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Effects of Ultrafiltration on Body Fluid Volumes and Transcapillary Colloid Osmotic Gradient in Hemodialysis Patients

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Intermittent fluid overload and the need for rapid fluid removal during dialysis frequently creates clinical complications in patients on maintenance hemodialysis. Alterations in the partition of volumes between the intravascular and the interstitial spaces are reported in chronic renal failure [1–3], and plasma volume depletion is an important factor in the pathogenesis of symptomatic hypotension during dialysis [4, 5]. Ultrafiltration implies a continuous shift of fluid between the interstitial and the intravascular compartments. The main force recruiting fluid into the vascular space during ultrafiltration is increase in plasma colloid osmotic pressure [6, 7].

The aim of these studies was to examine the effects of ultrafiltration on body fluid volumes and transcapillary colloid osmotic gradient in patients on maintenance hemodialysis. In addition, the changes in plasma volume, plasma colloid osmotic pressure and plasma refilling rate during isolated ultrafiltration was studied in patients with chronic renal failure and compared to patients with diuretic-resistant edema due to nephrotic syndrome or heart failure.

Material and Methods

Nine patients (2 females and 7 males, mean age 65.6 years, range 61–70 years) with chronic renal failure on a maintenance hemodialysis were studied [8] and compared to 6 patients with diuretic-resistant edema due to nephrotic syndrome [9] and 6 patients with therapy-resistant edema due to congestive heart failure [10].

On day 1 measurements of plasma and extracellular fluid volumes as well as measurements of plasma and interstitial fluid colloid osmotic pressure were performed. On days 2 and 3 ultrafiltration was performed in order to bring the patient as near to dry weight as possible, and was followed by hemodialysis without transmembrane pressure for 2 h. The measurements performed on day 1 were then repeated on day 4 in exactly the same manner.

Table 1. Colloid osmotic pressure and body fluid volumes in patients on maintenance hemodialysis and in normal subjects

	Predialysis state	Dry-weight state	Normal subjects
Plasma colloid osmotic pressure, mm Hg	28.0 ± 4.2	33.3 ± 5.5**	28.6 ± 3.4
Interstitial colloid osmotic pressure, mm Hg	12.7 ± 3.5*	16.1 ± 3.9**	15.8 ± 2.7
Transcapillary colloid osmotic gradient, mm Hg	15.3 ± 3.0*	17.2 ± 4.1*	12.8 ± 2.7
LBM, kg	52.5 ± 6.8	51.3 ± 6.6	51.3 ± 8.3
Plasma volume, ml/kg LBM	73.0 ± 10.6**	59.7 ± 11.6**	58.3 ± 5.2
Blood volume, ml/kg LBM	93.0 ± 15.1	78.5 ± 14.7**	82.7 ± 6.5
Interstitial fluid volume, ml/kg LBM	220.0 ± 54.9*	178.0 ± 43.3**	166.1 ± 20.1

* $p < 0.05$, ** $p < 0.01$ (comparisons between values in predialysis state and normal subjects and between values in the dry-weight and predialysis states). Mean values ± SD.

During ultrafiltration blood samples were collected from the arterial blood line at the start and after 30, 60 and 120 min, and at the end of ultrafiltration for measurements of plasma colloid osmotic pressure and hematocrit. The patients with nephrotic syndrome and heart failure were investigated and treated in exactly the same manner except for the sessions with hemodialysis.

Colloid osmotic pressure was measured using a colloid osmometer made for 5 μl samples [11]. Subcutaneous interstitial fluid was collected by the wick technique from nonedematous tissue on the side of the thorax [8]. Plasma volume was determined as the initial ^{125}I-albumin space [12] and extracellular fluid volume was measured as the radiosulfate space [12]. Blood volume was calculated from plasma volume and hematocrit using a F cell ratio of 84% in normal subjects and 81% in the dialysis patients. Values are given as ml/kg lean body mass (LBM) [13].

The plasma refilling rate was calculated as previous described [8].

Statistical methods: Wilcoxon's test for two independent samples and for paired observations were used. Correlations were calculated by the least squares linear regression analysis. Results are expressed as mean ± SD.

Results

Colloid Osmotic Pressures

Plasma colloid osmotic pressure (pII) in the dialysis patients on day 1 (predialysis state) was not different from normal subjects (table 1) and it increased significantly from day 1 to day 4 (from predialysis to dry-weight state). In the predialysis state interstitial colloid osmotic pressure (iII) was decreased by approximately 3 mm Hg (table 1) and increased significantly

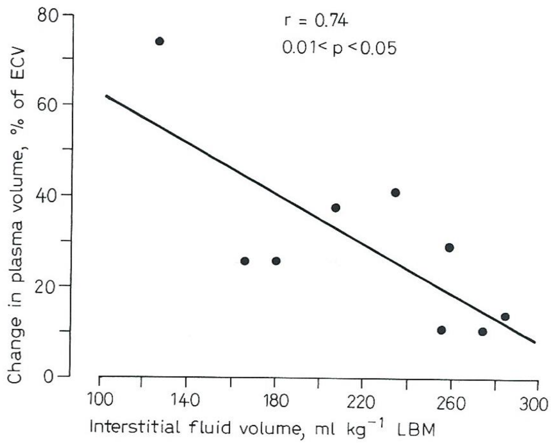

Fig. 1. Change in plasma volume from the predialysis to the dry-weight state expressed as reduction in plasma volume in percent of reduction of extracellular fluid volume (ECV) correlated to interstitial fluid volume in the predialysis state.

to the dry-weight state. In the dry-weight state it was not significantly different from normal subjects. The transcapillary colloid osmotic gradient (pII–iII) was increased in the predialysis state by 2.5 mm Hg compared to normal subjects and increased further after ultrafiltration (table 1).

Body Fluid Volumes

In the predialysis state plasma volume (PV), but not blood volume (BV), was increased compared to normal subjects (table 1) and both PV and BV decreased significantly from the predialysis to the dry-weight state. Interstitial fluid volume (IFV) was increased in the predialysis state and decreased significantly to the dry-weight state (table 1). In the dry-weight state PV, BV and IFV were not significantly different from values in normal subjects. There was a negative correlation between the reduction in PV from the predialysis to the dry-weight state (reduction of PV in percent of change in extracellular fluid volume) and IFV in the predialysis state ($r = 0.74$, $p < 0.05$) (fig. 1).

Ultrafiltration Data

In table 2 the results from the ultrafiltration sessions are given. The increase in pII was significantly less in the patients with nephrotic syndrome compared to renal failure ($p < 0.01$) and heart failure ($p < 0.01$). The ratio of plasma refilling rate (PRR) to increase in pII during ultrafiltration was much higher in the nephrotic syndrome compared to renal failure ($p < 0.01$) and heart failure ($p < 0.01$). The ratio was significantly higher in

Table 2. Ultrafiltration data for the three patient groups: mean values ± SD

	Renal failure	Nephrotic syndrome	Heart failure
Number of ultrafiltration sessions	18	12	12
Ultrafiltrate volume, ml per session	2,657 ± 783	3,730 ± 800	3,875 ± 441
Ultrafiltration rate, ml/min	21.9 ± 1.9	21.8 ± 4.3	17.4 ± 1.9
PRR, ml/min	16.5 ± 2.7	19.9 ± 4.8	12.7 ± 1.8
Increase in pII during ultrafiltration, mm Hg	9.9 ± 4.6	3.1 ± 1.9	13.2 ± 6.9
Ratio of PRR to change in pII, ml/min/mm Hg	2.3 ± 1.3	9.6 ± 5.4	1.3 ± 0.9

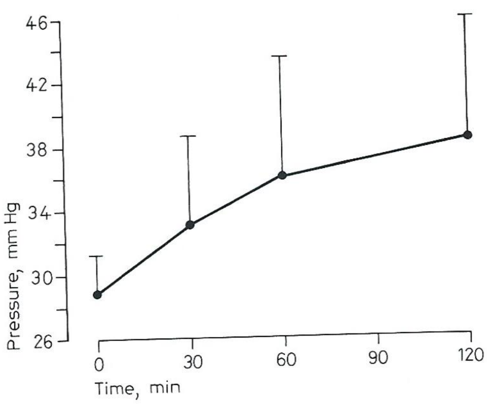

Fig. 2. Plasma colloid osmotic pressure during ultrafiltration (n = 18). Mean values with indication of SD.

renal failure compared to heart failure ($p < 0.05$). The increase in pII was rapid during the first hour of ultrafiltration and was nearly stable during the second hour (fig. 2), indicating nearly steady state between ultrafiltration rate (UFR) and PRR.

Discussion

The changes in the transcapillary colloid osmotic gradient and the body fluid volumes indicate that the predialysis state is characterized by fluid retention with increased IFV, reduced interstitial colloid osmotic pressure due to dilution [8] and increased transcapillary colloid osmotic gradient. In the dry-weight state IFV is normal, PV and BV reduced, and the gradient is still higher. The changes in the transcapillary gradient tend to limit the increase in IFV and to preserve BV, but activation of these edema-preventing and blood volume-preserving factors was not sufficient to normalize the transcapillary fluid balance either in predialysis or in the dry-weight state.

During ultrafiltration the degree of hypovolemia is determined by the difference between UFR and PRR. PRR is low during the first part of ultrafiltration until the reduction in PV leads to an increase in pII sufficient to result in nearly steady state between UFR and PRR after 60–120 min with the UFR used in these experiments. Rodriguez et al. [6] have shown that the increase in pII is equal during isolated ultrafiltration and hemodialysis with the same rate of fluid removal, indicating that also during hemodialysis increase in pII is the main force recruiting fluid from the interstitial space. The great difference between the three patient groups regarding the increase in pII during ultrafiltration and especially in the ratio of PRR to change in pII must be due to differences between the groups in the Starling forces determining the transcapillary fluid transport. The relatively small changes in the interstitial colloid osmotic pressure are in the same direction in all groups [12, 14]. Capillary hydrostatic pressure is highest in heart failure and the decrease during ultrafiltration is probably of smaller magnitude in the patients with renal failure and nephrotic syndrome. Thus, differences between the groups in the change of capillary hydrostatic pressure cannot explain the findings. Change in the interstitial hydrostatic pressure during ultrafiltration (tissue compliance) may be greater in patients near normovolemia [15], explaining the difference between the less overhydrated hemodialysis patients compared to the patients with nephrotic edema. This is supported by the negative correlation between the reduction in PV and the degree of fluid retention (fig. 1). Changes in the capillary filtration coefficient are probably an important factor explaining the difference between the patients with heart failure and the two other groups. In heart failure the capillary surface area, which is an important factor in the filtration coefficient, is reduced due to vasoconstriction.

Fluid removal by ultrafiltration leads to substantial reduction in PV. The tendency to hypovolemia is of greatest magnitude in hemodialysis patients near normovolemia and in patients with heart failure.

References

1 Bauer JH, Brooks CS: Body fluid composition in chronic renal failure. Clin Nephrol 1981;16:114–118.

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. Clin Nephrol

2 Mitch WE, Wilcox CS: Disorders of body fluids, sodium and potassium in chronic renal failure. Am J Med 1982;72:536–550.

3 Omvik P, Tarazi RC, Bravo EL: Determination of extracellular fluid volume in uremic patients by oral administration of radiosulfate. Kidney Int 1979;15:71–79.

4 Henderson LW: Symptomatic hypotension during hemodialysis. Kidney Int 1980;17:571–576.

5 Kinet JP, Soyeur D, Balland N, et al: Hemodynamic study of hypotension during hemodialysis. Kidney Int 1982;21:868–876.

6 Rodriguez M, Llach F, Pederson JA, et al: Changes in plasma oncotic pressure during isolated ultrafiltration. Kidney Int 1981;21:519–523.

7 Rouby JJ, Rottembourg J, Durande JP, et al: Importance of the plasma refilling rate in the genesis of hypovolaemic hypotension during regular dialysis and controlled sequential ultrafiltration-hemodialysis. Proc Eur Dial Transplant Ass 1978;15:239–244.

8 Fauchald P: Transcapillary colloid osmotic gradient and body fluid volumes in renal failure. Kidney Int 1986;29:895–900.

9 Fauchald P, Noddeland H, Norseth J: An evaluation of ultrafiltration as treatment of diuretic-resistant oedema in nephrotic syndrome. Acta Med Scand 1985;217:127–131.

10 Fauchald P, Forfang K, Amlie J: An evaluation of ultrafiltration as treatment of therapy-resistant cardiac edema. Acta Med Scand 1986;219:47–52.

11 Aukland K, Johnsen HM: A colloid osmometer for small fluid samples. Acta Physiol Scand 1974;90:485–490.

12 Fauchald P, Noddeland H, Norseth J: Interstitial fluid volume, plasma volume and colloid osmotic pressure in patients with nephrotic syndrome. Scand J Clin Lab Invest 1984;44:661–667.

13 Womersley J, Boddy K, King PC, et al: A comparison of the fatfree mass of young adults estimated by anthropometry, body density and total body potassium content. Clin Sci 1972;43:469–475.

14 Fauchald P: Colloid osmotic pressures, plasma volume and interstitial fluid volume in patients with heart failure. Scand J Clin Lab Invest 1985;45:701–706.

15 Koomans HA, Geers AB, Dorhout Mees EJ: Plasma volume recovery after ultrafiltration in patients with chronic renal failure. Kidney Int 1984;26:848–854.

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