681/ASN.V971285.
2. Fukui H, Hara S, Hashimoto Y, Horiuchi T, Ikezoe M, Itami N, et al. Review of combination of peritoneal dialysis and hemodialysis as a modality of treatment for end-stage renal disease. Ther Apher Dial. 2004;8:56–61. https://doi.org/10.1111/j.1526-0968.2004.00107.x.
3. Kawanishi H, Moriishi M, Tsuchiya S. Five years' experience of combination therapy: peritoneal dialysis with hemodialysis. Adv Perit Dial. 2002;18:62–7.
4. Nitta K, Abe Masanori, Masakane I, Hanafusa N, Taniguchi M, Hasegawa T, et al. An overview of regular dialysis treatment in Japan. Annual dialysis data report 2018. Ren Replace Ther. 2020;6:1–16. https://doi.org/10.1186/s41100-020-00290-z.
5. Kawanishi H, Moriishi M. Clinical effects of combined therapy with peritoneal dialysis and hemodialysis. Perit Dial Int. 2007;27(Suppl 2):S126–9. https://doi.org/10.1177/089686080702702s21.
6. Matsuo N, Yokoyama K, Maruyama Y, Ueda Y, Yoshida H, Tanno Y, et al. Clinical impact of a combined therapy of peritoneal dialysis and hemodialysis. Clin Nephrol. 2010;74:209–16. https://doi.org/10.5414/cnp74209.
7. Maruyama Y, Yokoyama K, Nakayama M, Higuchi C, Sanaka T, Tanaka Y, et al. Combined therapy with peritoneal dialysis and hemodialysis: a multicenter retrospective observational cohort study in Japan. Blood Purif. 2014;38:149–53. https://doi.org/10.1159/000368389.
8. Moriishi M, Kawanishi H, Tsuchiya S. Impact of combination therapy with peritoneal dialysis and hemodialysis on peritoneal function. Adv Perit Dial. 2010;26:67–70.
9. Kawanishi H, Kawaguchi Y, Fukui H, Hara S, Imada A, Kubo H, et al. Encapsulating peritoneal sclerosis in Japan: a prospective, controlled, multicenter study. Am J Kidney Dis. 2004;44:729–37. https://doi.org/10.1016/S0272-6386(04)00953-9.
10. Kanda R, Io H, Nakata J, Makita Y, Sasaki Y, Matsumoto M, et al. Evaluation of long-term combination therapy with peritoneal dialysis and hemodialysis. Ther Apher Dial. 2017;21:180–4. https://doi.org/10.1111/1744-9987.12517.
11. Maruyama Y, Yokoyama K, Higuchi C, Sanaka T, Tanaka Y, Sekai K, et al. Comparisons of clinical outcomes in patients transferred to combined therapy with peritoneal dialysis and hemodialysis over those directly transferred to hemodialysis: A prospective multicenter study in Japan. Res Sq. 2021;1:1–10.
12. Tanaka M, Ishibashi Y, Hamasaki Y, Kamijo Y, Idei M, Kawahara T, et al. Hospitalization for patients on combination therapy with peritoneal dialysis and hemodialysis compared with hemodialysis. Kidney Int Rep. 2020;5:468–74. https://doi.org/10.1016/j.ekir.2020.01.004.
13. Io H, Ro Y, Sekiguchi Y, Shimaoka T, Inuma J, Hotta Y, et al. Cardiac function and structure in longitudinal analysis of echocardiography in peritoneal dialysis patients. Perit Dial Int. 2010;30:353–61. https://doi.org/10.3747/pdi.2009.00007.
14. Suzuki H, Hoshi H, Inoue T, Kikuta T, Tsuda M, Takenaka T. Combination therapy with hemodialysis and peritoneal dialysis. Contrib Nephrol. 2012;177:71–83. https://doi.org/10.1159/000336938.
15. Williams JD, Craig KJ, Topley N, Von Ruhland C, Fallon M, Newman GR, et al. Morphologic changes in the peritoneal membrane of patients with renal disease. J Am Soc Nephrol. 2002;13:470–9. https://doi.org/10.1681/ASN.V132470.
16. Cheung AK, Rocco MV, Yan G, Leypoldt JK, Levin NW, Greene T, et al. Serum beta-2 microglobulin levels predict mortality in dialysis patients:

results of the HEMO study. J Am Soc Nephrol. 2006;17:546–55. https://doi.org/10.1681/ASN.2005020132.
17. Nakamoto H, Hamada C, Shimaoka T, Sekiguchi Y, Io H, Kaneko K, et al. Accumulation of advanced glycation end products and beta 2-microglobulin in fibrotic thickening of the peritoneum in long-term peritoneal dialysis patients. J Artif Organs. 2014;17:60–8. https://doi.org/10.1007/s10047-013-0741-1.
18. Lo WK, Bargman JM, Burkart J, Krediet RT, Pollock C, Kawanishi H, et al. Guideline on targets for solute and fluid removal in adult patients on chronic peritoneal dialysis. Perit Dial Int. 2006;26:520–2. https://doi.org/10.1177/089686080602600502.
19. Working group committee for preparation of guidelines for peritoneal dialysis, Japanese Society for Dialysis Therapy. Ther Apher Dial. 2009 Japanese society for dialysis therapy guidelines for peritoneal dialysis. Japn Soc Dial Ther. 2010;14:489–504. https://doi.org/10.1111/j.1744-9987.2010.00901.x.
20. Yokoyama K, Yoshida H, Matsuo N, Maruyama Y, Kawamura Y, Yamamoto R, et al. Serum beta2 microglobulin (beta2MG) level is a potential predictor for encapsulating peritoneal sclerosis (EPS) in peritoneal dialysis patients. Clin Nephrol. 2008;69:121–6. https://doi.org/10.5414/cnp69121.
21. Chung MC, Yu TM, Wu MJ, Chuang YW, Muo CH, Chen CH, et al. Is combined peritoneal dialysis and hemodialysis redundant? A nationwide study from Taiwan. BMC Nephrol. 2020;21:348. https://doi.org/10.1186/s12882-020-01989-1.
22. Murashima M, Hamano T, Abe M, Masakane I. Combination of once-weekly haemodialysis with peritoneal dialysis is associated with lower mortality compared with peritoneal dialysis alone: a longitudinal study. Clin Kidney J. 2021;14:1610–7. https://doi.org/10.1093/ckj/sfaa173.
23. Yamashita AC. A kinetic model for peritoneal dialysis and its application for complementary dialysis therapy. Contrib Nephrol. 2012;177:3–12. https://doi.org/10.1159/000336927.
24. Yamahatsu A, Hamada C, Kaneko K, Io H, Nakata J, Tomino Y. Long-term outcome of encapsulating peritoneal sclerosis (EPS) patients in a single center. Clin Exp Nephrol. 2015;19:961–7. https://doi.org/10.1007/s10157-015-1081-7.
25. Io H, Hara K, Nakata J, Sakamoto K, Tomino Y. Laparoscope is a useful tool for reducing and drawing off a peritoneal dialysis catheter in peritoneal dialysis patients. Kidney Int Rep. 2016;1:93. https://doi.org/10.1016/j.ekir.2016.06.001.
26. Hara K, Io H, Wakabayashi K, Maeda T, Kanda R, Nakata J, et al. Multicenter laparoscopic evaluation of the peritoneum in peritoneal dialysis patients. Semin Dial. 2020;33:170–7. https://doi.org/10.1111/sdi.12870.
27. Kawanishi H, Moriishi M, Katsutani S, Sakikubo E, Tsuchiya S. Hemodialysis together with peritoneal dialysis is one of the simplest ways to maintain adequacy in continuous ambulatory peritoneal dialysis. Adv Perit Dial. 1999;15:127–31.
28. Hashimoto Y, Matsubara T. Combined peritoneal dialysis and hemodialysis therapy improves quality of life in end-stage renal disease patients. Adv Perit Dial. 2000;16:108–12.
29. Kanno Y, Suzuki H, Nakamoto H, Okada H, Sugahara S. Once-weekly hemodialysis helps continuous ambulatory peritoneal dialysis patients who have insufficient solute removal. Adv Perit Dial. 2003;19:143–7.
30. Agarwal M, Clinard P, Burkart JM. Combined peritoneal dialysis and hemodialysis: our experience compared to others. Perit Dial Int. 2003;23:157–61. https://doi.org/10.1177/089686080302300211.
31. McIntyre CW. Bimodal dialysis: an integrated approach to renal replacement therapy. Perit Dial Int. 2004;24:547–53. https://doi.org/10.1177/089686080402400614.
32. Kawanishi H, Hashimoto Y, Nakamoto H, Nakayama M, Tranaeus A. Combination therapy with peritoneal dialysis and hemodialysis. Perit Dial Int. 2006;26:150–4. https://doi.org/10.1177/089686080602600205.
33. Hoshi H, Nakamoto H, Kanno Y, Takane H, Ikeda N, Sugahara S, et al. Long-term follow-up of patients treated with a combination of continuous ambulatory peritoneal dialysis and hemodialysis. Adv Perit Dial. 2006;22:136–40.
34. Tanaka M, Mise N, Nakajima H, Uchida L, Ishimoto Y, Kotera N, et al. Effects of combination therapy with peritoneal dialysis and hemodialysis on left ventricular hypertrophy. Perit Dial Int. 2011;31:598–600. https://doi.org/10.3747/pdi.2010.00273.
35. Ueda A, Nagai K, Hirayama A, Saito C, Yamagata K. Combination therapy with peritoneal dialysis and hemodialysis from the initiation of renal replacement therapy preserves residual renal function and serum albumin. Adv Perit Dial. 2017;33:74–8.
36. Banshodani M, Kawanishi H, Moriishi M, Shintaku S, Tsuchiya S. Impact of hybrid therapy comprising peritoneal dialysis and hemodialysis on acute cardiovascular events. Blood Purif. 2019;47:330–6. https://doi.org/10.1159/000495357.
37. Abe M, Hamano T, Hoshino J, Wada A, Nakai S, Hanafusa N, et al. Predictors of outcomes in patients on peritoneal dialysis: a 2-year nationwide cohort study [Sci. rep.:3967]. Sci Rep. 2019;9:3967. https://doi.org/10.1038/s41598-019-40692-6.
38. Maruyama Y, Nakayama M, Ueda A, Miyazaki M, Yokoo T. Comparisons of fatigue between dialysis modalities: a cross-sectional study. PLoS ONE. 2021;16:e0246890. https://doi.org/10.1371/journal.pone.0246890.
39. Kawanishi H, Marshall MR, Zhao J, McCullough K, Robinson B, Pisoni RL, et al. Mortality, hospitalization and transfer to haemodialysis and hybrid therapy, in Japanese peritoneal dialysis patients. Pert Dial Int. 2022;42:305–13. https://doi.org/10.1177/08968608211016127.
40. Ueda A, Nagai K, Yamagata K. Preserved peritoneal function by short-term 2-day peritoneal rest in hemodialysis combination therapy patients. J Artif Organs. 2021;24:296–300. https://doi.org/10.1007/s10047-020-01215-7.

Publisher's Note