INTRODUCTION

The number of patients with end-stage kidney disease (ESRD) has been increasing over the years and the treatment method that is most used is hemodialysis (HD).1-3 Although the development of HD by Willem Kolff and Belding Scribner has revolutionized the treatment of renal failure, mortality remains significantly high, with high rates of comorbidities and low quality of life.4 Several factors influence the risk of mortality among patients undergoing HD,4 but high mortality rates may be related to aspects of the dialysis procedure.5

To assess the quality of dialysis, the dialysis quality index (Kt/V) is measured, which can be calculated in several ways.6 This index needs to be at least 1.2 per dialysis session to verify that the session was of good quality. Observational studies have demonstrated a relationship between Kt/V and mortality and morbidity. Patient survival is longer when Kt/V is greater than 1.0.7,9

Studies have focused on prevention of and intervention in frequent HD-related complications, given that these complications reduce patients’ quality of life and can contribute to mortality.10,11 Approximately 30% of HD sessions have some type of complication,11 which may include hypotension, muscle cramps and post-dialysis complaints such as headache, fatigue and inability to concentrate.12

Frequent symptoms that are present in dialysis patients, such as headache, nausea and muscle cramps, can represent milder forms of dialysis disequilibrium syndrome (DDS), and this often remains undiagnosed.13 DDS occurs due to a sudden drop in urea levels, which results in an osmotic imbalance, with consequent failure of self-regulation of the cerebral circulation, thus leading to cerebral edema. Its clinical presentations depend on the brain region involved: for
example, edema in the occipitoparietal subcortical white matter can result in sudden loss of vision and other neurological symptoms.\textsuperscript{11}

To prevent this syndrome, it is recommended that high-risk patients should be identified, rapid correction of metabolic acidosis using bicarbonate should be avoided and the urea clearance rate and decrease in plasma osmolality should be controlled.\textsuperscript{13} Considering that cerebral edema and the consequent decrease in cerebral compliance are involved in the pathophysiology of DDS,\textsuperscript{15,17} assessment of intracranial pressure (ICP) could also contribute to a more positive outcome by helping to identify individuals with mild forms of DDS that are hard to recognize.\textsuperscript{13}

**OBJECTIVE**
The aim of this study was to evaluate the brain compliance of patients with ESRD before and at the end of the hemodialysis session, and to correlate the results obtained with the dialysis quality index (Kt/V).

**METHODS**
This was a cross-sectional study at a renal replacement therapy (RRT) center in Brazil. It was conducted after authorization had been received from the Research Ethics Committee of Universidade Estadual de Ponta Grossa (UEPG) (procedural number: 2174527; approved on June 26, 2014).

**Participants**
Sixty patients aged 18 years or over, with ESRD, who were undergoing hemodialysis three times a week for 3-4 hours in each session, were included. To define the sample size, studies with similar variables were consulted. However, given that the intracranial pressure variable remains poorly studied, the sample size was defined according to the number of volunteers available. The exclusion criteria were presence of acute infections, chronic viral diseases and pregnancy. All the participants received information about the study and provided written informed consent.

**Clinical and dialysis characteristics**
The clinical and dialysis characteristics of the participants were obtained through the computerized system of the RRT center at the Santa Casa de Misericórdia de Ponta Grossa Hospital.

**Assessment of brain compliance**
Brain compliance was assessed through the Brain4care method, using equipment provided by Brain4care (São Paulo, SP, Brazil) for non-invasive ICP monitoring. The method is based on measuring volumetric changes in the skull that are detected by a sensor attached to a bandana that is kept in contact with the patient’s head. The equipment filters, amplifies and digitizes the signal coming from the sensor and sends it to a computer. This method has been patented and validated through comparison with the invasive method for monitoring ICP\textsuperscript{18,19} and it has been registered with the Brazilian National Health Surveillance Agency (ANVISA; registration number 81157910004).

The results are obtained through analysis on the ICP wave pulse morphology. The curve obtained has three peaks: i) P1 is a percussion peak that results from transmission of blood pressure from the choroid plexus; ii) P2 varies according to brain compliance; and iii) P3 is related to closure of the aortic valve in the heart. In situations of intracranial compliance, the amplitudes of the peaks P1, P2 and P3 decrease sequentially.\textsuperscript{20,21} On the other hand, if the cranial adaptive capacity decreases, there is an increase in the ICP, as well as a change in the ICP pulse waveform because the amplitude of the P2 peak becomes higher than those of P1 and P3.\textsuperscript{22}

To numerically represent the volunteers’ brain compliance, the ratio between the amplitude of the peaks P1 and P2 was defined as P1/P2 (ratio R = AmpP1/AmpP2). Ideally, the result from this relationship should be > 1.10. A ratio between 1.00 and 1.10 indicates that the patient is on the threshold of abnormality. Values < 1.00 indicate abnormality, i.e. P2 > P1.

Pre-dialysis monitoring was performed before the patient started the hemodialysis session, and the patient was asked to remain immobile for 15-20 minutes of monitoring. At the end of the hemodialysis session, the same procedure was performed.

**Statistical analysis**
The Kolmogorov-Smirnov test was used to assess the normality of the data. Since most of the continuous variables did not present normal distribution, these were presented as the median and interquartile range. Categorical variables were presented as absolute numbers (n) and relative frequency (%). The paired parameters obtained pre and post-dialysis were analyzed by means of the Wilcoxon test, and the McNemar test was used to assess the significance of normal and altered ICPs. Possible differences between the groups were showed by means of the chi-square test (χ²) for categorical variables and the Mann-Whitney test for continuous variables. The ICP was also evaluated through a classification and regression tree (CART) model using the dialysis quality index (Kt/V) as the dependent variable and the pre and post-dialysis ICPs as independent variables. In all analyses, the significance level was set at P < 0.05. The data were evaluated using the statistical program SPSS 20.0 (SPSS, Chicago, United States).

**RESULTS**
The clinical parameters of the patients included in this study are shown in Table 1 and the parameters associated with hemodialysis are shown in Table 2.

Figure 1 shows the absolute distributions of individuals with and without ICP changes from before to after hemodialysis. Before
the hemodialysis session, 17 individuals (28%) presented ICP changes, while 43 (72%) had normal ICP. After the hemodialysis session, six individuals (10%) were identified as presenting altered ICP and 54 (90%) had normal ICP. Thus, there was a statistical difference (P = 0.035) from before to after hemodialysis for patients with ESRD. It is important to highlight that, out of the 17 patients who presented altered ICP pre-dialysis, 12 presented normal brain compliance after the session, while five continued to present altered ICP. Among the 43 patients who had normal pre-dialysis ICP, one exhibited abnormal ICP after the session.

Table 3 presents a comparison of the clinical and dialysis parameters of the patients with ESRD and their cerebral compliance (normal or altered), to show whether there was any parameter that was related to patients with worse cerebral compliance.

A comparison of the P1/P2 ratio of ICP before and after dialysis, for patients with ESRD who presented normal and altered brain compliance, is shown in Figure 2. Individuals with normal brain compliance showed median values for the P1/P2 ratio of 1.67 (range, 1.43-1.83) and those with altered cerebral compliance, 0.87 (range, 0.67-1.00). This difference in the pre-dialysis evaluation was statistically significant (P < 0.001). After dialysis, the patients with normal cerebral compliance exhibited median values of 1.60 (range, 1.33-1.77) and those with altered compliance, 1.34 (range, 1.02-1.50), which was also a statistical difference (P = 0.004). The increase in the P1/P2 ratio after dialysis may indicate an improvement in brain compliance in patients who presented changes in ICP parameters prior to hemodialysis treatment.

Through a classification and regression tree (CART), it was visualized that, out of the 60 volunteers with ESRD, 21 (35%) had a Kt/V < 1.20 and 39 (65%) had a Kt/V > 1.20. After the hemodialysis session, there were six individuals with abnormal brain compliance: three with a Kt/V < 1.20 and three > 1.20. Among these six individuals, five of them showed altered brain compliance before the dialysis and became improved through it, 10 of them had a Kt/V >1.20. Therefore, it can be suggested that efficient dialysis may have helped in improving cerebral compliance.

**DISCUSSION**

In the present study, the main finding was that the alteration in pre-dialysis brain compliance that was observed in 28% of the volunteers showed a tendency to become normalized, as seen immediately after the dialysis. Moreover, this study presented the possibility that this result may have been related to HD quality.

Previous studies that assessed the ICP of patients with renal failure did so through correlating the altered results with DDS. However, no studies had previously assessed the brain compliance.

**Table 1. Clinical characteristics of the subjects with end-stage renal disease (ESRD)**

| Clinical parameters | ESRD (n = 60) |
|---------------------|---------------|
| Age, in years, mean (range) | 60 (50-67) |
| Gender, n (%) | Male 32 (53) Female 28 (47) |
| Underlying diseases relating to CKD, n (%) | Hypertensive nephrosclerosis 35 (59) Diabetic nephropathy 23 (38) Polycystic kidney disease 2 (3) |
| Length of time on dialysis, in months, mean (range) | 45 (30-68) |

Values are expressed as the mean and range or the absolute number (n) and relative frequency (%). CKD = chronic kidney disease.

**Table 2. Dialysis characteristics of subjects with end-stage renal disease (ESRD)**

| Dialysis patients’ characteristics | ESRD (n = 60) |
|-----------------------------------|---------------|
| | Pre-dialysis | Post-dialysis | P-value |
| Weight (kg) | 70 (62-78) | 67 (58-76) | < 0.0001* |
| BMI (kg/m²) | 26 (22-30) | 25 (21-30) | < 0.0001* |
| SBP (mmHg) | 155 (128-181) | 151 (122-170) | 0.212 |
| DBP (mmHg) | 79 (70-92) | 78 (69-88) | 0.335 |
| MBP (mmHg) | 104 (91-123) | 103 (88-113) | 0.185 |
| BPM | 76 (67-85) | 72 (64-81) | 0.050 |
| Urea (mg/dl) | 102 (88-123) | 32 (29-42) | < 0.0001* |
| Kt/V > 1.20 - 39 (65) - |
| Kt/V < 1.20 - 21 (35) - |

Values are expressed as the median and interquartile range or absolute number (n) and relative frequency (%); *statistical difference between the groups studied, from Wilcoxon test (P < 0.05); BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; MBP = mean blood pressure; BPM = beats per minute; Kt/V = dialysis quality index.

**Figure 1.** Bar diagram showing the numbers of subjects with ESRD who had normal and altered intracranial pressure before and after hemodialysis.

**Figure 2.** Bar diagram showing the numbers of subjects with ESRD who had normal and altered intracranial pressure before and after hemodialysis.

**Figure 3.** Bar diagram showing the numbers of subjects with ESRD who had normal and altered intracranial pressure before and after hemodialysis.
compliance of routine HD patients, because the technique most used is highly invasive.

Noninvasive assessment of cerebral compliance through the Brain4care method could be useful in monitoring patients with ESRD in HD. It would constitute an additional tool for clinical evaluation of these patients and would possibly help in early detection of complications. This method has already been used in several situations such as epilepsy, hydrocephalus, cryptococcal meningitis associated with HIV infection, traumatic brain injury, hemorrhagic stroke and assessment of cerebral compliance in the elderly, among others.

ICP refers to the pressure inside the skull, which is influenced by blood and cerebral parenchyma and by the circulatory dynamics of cerebrospinal fluid (CSF). If there is an increase in the proportion of one of these components (blood, fluid or parenchyma) and the cerebral adaptive capacity is exceeded, the ICP increases.

The aim of HD is to simulate the process of glomerular ultrafiltration. It is based on the principle of diffusion, in which clearance or removal of a high concentration of uremic toxins present in the blood is achieved by means of migrating the blood through the dialysis filter.

**Table 3. Comparison of clinical and dialysis variables of subjects with end-stage renal disease (ESRD), according to intracranial pressure: normal or altered**

| Parameters | ESRD | Normal (n = 42) | Altered (n = 18) | P-value |
|------------|------|----------------|-----------------|---------|
| Clinical   |      |                |                 |         |
| Age, in years* | 62 (55-67) | 50 (44-66) | 0.021* |
| Gender, n (%)b |      |                |                 |         |
| Male       | 25 (60) | 7 (39) | 0.235 |
| Female     | 17 (40) | 11 (61) |             |
| Underlying diseases relating to CKD, n (%)c |      |                |                 |         |
| Hypertensive nephrosclerosis | 23 (55) | 12 (67) | - |
| Diabetic nephropathy | 17 (40) | 6 (33) | - |
| Polycystic kidney disease | 2 (5) | 0 (0) | - |
| Time on dialysis, in monthsa | 41 (30-65) | 49 (32-84) | 0.345 |
| Dialytic   |      |                |                 |         |
| Weight (kg)a |      |                |                 |         |
| Pre-dialysis | 69 (63-82) | 71 (56-77) | 0.425 |
| Post-dialysis | 66 (60-80) | 68 (54-75) | 0.429 |
| BMI (kg/m²)a |      |                |                 |         |
| Pre-dialysis | 25 (23-31) | 24 (21-29) | 0.302 |
| Post-dialysis | 25 (23-30) | 24 (20-28) | 0.379 |
| SBP (mmHg)a |      |                |                 |         |
| Pre-dialysis | 157 (135-190) | 134 (121-159) | 0.031* |
| Post-dialysis | 153 (119-175) | 142 (124-154) | 0.220 |
| DBP (mmHg)a |      |                |                 |         |
| Pre-dialysis | 79 (70-91) | 79 (67-95) | 0.771 |
| Post-dialysis | 77 (68-86) | 80 (68-91) | 0.942 |
| MBP (mmHg)a |      |                |                 |         |
| Pre-dialysis | 106 (93-128) | 103 (85-113) | 0.208 |
| Post-dialysis | 102 (88-118) | 103 (90-110) | 0.463 |
| BPMa |      |                |                 |         |
| Pre-dialysis | 74 (63-84) | 82 (74-92) | 0.023* |
| Post-dialysis | 70 (62-77) | 79 (71-91) | 0.008* |
| Urea (mg/dl)a |      |                |                 |         |
| Pre-dialysis | 102 (84-127) | 99 (89-116) | 0.910 |
| Post-dialysis | 37 (28-45) | 32 (29-39) | 0.375 |
| Kt/Vb |      |                |                 |         |
| < 1.20 | 16 (38) | 5 (28) | 0.637 |
| > 1.20 | 26 (62) | 13 (72) |             |

Values are expressed as the median and interquartile range or absolute number (n) and relative frequency (%); *Mann-Whitney test; χ² test; descriptive statistics; *statistical difference between the groups studied (P < 0.05); CKD = chronic kidney disease; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; MBP = mean blood pressure; BPM = beats per minute; Kt/V = dialysis quality index.
a semipermeable membrane (the dialyzer or filter), to form a solution of lower concentration, called the dialyzed solution.\textsuperscript{32}

A normal ICP waveform (Figure 3) was observed in 90% of the patients in the present study after dialysis. Considering the mechanisms of HD and the pathophysiology of changes to ICP, it can be suggested that the removal of fluids that occurs in HD directly influences the maintenance of the balance between blood, CSF and cerebral parenchyma, thereby normalizing ICP.

According to Robertson et al.,\textsuperscript{33} patients with intracranial hypertension often have elevated blood pressure due to sympathetic hyperactivity, especially in cases of head trauma. However, in the present study, patients with altered ICP parameters had lower systolic blood pressure (SBP). At the same time, it was found that patients with changes to their cerebral compliance had higher heart rate values, both pre and post-dialysis. Dimitri et al.\textsuperscript{34} suggested that there was direct interaction or communication between the heart and the brain, with the observation that when the ICP rose, the heart rate also increased. This is important information, because it can assist in validation of the ICP parameters for assessing cerebral compliance.

Another important result from the present study was the relationship between cerebral compliance and the best-quality dialysis, as shown by Kt/V > 1.20. It can be suggested that good-quality dialysis can help to improve the post-dialysis ICP parameters of patients with ESRD who presented altered brain compliance before HD.

In this study, one volunteer showed changes to his brain compliance only after dialysis. No complications were reported in this patient’s medical records during his HD session, and his Kt/V was 1.25. In addition, it was not possible to establish any relationship between this finding and the patient’s clinical and dialysis parameters.

In the formula of the Kt/V ratio, K refers to the dialyzer urea clearance, which is multiplied by the treatment time (t) and divided by the patient’s urea distribution volume (V). K depends on the blood flow rate, size of the dialyzer and flow of the dialysate, t varies from three to four hours and the urea distribution volume of

---

**Figure 3.** Classification and regression tree (CART) for dialysis quality (Kt/V) in relation to pre and post-dialysis intracranial pressure.
the patient (V) corresponds to approximately 55% of the individual’s body weight. This volume can be more accurately estimated through an anthropometric equation that uses an individual’s gender, age, height and weight (e.g. the Watson equation). Based on the above, several factors can influence the quality of HD and be reflected in the Kt/V ratio, such as the duration of the session and the interdialytic weight gain, which needs to be controlled by the patient through dietary care.

Inadequate hemodialysis (Kt/V < 1.20) can occur due to low adherence or non-adherence to treatment recommendations (such as fluid restriction, regular frequency of dialysis sessions and adherence to 240-minute sessions) and because of the clearance limitations of the conventional HD technique. It has been shown that not attending just one dialysis session is associated with a 25%-30% increase in the risk of death. This is a common problem with regard to HD. According to Kimata et al., small changes in the way of conducting HD sessions, such as increasing the blood flow rate to 200 ml/min and the treatment time to four hours for some patients, can decrease the percentage of patients with Kt/V < 1.20, with a consequent increase in survival among these patients.

However, four-hour dialysis sessions do not guarantee good-quality dialysis. It is necessary to consider the residual renal function, the Kt/V ratio normalized according to body surface area and the expected ultrafiltration rate. In addition, it is important to consider the patients’ acceptance of the duration of dialysis to which they are subjected, since this directly impacts their quality of life and treatment adherence. Madero and Sarnak questioned whether the hemodialysis procedure might be partly responsible for brain structural and cognitive changes, such as cerebral edema, which leads to increased ICP. However, our results suggested that an adequate hemodialysis session, with Kt/V > 1.20, may be effective in normalizing the ICP of individuals who have presented changes.

Lastly, it is worth mentioning that the clinical assessment is superior to any Kt/V formula and should serve as the basis for determining the adequacy of dialysis. Thus, the importance of clinical assessment of cerebral compliance among patients undergoing HD can be emphasized.

CONCLUSION

Through noninvasive assessment of the ICP parameters by means of the Brain4care method, it could be seen that changes to cerebral compliance among patients on hemodialysis can occur frequently. Moreover, it can be suggested that good-quality hemodialysis (i.e. when Kt/V is greater than 1.20) may help to normalize the ICP parameters. Thus, the importance of maintaining a Kt/V ratio of at least 1.20 can be emphasized, in order to ensure good-quality dialysis for patients with ESRD.

REFERENCES

1. Neves DPM, Sesso RCC, Thomé FS, Lugon JR, Nascimento MM. Censo Brasileiro de Diálise: análise de dados da década 2009-2018. J Bras Nefrol. 2020;42(2):191-200. https://doi.org/10.2175-8239-JBN-2019-0234.
2. Liew A. Perspectives in renal replacement therapy: Haemodialysis. Nephrology (Carlton). 2018;23 Suppl 4:95-9. PMID: 30298645; https://doi.org/10.1111/nep.13449.
3. Himmelfarb J, Vanholder R, Mehrotra R, Tonelli M. The current and future landscape of dialysis. Nat Rev Nephrol. 2020;16(10):573-85. PMID: 32733095; http://dx.doi.org/10.1038/s41581-020-0315-4.
4. Ma L, Zhao S. Risk factors for mortality in patients undergoing hemodialysis: A systematic review and meta-analysis. Int J Cardiol. 2017;238:151-8. PMID: 28341375; http://dx.doi.org/10.1016/j.ijcard.2017.02.095.
5. Flythe JE, Curhan GC, Brunelli SM. Shorter length dialysis sessions are associated with increased mortality, independent of body weight. Kidney Int. 2012;83:104-13. PMID: 23014457; https://doi.org/10.1038/ki.2012.346.
6. Breitsameter G, Figueiredo AE, Kochhann DS. Cálculo de Kt / V em hemodiálise: comparação entre fórmulas. J Bras Nefrol. 2012;34(1):22–6. https://doi.org/10.1590/S0101-28002012000100004.
7. Depner T, Daugirdas J, Greene T, et al. Dialysis dose and the effect of gender and body size on outcome in the HEMO Study. Kidney Int. 2004;65(4):1386–94. PMID: 15086479; https://doi.org/10.1111/j.1523-1755.2004.00519.x.
8. Parker TF, Husni L, Huang W, Lew N, Lowrie EG. Survival of hemodialysis patients in the United States is improved with a greater quantity of dialysis. Am J Kidney Dis. 1994;23(5):670-80. PMID: 8172209; http://dx.doi.org/10.1016/S0272-6386(12)70277-9.
9. Held PJ, Port FK, Wolfe RA, et al. The dose of hemodialysis and patient mortality. Kidney Int. 1996;50(2):550-6. PMID: 8840285; https://doi.org/10.1038/ki.1996.348.
10. BiLM, Chen YL, Chen YF, et al. Strategies of intervening complications in hemodialysis with classical prescriptions from clinical cases. Zhongguo Zhongyao Zazhi. 2018;43(12):2470-3. PMID: 29950062; https://doi.org/10.19540/j.cnki.1996.348.
11. De Castro MCM. Atualização em diálise: Complicações agudas em hemodiálise. J Bras Nefrol. 2001;23(2):108-13. Available from: https://www.scielo.br/pdf/jbnci/v23n2a05.pdf. Accessed in 2021 (Sep 14).
12. Denhaerynck K, De Geest M, Manhaeve D, et al. Prevalence and consequences of nonadherence to hemodialysis regimens. Am J Crit Care. 2007;16(3):222-35; quiz 236. PMID: 17460313.
13. Mistry K. Dialysis disequilibrium syndrome prevention and management. Int J Nephrol Renovasc Dis. 2019;12:69-77. PMID: 31118737; https://doi.org/10.2147/ijnrd.s165925.
14. Sengupta P, Biswas S. Dialysis disequilibrium leading to posterior reversible encephalopathy syndrome in chronic renal failure. CEN Case Reports. 2016;5(2):154-7. PMID: 26508968; https://dx.doi.org/10.1007%2Fs13730-016-0215-4.
15. Krane NK. Intracranial Pressure Measurement in a Patient Undergoing Hemodialysis and Peritoneal Dialysis. Am J Kidney Dis. 1989;13(4):336-9. PMID: 2650541; https://doi.org/10.1016/S0272-6386(89)80042-3.

16. Lund A, Damholt MB, Strange DG, et al. Increased Intracranial Pressure during Hemodialysis in a Patient with Anoxic Brain Injury. Case Reports Crit Care. 2017;2017:1-4. PMID: 28409034; https://doi.org/10.1155/2017/5378928.

17. Zepeda-Orozco D, Quigley R. Dialysis disequilibrium syndrome. Pediatr Nephrol. 2012;27:2205-11. PMID: 22710692; https://dx.doi.org/10.1007/s00467-012-2199-4.

18. Vilela GHF, Cabella B, Mascarenhas S, et al. Validation of a new minimally invasive intracranial pressure monitoring method by direct comparison with an invasive technique. Acta Neurochir Suppl. 2016;122:97-100. PMID: 27165885; https://doi.org/10.1007/978-3-319-22533-3_19.

19. Frigieri G, Andrade RAP, Dias C, et al. Analysis of a non-invasive intracranial pressure monitoring method in patients with traumatic brain injury. Acta Neurochir Suppl. 2018;126:107-10. PMID: 29492543; https://doi.org/10.1007/978-3-319-65798-1_23.

20. Adams JP, McKinlay J, Bell D. Neurolcritical Care: A Guide to Practical Management. J Intensive Care Soc. 2010;11(3):215. https://www.springer.com/gp/book/9781848820692. Accessed in 2021 (Sep 14).

21. Cardoso ER, Rowan JO, Galbraith S. Analysis of the cerebrospinal fluid pulse wave in intracranial pressure. J Neurol. 1983;59(5):817-21. PMID: 6619934; https://doi.org/10.1171/jn.1983.59.5.0817.

22. Avezaat C, van Eijndhoven J, Weyer D. Cerebrospinal fluid pulse pressure and intracranial-volume-pressure relationships. J Neurol Neurosurg Psychiatry. 1979;42(8):687-700. PMID: 490174; https://doi.org/10.1136/jnnp.42.8.687.

23. Lin CM, Lin JW, Tsai JT, et al. Intracranial pressure fluctuation during hemodialysis in renal failure patients with intracranial hemorrhage. Acta Neurochir Suppl. 2008;101:141-4. PMID: 18642649; https://doi.org/10.1007/978-3-211-78205-7_24.

24. Enauts P, Lacroix G, Cungi PJ, et al. Dialysis disequilibrium syndrome in neurointensive care unit: the benefit of intracranial pressure monitoring. Crit Care. 2012;16(6):472. PMID: 2328051; https://doi.org/10.1186/cc11877.

25. Cardim DA, Frigieri GH, Cabella BCT, et al. Characterization of intracranial pressure behavior in chronic epileptic animals: A preliminary study. Acta Neurochir Suppl. 2016;122:329-33. http://dx.doi.org/10.1007/978-3-319-22533-3_65.

26. Ballestero MFM, Frigieri G, Cabella BCT, de Oliveira SM, de Oliveira RS. Prediction of intracranial hypertension through noninvasive intracranial pressure waveform analysis in pediatric hydrocephalus. Child’s Nerv Syst. 2017;33(9):1517-24. PMID: 28623520; https://doi.org/10.1007/s00381-017-3475-1.

27. Bollela VR, Frigieri G, Vilar FC, et al. Noninvasive intracranial pressure monitoring for HIV-associated cryptococcal meningitis. Brazilian J Med Biol Res. 2017;50(9):e6392. https://doi.org/10.1590/1414-431x20176392.

28. Cardim DA, do Val da Silva RA, Cardim AC, et al. Characterization of ICP behavior in an experimental model of hemorrhagic stroke in rats. Acta Neurochir Suppl. 2016;122:121-4. PMID: 27165890; https://doi.org/10.1007/978-3-319-22533-3_24.

29. Bueno BF, Barbosa CR, Borato DCK, Vellosa JCR. Monitorização não invasiva da pressão intracraniana em idosos: um relato de morfologia de onda e complacencia cerebral. Brazilian J Dev. 2021;7(1):6952-60. https://doi.org/10.34117/bjdv7n1-470.

30. Czosnyka M, Pickard JD. Monitoring and interpretation of intracranial pressure. J Neurol Neurosurg Psychiatry. 2004;75(6):813-21. PMID: 15145991; https://doi.org/10.1136/jnnp.2003.033126.

31. Elixmann IM, Hansinger J, Goffin C, et al. Single pulse analysis of intracranial pressure for a hydrocephalus implant. Annu Int Conf IEEE Eng Med Biol Soc. 2012;2012:3939-42. PMID: 23366789; https://doi.org/10.1109/embc.2012.6346828.

32. Ledebo I, Blanketstijn PJ. Haemodiafiltration - Optimal efficiency and safety. NDT Plus. 2010;3(1):8-16. PMID: 20090878; https://doi.org/10.1093/ndtplus/sfp149.

33. Robertson CS, Clifton GL, Taylor AA, Grossman RG. Treatment of hypertension associated with head injury. J Neurosurg. 1983;59:455-60. PMID: 6886759; https://doi.org/10.3171/jns.1983.59.3.0455.

34. Dimitri GM, Agrawal S, Young A, et al. Simultaneous transients of intracranial pressure and heart rate in traumatic brain injury: Methods of analysis. Acta Neurochir Suppl. 2018;126:147-51. PMID: 29492551; https://doi.org/10.1007/978-3-319-65798-1_31.

35. Daugirdas JT, Blake PG, Ing TS. Manual de Diálise. 2ª. Ed. Medsi Editora Médica e Científica Ltda; 1996.

36. Watson PE, Watson ID, Batt R. Total body water volumes for adults est from simple anthropometric measurements. Am J Clin Nutr. 1980;33(1):27-39. PMID: 6986752; http://doi.org/10.1093/ajcn/33.1.27.

37. Kimata N, Karaboyas A, Bieber BA, et al. Gender, low Kt/V, and mortality in Japanese hemodialysis patients: Opportunities for improvement through modifiable practices. Hemodial Int. 2014;18(3):596-606. PMID: 24612374; http://doi.org/10.1111/hdi.12142.

38. Daugirdas JT. Hemodialysis Treatment Time: As Important as it Seems? Semin Dial. 2017;30(2):93-8. PMID: 28092113; http://doi.org/10.1111/ndt.12142.

39. Madero M, Sarnak MJ. Does Hemodialysis Hurt the Brain? Semin Dial. 2011;24(3):266-8. PMID: 21435001; http://doi.org/10.1111/j.1525-8757.2010.01941.x.

Authors’ contributions: Rickli C: conceptualization (lead), investigation (lead), methodology (lead), project administration (lead), resources (equal), supervision (lead), validation (equal), visualization (lead), writing-original draft (lead) and writing-review and editing (equal); Kalva DC: data curation (equal), formal analysis (lead), methodology (equal), validation (equal), visualization (equal) and writing-review and editing (equal); Mascarenhas S: software (lead), supervision (equal), visualization (equal) and writing-review and editing (equal); Schuinski AFM: project administration (lead), resources (lead), writing-review and editing (equal).
Relationship between dialysis quality and brain compliance in patients with end-stage renal disease (ESRD): a cross-sectional study

© 2022 by Associação Paulista de Medicina
This is an open access article distributed under the terms of the Creative Commons license.

conceptualization (equal), investigation (equal), methodology (equal), visualization (equal) and writing-review and editing (equal); Mascarenhas S: conceptualization (equal), data curation (equal), funding acquisition (equal), resources (equal), software (equal), visualization (equal) and writing-review and editing (equal); and Vellosa JCR: conceptualization (equal), funding acquisition (equal), project administration (lead), resources (equal), supervision (lead), validation (equal), visualization (equal) and writing-review and editing (lead). All authors actively contributed to production of the study, and reviewed and approved the final version to be published.

Date and place of the event where the work was presented: Presented at the 8th Paraná Congress of Biomedical Sciences in 2018; Presented at the 11th International Congress of Pharmaceutical Sciences in 2017; and in the form of a Master’s dissertation by Cristiane Rickli, within the Postgraduate Program on Pharmaceutical Sciences, Universidade Estadual de Ponta Grossa, in 2016.

Sources of funding: Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), through procedural number 443571/2014-7

Conflicts of interest: Rickli C, Kalva DC, Schuinski AFM and Vellosa JCR declare that there were no conflicting interests and that they have nothing to disclose. Frigieri GH declares personal fees as an employee (Research Coordinator) at Braincare Desenvolvimento e Inovação Tecnológica S.A., at the time when the study was being conducted. In addition, Frigieri GH declares that he holds the issued patent US9826934B2 and the issued patent US9993170B1. Mascarenhas S declares that he holds the issued patent US9826934B2 and the issued patent US9993170B1.

Date of first submission: February 12, 2021
Last received: July 5, 2021
Accepted: September 14, 2021

Address for correspondence:
José Carlos Rebuglio Vellosa
Universidade Estadual de Ponta Grossa (UEPG),
Av. General Carlos Cavalcanti, 4.748
Ponta Grossa (PR) — Brasil
CEP 84030-900
Tel./Fax. (+55 42) 3220-3000
E-mail: josevellosa@yahoo.com.br