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NURSING INTERVENTIONS FOR INTRADIALTYIC HYPOTENSION:
USING BLOOD VOLUME MONITORING GUIDED ULTRAFILTRATION

by

Suzette Cedeno

A thesis submitted in partial fulfillment of the requirements
for the Honors in the Major Program in Nursing
in the College of Nursing
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ABSTRACT

Background: Intradialytic hypotension is a potential complication experienced by patients with end-stage renal disease who receive hemodialysis. This complication occurs during the dialysis treatment in 15-30% of all treatments. The multiple comorbidities that exist in hemodialysis patients predispose them to recurrent intradialytic hypotension episodes. Recurrent intradialytic hypotensive episodes can result in negative short-term and long-term clinical consequences. Short-term consequences include complications such as ischemic events (e.g., heart attacks, strokes), clotting of patient dialysis access, or heart rhythm abnormalities. Long-term consequences include end-organ damage, increased cardiovascular morbidity, and a higher mortality rate. **Problem Statement:** Available nursing interventions used to treat intradialytic hypotension such as decreased dialysis fluid temperature, changes in the calcium and sodium concentrations in the dialysis fluid and oral medication have limited success. Another existing technological intervention called blood volume monitoring shows greater potential success but is currently underutilized. **Purpose:** The purpose of this literature review is to synthesize current literature on blood volume monitoring technology used to prevent intradialytic hypotension in hemodialysis patients. **Methods:** A literature review was conducted analyzing pertinent research articles published in the last ten years, in addition to seminal articles. Seventeen articles were retrieved and analyzed that met criteria. **Results:** Fourteen of the seventeen research studies reached a consensus on the successful use of blood volume monitoring to decrease intradialytic hypotension and the related symptoms. **Conclusion:** Results of the literature review support the use of blood volume monitoring technology as an effective nursing intervention to prevent intradialytic hypotension in hemodialysis patients.

DEDICATION

This work is inspired by the patients at my dialysis clinic. Thank you to all the patients I have ever had the pleasure in treating for challenging me to become a better nurse in every aspect of care. This work is dedicated to you with the hopes that one-day dialysis will be more tolerable - or better yet that it will cease to exist. You are a true inspiration.

Thank you to my mother, Amada Cedeno, my father, Xavier Cedeno, for showing me the importance of hard work and determination and for living up to those values. I want to thank my brother, Kevin Cedeno, for being my support system and showing me, it is never too late to follow your dreams. Everything I do is because and for you all.

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INTRODUCTION

Intradialytic hypotension (IDH) is an incommodious and pernicious side effect seen in many patients with end-stage renal disease (ESRD) who receive hemodialysis (HD). IDH can result in serious complications, including ischemic events, vascular access thrombosis, dysrhythmias, and mesenteric venous infarction (Kidney Dialysis Outcomes Quality Initiatives Workgroup [KDOQI], 2005). Other long-term complications may include fluid volume overload due to fluid resuscitation, left ventricular hypertrophy (LVH), and interdialytic hypertension (KDOQI Workgroup, 2005). Nurses are at the forefront of dialysis care and are in a unique position to recognize early signs of IDH and intervene.

SIGNIFICANCE

IDH occurs in 15%-30% of HD treatments (Reilly, 2014). The incidence increases to 50% with predisposed ESRD individuals, with comorbidities like diabetes and cardiac anomalies (Reilly, 2014).

Intradialytic systolic blood pressure (SBP) of <100 mm Hg, with a predialysis SBP of ≥160 mm Hg in patients who receive HD is associated with increased mortality (Reeves & Mc Causland, 2018). Patients with intradialytic SBP of <90 mm Hg with a predialysis SBP of <160 mm Hg have the same increased risk of mortality (Reeves & Mc Causland, 2018). Van Buren and Inrig (2017) noted that the risk of death is greater among patients with a decrease in SBP of ≥30 mm Hg from pre- to post-dialysis. Alternatively, Reeves and Causland (2018) found that absolute blood pressure declines (30 mm Hg from pre-dialysis blood pressure) had no association with mortality rates, suggesting that there is a threshold below which end-organ hypoperfusion occurs. The higher the frequency of IDH occurrence, the greater the mortality rate (Reeves & Mc Causland, 2018).

Transient oxygen deprivation to myocardial tissue from IDH causes prolonged left ventricular (LV) systolic dysfunction, also called myocardial stunning (Ok, Levin, Asci, Chazot, Tox, & Ozkahya, 2017). Although ischemic episodes of short duration may not cause cardiac cell death, they may eventually lead to permanent damage to LV function (Ok et al., 2017). During dialysis, patients without significant coronary artery disease (CAD) show LV wall abnormalities and decreased blood flow to cardiac muscle tissue (Ok et al., 2017).

Dialysis-related LV systolic dysfunction is linked to decreased LV ejection fraction, higher endotoxin level, and increased risk of mortality (Ok et al., 2017). According to Dasselaar et al. (2009), non-diabetic patients who underwent dialysis with a minimal ultrafiltration (UF)

had a decrease in myocardial blood volume within the first 30 minutes of treatment, without substantial blood pressure or blood volume changes. IDH has been independently linked to cardiac mortality, myocardial infarction, and hospitalization for heart failure and volume overload (Reeves & Mc Causland, 2018).

Intradialytic blood pressure declines are associated with decreased blood flow to the middle cerebral artery, leading to hypoperfusion of brain tissue (Reeves & Mc Causland, 2018). Consequently, higher incidence of IDH is associated with a decrease in frontal brain area to intracranial frontal space (Reeves & Mc Causland, 2018) and cognitive decline (Chou, Kalantar-Zadeh & Mathew, 2017). MRI findings of patients with IDH include cerebral infarcts, atrophy, and leukoaraiosis (caused by the deprivation of oxygen and is a risk factor for dementia and strokes) (Chou, Kalantar-Zadeh, & Matthew, 2017).

Hemodynamic instability with IDH also causes the gut to displace endotoxins across the intestinal lining causing bowel edema and hypoperfusion (Chou et al., 2017). Patients on HD have high endotoxin levels that aid in creating pro-inflammatory processes that lead to malnutrition, wasting, and poor cardiovascular outcomes (Chou et al., 2017). This increase in endotoxin levels is due, in part, to poor mesenteric blood flow during dialysis (Chou et al., 2017).

Patients with greater decline in SBP had two times the risk of developing thrombosis in their vascular access (i.e., arteriovenous fistula, arteriovenous graft, or central venous catheter) during follow-up (Reeves & Mc Causland, 2018). Patients with an IDH frequency of >29% had twice the risk of developing thrombosis in their vascular access compared to patients without IDH (Ok et al., 2017).

PROBLEM STATEMENT

Although dialysis technology has improved in the past decade, the frequency of IDH remains unchanged (Reilly, 2014). Many HD patients continue to experience IDH, despite the use of current interventions, such as decreased dialysate temperature, sodium and calcium modeling, and the use of midodrine (KDOQI Workgroup, 2005). IDH contributes to long-term complications such as end-organ damage, increased cardiovascular morbidity, and a greater mortality rate (Reilly, 2014). Given the substantial adverse complications associated with IDH including increased morbidity and mortality, a currently existing, but underutilized, dialysis technology intervention merits further consideration (Reilly, 2014). The use of blood volume monitoring (BVM) is one such technological advancement that nurses can utilize to prevent IDH.

PURPOSE

The purpose of this literature review is to synthesize the current literature on BVM with biofeedback UF technology used to prevent IDH in HD patients.

BACKGROUND

Intradialytic Hypotension

IDH is an intradialytic complication where blood pressure is markedly decreased in response to fluid volume and urea removal. IDH is defined as a decrease in SBP $\geq$ 20 mm Hg or a decrease in mean arterial pressure (MAP) of $\geq$ 10 mm Hg during a dialysis treatment (KDOQI Workgroup, 2005). Symptoms accompanying IDH include nausea, vomiting, muscle cramps, and dizziness (KDOQI Workgroup, 2005). Consequently, the treatment of IDH-related symptoms, after they occur, may lead to suboptimal dialysis treatments and affect the Kt/V (the laboratory value reflecting the toxin removal from the blood). The Kt/V value reflects the effectiveness of dialysis treatment and indicates whether changes in dialysis prescription are merited (KDOQI Workgroup, 2005). Established measures used to treat IDH when it occurs currently include decreasing dialysate temperature, sodium and calcium modeling, and the use of pharmacologic agents, such as midodrine (ProAmatine) (KDOQI Workgroup, 2005). There is no established measure to prevent IDH in clinical practice.

Risk Factors for IDH

Non-modifiable risk factors for IDH include older age (>60 years of age) (KDOQI, 2005), female gender, Hispanic ethnicity, and increased number of years on dialysis (Chou et al., 2017). Patients with the following comorbidities are predisposed to IDH: diabetes mellitus (DM), CAD, systolic dysfunction, LVH, and increased cardiac enzymes (Chou et al., 2017). IDH risk factors that can be modified with patient health behavior change include hyperphosphatemia, antihypertensive medication usage, eating a meal before hemodialysis treatments, increased body mass index, decreased albumin levels, and interdialytic fluid weight gain (Chou et al., 2017). Dialysis prescription of low sodium dialysate (fluid used to clean blood during dialysis) ($\leq$ 135

mmol/L) is associated with increased frequency of IDH, while higher dialysate calcium is associated with decreased rate of IDH (Chou et al., 2017).

Pathophysiology of IDH

To address how IDH occurs, the different factors that affect blood pressure must be considered. Blood pressure is determined by blood volume, systemic vascular resistance, and cardiac output (Santos, Peixoto, & Perazella, 2012). Hemodialysis may cause impairment in more than one of these factors, affecting the body's normal compensatory mechanism (Santos et al., 2012).

High UF rates (the rate at which the blood is cleaned, and fluid is removed during dialysis) is often higher than the patient's plasma volume (Agarwal, 2012; Santos et al., 2012). Elevated UF rates, combined with decreased extracellular osmolality, cause a drastic reduction in plasma volume (Reeves et al., 2018; Santos et al., 2012). These combined processes lead to reduced plasma refilling and hemodynamic instability (Reilly, 2014; Santos et al., 2012). The effects are greater in patients with impaired vascular compliance and blood redistribution (Santos et al., 2012).

Vasoconstriction of the splenic and cutaneous circulation occurs to compensate for lack of plasma refilling, leading to decreased venous pooling (Reeves et al., 2018; Santos et al., 2012). This mechanism redistributes blood to the central blood compartment to support adequate cardiac filling and cardiac output (Chou et al.,2017; Santos et al., 2012). This compensatory process of blood redistribution is impaired in ESRD patients due to their comorbidities (Reilly, 2014; Santos et al., 2012). Increased core temperatures during dialysis cause the blood to redistribute from the central circulation to the skin (to reduce core temperature), further decreasing central blood volume (Santos et al., 2012).

Patients with DM, structural heart disease, and the elderly are afflicted with autonomic dysfunction, decreased function of cardiopulmonary receptors, and diminished arterial pressoreceptors (Reilly, 2014; Santos et al., 2012). Patients at greater risk of IDH were identified as having impaired resting baroreflex sensitivity (Agarwal, 2012; Santos et al., 2012). The uremic component of autonomic dysfunction is linked to the development of IDH (Agarwal, 2012; Santos et al., 2012). There is also an imbalance between vasoconstrictor (less endothelin-1) and vasodilator (elevated nitric oxide) processes supporting vasodilation which predisposes patients to IDH (Santos et al., 2012).

Some ESRD patients may have large amounts of adenosine production from oxygen-deprived tissues during UF (Santos et al., 2012). Elevated adenosine is believed to decrease blood pressure by reducing norepinephrine secretion and stimulating vasodilation and venous blood pooling (Bradshaw, 2014; Santos et al., 2012). Vasopressin release in some IDH patients is deficient and escalates hemodynamic instability (Santos et al., 2012).

Patients in HD have circulating endotoxemia (immune marker indicating low grade inflammation), which is associated with increased relative IDH (Agarwal, 2012; Santos et al., 2012). ESRD patients with any of the disorders (impaired resting baroreflex sensitivity, increased adenosine production, or endotoxemia) cannot compensate by increasing vascular resistance. Their inability to compensate breeds a perfect environment for IDH to occur (Chou et al., 2017; Santos et al., 2012).

Another underlying structural cardiac abnormality that frequently results in IDH is LVH (Chou et al., 2017; Santos et al., 2012). In patients with ESRD, LVH is caused by long-standing hypertension, chronic volume overload, severe anemia, and arteriovenous shunts (Santos et al., 2012). LVH is the most prevalent cardiac anomaly in ESRD patients (Santos et al., 2012).

LVH is frequently associated with systolic or diastolic cardiac dysfunction, which may increase the propensity of patients to develop IDH (Chou et al., 2017; Santos et al., 2012). Cardiac output decreases when intravascular blood volume, central blood volume, and cardiac preload are reduced. The diminished cardiac output, as seen with systolic and diastolic dysfunction, can precipitate a drop in blood pressure and lead to IDH occurrence (Santos et al., 2012).

Current IDH Interventions

There are four interventions currently in practice to treat IDH: decreasing dialysate temperature, sodium modeling, calcium modeling, and pharmaceutical intervention. These interventions will be described in greater detail.

Dialysis Interventions Used to Treat IDH When It Occurs.

Decreasing Dialysate Temperature.

During HD, it is common for the core body temperature to increase (due to heat load from the dialysis machine or secondary to volume removal) (KDOQI Workgroup, 2005). Once core temperatures reach a critical level (level at which the body's homeostatic mechanism are triggered), peripheral dilation occurs (Reilly, 2014), leading to an increased risk of IDH (KDOQI Workgroup, 2005). Lower dialysate temperature (decreasing dialysate temperature lower than the patient's core temperature) compared with standard dialysate temperature (37° C) is thought to reduce the frequency and intensity of symptomatic IDH (KDOQI Workgroup, 2005). Lower dialysate temperature is related to a decline in LV regional wall abnormalities, improved peripheral vasopressor reactions, and an increase in baroreceptor sensitivity (Reilly, 2014). The patients may complain of feeling cold with this intervention (Reilly, 2014) and patients are at an increased risk of diminished Kt/V (Larkin, Reviriego-Mendoza, Usvyat, Kotanko, & Maddux,

2017). Many dialysis patients are already hypothermic, making them inadequate candidates for this intervention (Reilly, 2014). This treatment modality is only useful on the short-term basis (Larkin et al., 2017). Larkin et al. (2017) did a literature review on the effectiveness of decreasing dialysate temperature and found that there is a lack of studies to suggest the effectiveness of decreasing dialysate temperature for the long-term prevention of IDH.

Sodium Modeling.

Sodium modeling is an intervention in which the sodium dialysate concentration is higher at the beginning of dialysis and decreases gradually towards the end of the dialysis treatment (KDOQI Workgroup, 2005). Nurses preset the HD machine according to a physician's or nurse practitioner's orders before the start of the HD treatment to carry out sodium modeling automatically. Sodium profiling prevents IDH by increasing extracellular fluid sodium levels at the time of peak UF, which helps shift water from the intracellular space to the extracellular space and improves venous refill and prevents the Bezold-Jarisch reflex (a cardiovascular mechanism activated in response to decreased oxygenation levels to myocardial tissue that leads to vasodilation, bradycardia, and hypotension [Johnson, 2013, p. 215]) (KDOQI Workgroup, 2005).

Sodium profiling also ameliorates the urea equilibrium between the intracellular fluid and extracellular fluid (KDOQI Workgroup, 2005). Using higher levels of dialysate sodium concentrations during the start of dialysis necessitates lower than mean dialysate sodium concentration towards the end of treatment (Reilly, 2014).

During the period when lower sodium concentration is implemented, the patients are at a higher risk of IDH (Reilly, 2014). The ramification of sodium modeling is a positive sodium

balance in the patient at the end of dialysis which often leads to elevated blood pressure, increased thirst, and increased interdialytic weight gain (Chou et al., 2017).

Calcium Modeling.

Low calcium dialysate is associated with decreased LV contraction and hypotension (KDOQI Workgroup, 2005). Associations between low calcium baths and low blood pressure affect IDH-prone patients and non-IDH prone patients (KDOQI Workgroup, 2005). Increased calcium concentrate in dialysate provides increased stroke volume, increased SBP, and elevated serum calcium concentration (Reilly, 2014).

In a small subgroup of predisposed IDH individuals, Reilly (2014) found that changes in MAP were modest and did not result in a significant decrease in IDH occurrence. Higher calcium dialysates, for example a 3.5 mEq/L calcium bath, can cause hypercalcemia and significantly increase the risk of decreased bone turnover (KDOQI Workgroup, 2005). Given the minimal effects of calcium modeling on IDH and the increased risk of positive calcium balance, changing calcium dialysate prescription is not commonly used (Reilly, 2014).

Pharmaceutical Intervention.

Midodrine (ProAmatine) is a selective alpha one agonist and has an off-label use for IDH prevention (Chou et al., 2017). The use of Midodrine is associated with a decrease in the severity of symptoms related to IDH (KDOQI Workgroup, 2005). It prevents IDH by preserving the central blood volume and cardiac output with a marginal increase in peripheral vascular resistance (KDOQI Workgroup, 2005). Dialysis patients self-administer this medication 30 minutes before the initiation of HD, as this medication is not available to nurses in outpatient dialysis clinics (Chou et al., 2017). A second dose is administered halfway through the treatment, if needed (Reilly, 2014). The peak action of the drug is one hour after administration, and it is

dialyzed out of the body. Thus, the half-life of the medication on dialysis is three hours (Reilly, 2014). Some patients experience unpleasant side effects from midodrine such as pruritus, supine hypertension, and goosebumps, which may discourage use of the medication (Chou et al., 2017). The side effect of supine hypertension occurs in less than 10% of patients, but, warrants cessation of the medication for patients who experience this side effect (KDOQI Workgroup, 2005).

Dialysis Technological Intervention Used to Prevent IDH.

Blood Volume Monitoring.

A technological device used to monitor blood volume is one in which the patient's relative blood volume (RBV) is recorded in real time throughout the HD treatment (Bradshaw, 2014; Micklos, 2013). These devices non-invasively monitor relative blood volume, hematocrit, and oxygen saturation (Gul, 2016). Some newer dialysis machines come equipped with a blood volume monitor, however, one can be added to the dialysis machine (e.g., Crit-line monitor) (Micklos, 2013).

A Crit-line monitor measures RBV based on hematocrit (Micklos, 2013). It measures hematocrit concentration using photo-optical technology, a sensor emitting a light beam through the blood chamber, the red blood cells reflect the light, the dispersion of the light change due to fluctuations in hematocrit concentrations, and these values are recorded (Micklos, 2013).

In machines equipped with a blood volume monitor, the RBV is tracked in response to changes in hematocrit levels. Specific prompts advise the nurse when the UF rate is less than, equal to, or greater than the plasma refill rate (Bradshaw, 2014). The fluid removal progress is also displayed on the dialysis machine screen (Bradshaw, 2014). The RBV trends provide more information on the patient's hemodynamic stability rather than the absolute value at any point in

time during the dialysis treatment (Bradshaw, 2014). The greater the slope of RBV, the greater the fluid removal rate compared to the plasma refill rate, which does not allow for safer removal of fluid volume and precipitates IDH (Bradshaw, 2014).

Over successive HD treatments, critical RBV (threshold in which the plasma refill rate is greater than the fluid removal rate) levels are determined by the nephrology team for each patient (Bradshaw, 2014). Once the machine is programmed by the dialysis nurse based on each patient's critical RBV, the biofeedback mechanism will inform staff when critical RBV is achieved and will automatically adjust the UF rate accordingly, thus preventing IDH (Bradshaw, 2014).

METHODS

A literature review was conducted analyzing the articles published in the last ten years, in addition to seminal articles. CINAHL, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Medline, and PsychINFO were utilized to identify journals published in nursing. Search terms included: (a) dialysis, (b) intradialytic, (c) dialysis patients, (d) ultrafiltration (and UF, modeling, profiling, monitoring, and biofeedback), (e) hypoten* (and low blood pressure), and (f) blood volume. The population was limited to patients ≥18 years old. The search was limited by those published in English. Duplicate articles were excluded.

Each article was evaluated individually to determine the relevancy of using BVM to determine the UF rate by a title and abstract review. Hierarchy of evidence was considered to assess the reliability and validity of each article. An evidence table was developed to organize the journals and significant findings. A synthesis of the research is presented as a thesis.

By using the search criteria and limiters, a total of 85 journal articles were retrieved. After the title review, 43 articles went under an abstract review, resulting in 12 articles that met the inclusion and exclusion criteria. Five seminal articles were included, accruing a total of 17 articles analyzed in this literature review.

FINDINGS

The literature review demonstrated a consensus that BVM biofeedback technology not only decreased the frequency of IDH but also offered other benefits during treatment. The analyzed studies included randomized control trials (7), nonrandomized control trials (1), prospective studies (5), systematic review and metanalysis (1), pilot study (1), prospective audit (1), and descriptive clinical evaluation (1). The findings are divided into two sections based on the relevant themes found in the review: 1. IDH & intradialytic morbid events (IME) and 2. adequacy & target weight.

Intradialytic Hypotension & Intradialytic Morbid Events

BVM technology demonstrated a reduction in IMEs, which are described as symptomatic hypotensive episodes, muscle cramps, nausea, dizziness, headache vomiting, unconsciousness, or other adverse symptoms requiring nursing intervention (Gabrielli et al., 2009).

Winkler et al. (2008) found similar results in a descriptive clinical evaluation of diabetic patients with cardiac disease. BVM corrected cardiac function and reduced the pure water overload triggered by diabetes and intermittent hyperglycemia (Winkler et al., 2008). The improved refilling rates significantly increased ejection fraction and nearly normalized left ventricular mass index ($p < 0.05$) (Winkler et al., 2008). Clinically, the use of BVM significantly reduced IDH ($p < 0.01$) and muscle cramps ($p < 0.01$) (Winkler et al., 2008).

In a prospective study, McIntyre et al. (2003) showed that treatments using BVM had an IME reduction of 1.5% during HD treatments. McIntyre et al. (2003) identified that BVM technology reduced the incidence of symptomatic and asymptomatic IDH in the patient population prone to IDH and those not prone to IDH ($p < 0.001$).

In a randomized crossover study, Veljančic et al. (2011) further explained that although not all patients benefit from BVM and blood temperature monitoring (BTM), both account for more than 70% of patients experiencing fewer IMEs compared to standard hemodialysis (SHD) ($p = 0.024$). Veljančic et al. (2011) observed that the combination of BVM and BTM contributed to a 45% reduction in IMEs compared to non-isothermal HD. The results were partially attributed to the blood volume control mechanism rather than the BTM (Veljančic et al., 2011).

Steurer et al. (1996) conducted a single sample nonrandomized trial to study five patients for a total of 106 dialysis treatment sessions. The patient sample underwent a control session with SHD alternating with an experimental session, in which BVM was the independent variable. The authors found that blood pressure was not a predictor of intradialytic morbidity. Other symptoms (i.e., muscle cramping, lightheadedness, and nausea) correlated with hypovolemia, although intradialytic symptoms were not constantly reflected by blood pressure changes (Steurer et al., 1996). The variability in intradialytic morbid events and hypotension was due to other factors that affected blood volume shifts, including predialysis hydration status, physical exertion, mental state, and neurohormonal compensatory mechanisms (Steurer et al., 1996). Monitoring blood volume demonstrated that it was more beneficial than blood pressure monitoring in preventing IDH related to hypovolemia ($p = 0.02$) (Steurer et al., 1996). Every subject who experienced IDH and intradialytic symptoms did so at specific hematocrit thresholds (Steurer et al., 1996). This hematocrit threshold was consistent for each patient in subsequent treatments (Steurer et al., 1996). Sessions complicated by IMEs resulted from exceeding the subject's hematocrit threshold (Steurer et al., 1996).

Basile et al. (2001) conducted a prospective randomized crossover study utilizing bicarbonate dialysis treatment in addition to BVM-guided UF. Their study revealed that BVM

improved intra- and inter- dialytic symptoms, specifically symptomatic IDH related to hypovolemia ($p < 0.02$). Basile et al. (2001), also analyzed the effectiveness and safety of long-term dialysate monitoring. Although Basile et al. (2001), did not measure the sodium mass balance directly, there was sufficient evidence to suggest that that sodium balance was not different between the gold standard bicarbonate treatment and the bicarbonate treatment with BVM. Blood pressure, body weight, and serum sodium levels remained unchanged and were identical in a follow up of two years (Basile et al., 2001).

Santoro et al. (2002) utilized a multicenter prospective randomized crossover study to demonstrate that the decrease in IME was due to BVM allowance for greater equilibrium throughout the dialysis treatment. This subjected the body to fewer extreme conditions, both in refilling and pressure. The decreased exposure to extreme conditions led to saved energy and contributed to a decrease in morbid symptoms (Santoro et al., 2002). Sessions complicated by IDH was 33.5% in group A (alternating between standard HD followed by BVM treatment) and 23.5% in the group B (BVM treatments were initiated first followed by SHD) ($p = 0.004$) (Santoro et al., 2002). Group A IDH rates decreased from 34% to 20% when transitioning from SHD to BVM HD (Santoro et al., 2002). In group B, IDH rates went from 31% in the BVM period to 30% in the SHD period ($p > 0.05$). In the second trial, the IDH rates increased from 28% in the BVM period to 39% in the conventional HD period (Santoro et al., 2002). Rates of interdialytic symptoms were also significantly reduced ($p < 0.001$), and better post dialysis tolerance was noted ($p < 0.001$) (Santoro et al., 2002). The patient population that received the greatest benefit from the application of BVM were unstable cardiovascular patients – the more critical the patient, the greater the benefits (Santoro et al., 2002). Patients with refilling problems and those who have significant intradialytic hypovolemia reaped more benefits from the

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continuous use of BVM as compared to patients with good plasma refilling rates, but with cardiomyopathies (Santoro et al., 2002).

In a randomized crossover study, Gabrielli et al. (2009), observed that treatments utilizing BVM had a reduction of IME from 40% to 32% compared to SHD (p = 0.02). BVM was effective in 46% of the sample (Gabrielli et al., 2009). The rate of symptomatic IDH and the average number of episodes were dramatically reduced with the use of BVM (p = 0.04) (Gabrielli et al., 2009). The need for intervention for IMEs and IDH were reduced, but did not reach statistical significance (p > 0.05) (Gabrielli et al., 2009). The blood pressures and heart rates from the beginning to the end of HD treatments were not significantly different between the BVM group and the control group (p > 0.05) (Gabrielli et al., 2009).

Gil et al. (2014) conducted a prospective crossover study and found that IDH was significantly reduced with the use of BVM (p < 0.001). Other observed benefits were a significant reduction in time to recover from fatigue after dialysis (p = 0.048) and a greater reduction in IDH related nursing interventions (p < 0.001) (Gil et al., 2014). The lower the rate of IDH, the less the degree of patient fatigue after dialysis (p = 0.002) (Gil et al., 2014). These results were seen among diabetic and non-diabetic patients (Gil et al., 2014). The number of IMEs without IDH did not significantly differ between SHD and BVM sessions (p > 0.05) (Gil et al., 2014).

Saxena et al. (2015) conducted a longitudinal pilot study and evaluated the use of BVM with BTM compared to a control group not receiving BVM with BTM in a patient population noncompliant with fluid restrictions. The researchers found dialysis treatments uneventful – no incidence of IDH or IMEs. The patients remained stable throughout the dialysis treatment (Saxena et al., 2015). The authors demonstrated that the use of BVM and BTM was highly

accurate and delivered safe HD to a patient population with increased interdialytic weight gain

and noncompliance ($p = 0.012$) (Saxena et al., 2015). Study findings also included that patient

BP during treatments was >120/80 mmHg and that no IDH symptoms occurred, as patients were

overhydrated and did not achieve target weight (Saxena et al., 2015).

A systematic review and meta-analysis by Nesrallah et al. (2013) revealed that patients

who received the BVM treatments had lower IDH rates, along with a reduction of IDH-

associated symptoms. Out of the eight studies included in the meta-analysis, six of the studies

changed the sodium concentration of the dialysate and the UF rate to maximize plasma refilling

(Nesrallah et al., 2013). Sodium biofeedback can theoretically cause positive sodium balance in

HD patients, however, the decreased rate of IDH in the study was not associated with increased

pre-dialysis BP, target weight (estimated patient weight, the goal weight trying to obtain after

HD treatment), interdialytic weight gain, or post-dialysis sodium serum levels (Nesrallah et al.,

2013). The data did not suggest that lower rate of IDH with the use of sodium modeling resulted

in positive sodium loading (Nesrallah et al., 2013).

In Nesrallah et al's (2008) randomized control study, the authors primarily studied BVM

and its effects in extracellular fluid volume (ECFV). The authors reported that the frequency of

IDH was decreased with the use of BVM compared to SHD treatments ($p = 0.04$). Since the

BVM device also influences dialysate conductivity, it could potentially affect the patient's serum

sodium base balance. However, serum sodium level changes were negligible and were not

statistically significant ($p > 0.05$) (Nesrallah et al., 2008).

Sentveld et al. (2008) conducted a prospective crossover study to determine whether

BVM was beneficial in improving hemodynamic stability and quality of life in HD patients as

compared to SHD. The study findings demonstrated that the use of BVM resulted in a

significantly decreased pre-dialysis SBP (p = 0.003). Increased post-dialysis SBP was noted in both groups, the SHD phase to the BVM phase (p = 0.018), and in the BVM phase to SHD phase (p = 0.043) (Sentveld et al., 2008). Treatment time remained unchanged; thus, the duration of treatment was not responsible for increased hemodynamic stability (Sentveld et al., 2008). Quality of life in relation to post-dialysis fatigue was not significantly different between the control and the intervention group (p > 0.05); however, there was a significant difference in fatigue when switching from the BVM to the SHD phase (p = 0.035) (Sentveld et al., 2008).

   Franssen at al. (2005) utilized a prospective clinical trial to study whether BVM improved post-dialysis BP levels in IDH-prone patients and whether BVM is effective in decreasing post-dialysis weight. IDH requiring intervention dropped from 64% (SHD phase) to 37% (BVM phase with constant target weight), and 28% (BVM phase with target weight reduction) (p < 0.01). Post-dialysis SBP with BVM (constant weight and with target weight reduction) was higher compared to those with SHD, but it was not statistically significant (p = 0.07), p = 0.15 respectfully) (Franssen et al., 2005). Alternatively, post-dialysis diastolic BP with BVM was significantly higher compared to SHD (p < 0.05) (Franssen et al., 2005). Monitoring BP post dialysis revealed an increase in SBP during the first 16 hours after the end of treatment in the BVM group as compared to the control group (p < 0.05) (Franssen et al., 2005). These findings can be attributed to: 1) BVM prevented extreme fluctuations of RBV and led to improved hemodynamic stability and 2) stress caused by IDH required a recovery time (Franssen et al., 2005). During the recovery time, the autonomic nervous system is less responsive to low blood pressure by increasing heart rate and/or vasoconstriction and thus inhibits BP variation (Franssen et al., 2005).

Du Cheyron et al. (2010) studied BVM in an acute kidney injury (AKI) patient population in the intensive care unit (ICU) in a prospective randomized control trial. The authors found that the implementation of BVM with blood temperature controls are feasible and safe (Du Cheyron et al., 2010). The rate of hypotension decreased from 29% to 17% with the use of BVM and blood temperature controls ($p = 0.03$) (Du Cheyron et al., 2010).

Some studies demonstrated no significant differences in IDH and IMEs. Four of the 17 studies found no correlation between BVM and decreased rates of IDH and IMEs.

In a prospective clinical crossover trial, Sentveld et al. (2008) that the frequency of complaints associated with hypotension was reduced in both the BVM and the SHD group, but the frequency did not reach statistical significance ($p > 0.05$). The participants had a SHD, followed by BVM phase, and then another SHD phase. For the BVM group, the incidence of complaints was 8.8% while the SHD groups in phase one and three were 14.6% and 12.8% (respectively), but the results were not statistically significant ($p > 0.05$) (Sentveld et al., 2008).

Leung et al. (2017) conducted a randomized single-blind crossover trial assessing whether BVM alone or BVM with adjustments to the dialysate resulted in a decrease in the frequency of symptomatic IDH compared to SHD (control group). Leung et al. (2017) noted that when the intervention treatment period data were combined, the rate of IDH did not differ between the BVM intervention group and the control group ($p = 0.29$). The rate of IDH was lower in the control period than in the run-in period (the period of the trial in which the dialysis prescription was standardized, and target weights were adjusted), showing a 50.8% decline ($p = 0.01$). There were no significant differences in the degree of change in the frequency of IDH from the run-in period to the control or the run-in period to the BVM period ($p = 0.55$) (Leung et al., 2017). The number of treatments with symptomatic IDH ($p = 0.52$), asymptomatic IDH ($p =$

0.67), and IMEs (p = 0.96) were consistent in relation to the primary analysis (Leung et al., 2017). The rate of asymptomatic IDH, symptomatic IDH or IMEs was not decreased with the use of BVM (Leung et al., 2017).

Du Cheyron et al. (2013) conducted a prospective three-arm randomized controlled trial and compared the risks and benefits between BVM alone, BVM with BTM biofeedback, and SHD with cool dialysate and high sodium conductivity. Du Cheyron et al. (2013) determined that there was no difference in the rate of IDH between the BVM intervention group and the control group in an AKI ICU patient population (p = 0.99) (Du Cheyron et al., 2013). SHD was also compared with BVM and blood temperature monitoring and there was no decrease in the rate of IDH (p = 0.39) (Du Cheyron et al., 2013).

Booth et al (2011) conducted a prospective audit of BVM records of 72 stable outpatient adults to determine the usefulness of BVM. No relationship between BP and BVM could be determined (Booth et al., 2011). A drop in SBP of ≥20mm Hg did not show a correlation with the use of BVM or with the amount of fluid removed (Booth et al., 2011).

Adequacy & Target Weight

Adequacy in dialysis is measured by Kt/V values. These values can be determined by two methods. One method is inserting the average blood volume processed during a dialysis treatment into the interface of the dialysis machine, the value is determined by an algorithm in the dialysis machine system and this is an estimated Kt/V value or single pool Kt/V (Advanced Renal Education Program, 2015). This algorithm suggests that urea is confined to one compartment in the body (Advanced Renal Education Program, 2015). The second, more precise measurement of adequacy, called double pool or equilibrated Kt/V, is drawing a serum sample (Advanced Renal Education Program, 2015). The result of the serum sample is plugged into the

algorithm to determine the adequacy for the month (Advanced Renal Education Program, 2015). Both are utilized in clinical practice, however, the double pool Kt/V is used to determine HD prescription change.

Target weight is the goal weight to be achieved at the end of HD treatment. It helps determine the amount of fluid to be removed and it is the anticipated post weight of the patient. It has been suggested that BVM can increase adequacy and better determine precise target weights (KDOQI, 2005).

Out of the 17 studies, 10 addressed target weight and/or adequacy (target weight [2], adequacy [4], both target weight and adequacy [4]). Two of the six studies found no relation to and/or not significant differences between target weight and BVM (Franssen et al., 2005; Gil et al., 2014; McIntyre et al., 2003; Nesrallah et al., 2008). Four out of the eight studies found no significant correlation between adequacy and BVM (Franssen et al., 2005; Gil et al., 2014; Nesrallah et al., 2008; Santoro et al., 2002).

McIntyre et al. (2003) conducted a prospective study and demonstrated that although the use of BVM did not affect target weight, there was a significant decrease in interdialytic weight gain in unstable patients ($p = 0.009$). The researchers hypothesized that the decreased interdialytic weight gain was due to a reduced thirst which occurred immediately after treatment. McIntyre et al. (2003) also reported a significant increase in urea clearance with BVM as compared to SHD (single pool $p = 0.03$, equilibrated $p < 0.01$).

In a randomized control study, Nesrallah et al. (2008) determined that extracellular fluid volume and target weight were not reduced during the six month timeframe of the study. There was no relationship between BVM and Kt/V (Nesrallah et al., 2008).

Santoro et al. (2002) conducted a prospective randomized crossover trial and determined that the Kt/V delivered during treatment was not significantly different, the control group and the BVM group ($p > 0.05$). Weight loss between both groups was not significantly different ($p > 0.05$) (Santoro et al., 2002). The high responders (those benefiting the most from BVM) achieved a weight 0.5 kg higher than those in SHD at the same weight loss (Santoro et al., 2002). The poor responders (those not benefitting from BVM) had a lower post-dialysis weight with BVM than with SHD (0.2 kg), but this corresponded with a higher total weight loss than SHD period (2.9 kg [SHD] vs. 3.3 kg [BVM]) (Santoro et al., 2002)

In critical AKI patients, the incidence of hypotension was inversely related to adequacy (Du Cheyron et al., 2010). Findings from this prospective randomized control study reported a decrease in IDH, with the delivered Kt/V of 1.36 ($\pm$ 0.39), exceeding the goal of 1.2 (Du Cheyron et al., 2010).

In a different prospective three-arm randomized control trial by Du Cheyron et al. (2013), the observed median Kt/V of 1.2 exceeded the prescribed goal.

In a pilot study by Saxena et al. (2015), the researchers reported that the BVM group was better able to tolerate UF during treatments than the SHD group (3L of fluid removal in the BVM group versus 1.9L in the SHD group).

Winkler et al. (2008) used a descriptive clinical study to evaluate a possible reduction in lower target weights after BVM sessions in combination with lower dosage antihypertensive drug therapy. BVM use decreased fluid overload of pure water caused by diabetes and intermittent hyperglycemia (Winkler et al., 2008). Other benefits of BVM included higher Kt/V results ($p < 0.05$, single pool; $p < 0.05$, double pool) as compared to SHD.

In a crossover study, Sentveld et al. (2008) concluded that larger UF rates could be achieved with BVM as compared to SHD ($p = 0.049$). The researchers also demonstrated a significant decrease in target weight with the use of BVM as compared to SHD ($p = 0.032$) (Sentveld et al., 2008).

Gil et al. (2014) completed a prospective crossover study which demonstrated that the body weight (pre-dialysis weight [$p = 0.456$], post-dialysis [$p = 0.432$]) and intradialytic weight gain ($p = 0.320$) did not differ from the BVM group and the control group (SHD group). Dialysis adequacy measured by urea did not differ between the BVM group and the SHD control group ($p = 0.910$) (Gil et al., 2014).

Franssen et al. (2005) completed a prospective study and noted that the Kt/V and target weight reductions did not differ between the control (SHD) and the BVM group. Failure to reduce target weight with BVM necessitated modification of target weight by changing the dialysis prescription (e.g., increasing treatment time) (Franssen et al., 2005).

DISCUSSION

Synthesis of current literature demonstrated the effectiveness of BVM in decreasing the incidence of IDH (Basile et al., 2001; DuCheyron et al., 2010; Franssen et al., 2005; Gabrielli et al., 2009; Gil et al., 2014; McIntyre et al., 2003; Nesrallah et al., 2013; Nesrallah et al., 2008; Santoro et al., 2002; Saxena et al., 2015; Sentveld et al., 2008; Steuer et al., 1996; Veljančic et al., 2011). BVM alleviated intradialytic symptoms of IDH such as muscle cramps, nausea, dizziness, headache vomiting, unconsciousness, or other adverse symptoms requiring nursing intervention (Basile et al., 2001; Gabrielli et al., 2009; McIntyre et al., 2003; Santoro et al., 2002; Saxena et al., 2015; Steuer et al., 1996; Veljančic et al., 2011; Winkler et al., 2008). The benefits of BVM use were seen in both patients prone to IDH and in non-IDH prone patients (Basile et al., 2001; DuCheyron et al., 2010; Franssen et al., 2005; Gabrielli et al., 2009; Gil et al., 2014; McIntyre et al., 2003; Nesrallah et al., 2013; Nesrallah et al., 2008; Santoro et al., 2002; Saxena et al., 2015; Sentveld et al., 2008; Steuer et al., 1996; Veljančic et al., 2011). Patients in a more critical condition, such as unstable cardiovascular patients, experienced greater benefit from the use of BVM (Santoro et al., 2002).

BVM allows greater blood volume stability, which fosters less extreme conditions in refilling and pressure rates (Santoro et al., 2002). Improved refilling rates increased ejection fraction and nearly normalized LV mass index (Winkler et al., 2008). Patients who experienced IDH and IDH-related symptoms did so at specific hematocrit thresholds (Steurer et al., 1996). This threshold was consistent with successive treatments (Steurer et al., 1996).

The studies using sodium modeling in conjunction with BVM did not lead to positive sodium loading after dialysis treatments (Basile et al., 2001; Nesrallah et al., 2013; Nessrallah et

al., 2008). Blood pressure, body weight, and serum sodium levels remained the same in the subsequent two years (Basile et al., 2001; Nesrallah et al., 2013; Nessrallah et al., 2008).

The literature synthesis showed no consensus on the improvement in the dialysis adequacy and optimal target weight. Several studies measured Kt/V by a single pool and equilibrated pool, however not all studies measured both or differentiated the values between the two.

Although BVM technology was determined to be effective and allows for a safer dialysis treatment, nursing judgment continues to be essential to provide high-quality and safe care to patients. This includes advocating for an increase or decrease in hematocrit thresholds, so the patient continues to reap benefits with the utilization of BVM during routine HD treatments.

LIMITATIONS

Although the majority of the research studies analyzed in the literature review were randomized controlled trials, studies higher in the hierarchy of evidence, there are limitations to the literature review findings. One limitation is that not all the included studies used BVM as the only independent variable. Some studies included BTM or sodium biofeedback with BVM (Du Cheyron et al., 2013; Du Cheyron et al., 2010; Nesrallah, 2013; Nesrallah et al., 2008; Saxena et al., 2015; Steurer et al., 1996; Veljančic et al., 2011; Winkler et al., 2008;). It was unclear whether the benefits of reduced IDH and IMEs were attributed solely to the BVM.

Another limitation was that each study defined IDH differently. Some studies used the KDOQI guidelines (Basile et al., 2001; Booth et al., 2011; Leung et al., 2017; Saxena et al., 2015), and others described a hypotensive episode as one that required nursing intervention or one that resulted in IMEs (DuCheyron et al., 2013; Gabrielli et al., 2009; Veljančic et al., 2011). Other definitions included a drop in BP of $\geq$20 mmHg with symptoms (Frannsen et al., 2005; Gil et al., 2014; Sentveld et al., 2008) or without symptoms (McIntyre et al., 2003). Other studies created their own definition of hypotension such as DuCheyron et al. (2010), who described IDH as SBP < 90 mm Hg or a drop in SBP of > 40 mm Hg from baseline that required intervention. Santoro et al. (2002) defined IDH as: 1. a reduction of SBP to < 90 mm Hg with application of nursing interventions, or 2. a combination of pre-dialysis SBP of $\geq$100 mm Hg with a decrease in SBP $\leq$ 90 mmHg without symptoms, predialysis SBP of <100 mm Hg with symptoms or a reduction in SBP of $\geq$25 mm Hg with symptoms. Nesrallah et al. (2008) defined IDH more conservatively as a reduction in SBP of >10 mm Hg, requiring nursing intervention. Steuer et al. (1996) used IMEs as end points into his study and included IMEs as an event, regardless of a

drop in BP. Winkler et al. (2008) did not define IDH but did include IMEs, such as muscle cramping.

Another limitation is the lack of studies within the last five years that address BVM technology and its effects on IDH. Five studies are research published within the last 5 years, indicating a gap in current literature. Additional research is warranted to determine the efficacy of BVM to prevent IDH and other clinically relevant benefits of BVM.

CONCLUSION

The literature review demonstrated that BVM is effective in preventing IDH and IME events. Results did not reveal a strong correlation between BVM and decreased target weights or increased dialysis adequacy (Kt/V). A clear global definition of IDH is needed based on the widely disparate definitions used in the studies. Further research is merited that can examine the effects of BVM use alone without the addition of other variables. The lack of recent studies in the literature indicates that more research is merited in the use of BVM technology with dialysis patients to support the use of BVM in clinical settings and to determine the population that will benefit the most from this intervention. The barriers which prevent the implementation of BVM in clinical settings warrants consideration.

TABLE 1: HIERARCHY OF EVIDENCE

Level I: Evidence from a systematic review of all relevant randomized controlled trials (RCT's), or evidence-based clinical practice guidelines based on systematic reviews of RCT's

Level II: Evidence obtained from at least one well-designed Randomized Controlled Trial (RCT)

Level III: Evidence obtained from well-designed controlled trials without randomization, quasi-experimental

Level IV: Evidence from well-designed case-control and cohort studies

Level V: Evidence from systematic reviews of descriptive and qualitative studies

Level VI: Evidence from a single descriptive or qualitative study

Level VII: Evidence from the opinion of authorities and/or reports of expert committees

TABLE 2: SUMMARY TABLE OF RESEARCH LITERATURE ON BLOOD VOLUME MONITORING

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Randomized crossover trial of blood volume monitoring-guided ultrafiltration biofeedback to reduce intradialytic hypotensive episodes with hemodialysis.	Leung K.C.W., Quinn R.R., Ravani P., Duff H., and MacRae J.M. (2017)	Randomized single blind Crossover Trial	n= 32 Mean age 67, women in sample 17%, years in dialysis 3.65, BMI 30, race: White 17%, Asian 10%, Other 6%; cause of ESRD: DM, HTN, GN, obstructive and other. Access: AVF 12% and CVC 20%. Inclusion criteria: Age >18, medically stable, on HD for >3 months, treating 3-4 x/week for at least 3 hours and ≥30% HD treatments complicated by symptomatic IDH in the preceding 8 weeks. Exclusion criteria: serum hemoglobin <8.0 g/dl, serum sodium <133 meq/L active malignancy, history of blood transfusion or hospitalization in the preceding 4 weeks, ongoing urine output estimated ≥250mL/day, routinely used diuretics for volume management, a planned change in the renal replacement modality	Evaluate whether BVM alone without adjustment of dialysate resulted in decrease in symptomatic IDH when compared to best clinical practice.	BVM did not reduce the rates of symptomatic IDH, asymptomatic IDH or symptoms alone (p= 0.29).	More studies to determine the specific population and the optimal critical blood volume to best utilize this technology.	S: manipulative variable is BVM, washout period, target weight assessed weekly, defined IDH and predisposed IDH sample. L: Small sample size, strict inclusions and exclusion criteria (<10% of those screened were in the study), and not every BP reading was analyzed.	Manipulative variable is BVM.	Level I

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
			during the study period, or unable to provide written informed consent. Setting: Five outpatient HD centers in Calgary, Alberta, Canada.						
Non-invasive method for preventing intradialytic hypotension	Saxena A., Sharma R.K., Gupta A., and John M.M. (2015)	Longitudinal Pilot Study	n= 40 Mean age 41.5 yrs, height (cm) 165.5, BMI 21.1, Hemoglobin (Hbg) (mg%) 8.44, Hematocrit (hct) (%) 27.8, platelets 196,000, serum albumin (g/dL) 3.4,	Evaluate the feasibility of BVM and blood temperature monitoring (BTM)	BVM with BTM strongly correlated with a reduced rate of IDH, the	BVM with BTM should be included in the dialysis protocol.	S: IDH defined according to KDOQI guidelines and no consumption	Intervention included BVM.	Level IV

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
: a pilot study.			and serum creatinine mg (%) 8.2 Inclusion criteria: ≥ 18-years of age, non-diabetic, dose of erythropoietin constant for ≥3 months. Exclusion criteria: overt CHF, cardiac arrhythmia, severe carotid stenosis, history of symptomatic cerebral vascular disease, and positive viral markers (HBV and HIV). Setting: Dialysis unit in tertiary care hospital (India).	preventing IDH prone patients due to noncompliance to fluid restrictions and to assess changes in water compartments.	use of nursing interventions, and intra- and inter-dialytic symptoms (p=0.012).		of food or fluids allowed to prevent food-induced IDH. L: Unclear which intervention influenced results, no female in sample, and patients received HD 2X/week.		
Efficacy of hemocontrol biofeedback system in intradialytic hypotension-prone hemodialysis patients.	Gil H.W., Bang K., Lee S.Y., Han B.G., Kim J.K., Kim Y.O., Song H.C., Kwon Y.J., and Kim Y.S. (2014)	Multi-center prospective crossover study	n= 60 Age 57, Male 31.6%, Diabetes 31.6%, HTN 63.3%, mean time in dialysis 58.3, vascular access: AVF 76.7% and AVG 23.3%, hgb (g/dL) 10.6, serum albumin (g/dL) 3.84, and Antihypertensive meds ACE or ARBs 50%, CCB 43.3%, α or β blocker 41.7%, Direct vasodilator 3.3%. Inclusion criteria: chronic HD patients on 3x/week HD, >3 months on HD,	Determine whether hemocontrol biofeedback system (HBS) improves IDH in IDH prone patients compared with conventional HD.	HBS reduces occurrence of IDH (p <0.001), promote faster recovery from post dialysis fatigue (p =0.048), and decreases IDH related nursing	HBS in clinical setting to reduce IDH.	S: First multicenter prospective study that assessed HBS in Asian patient population, large sample size, defined IDH similar to KDOQI guidelines, and used multiple centers.	HBS is a form of BVM.	Level II

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
			>25% incidence of IDH during the last month preceding the study, age 18-74, ability to provide consent, and interdialytic weight gain >1.5 kg. Exclusion criteria: pre-dialysis MAP in supine position < 90 mmHg, delivered blood flow rate for dialysis < 200 mL/min, pre-dialysis hemoglobin level > 13 g/dL, treatment by hemodiafiltration, unstable angina, myocardial infarction, decompensated congestive heart failure, history of hemodynamically important valvular heart disease, and expected need for blood transfusions. Setting: 9 outpatient HD centers (Korea).		intervention s (p <0.001).		L: Results of the study cannot be generalized to other populations, cardiovascul ar disease was determined by history, crossover design bias on subjective assessment, and target weight assessed by study physician based on clinical evaluation.		

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Biofeedback dialysis for hypotension and hypervolemia: a systematic review and meta-analysis.	Nesrallah G.E., Suri R.S., Guyatt G., Mustafa R.A., Walter S.D., Lindsay R.M., and Akl E.A. (2013)	Systematic Review & metanalysis	Inclusion criteria: age >18, 3x/week dialysis for at least 90 days, chronic fluid overload and symptomatic IDH. Exclusion criteria: Varied by study included reduced life expectancy, severe anemia, pregnancy, and cardiac arrhythmia. Setting: ICHD.	To determine whether biofeedback HD using biofeedback UF and/or variation in dialysate conductivity improves outcomes in patients with chronic fluid overload or symptomatic IDH compared with constant UF and conductivity.	Biofeedback dialysis statistically and clinically significant reduced frequency of IDH. No evidence of harmful effects such as sodium loading with variation of dialysate conductivity.	Biofeedback technology should be considered for IDH prone patients and those with expanded ECF volume.	S: Imposed no language restriction on language of publication, used detailed search strategy, limited metanalysis to patient important outcomes. L: Studies were single blinded, unclear of randomization techniques, studies included biofeedback that adjusted dialysate conductivity unclear which intervention was effective.	BVM biofeedback was the intervention implemented to guide UF and conductivity dialysate.	Level I

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Use of online blood volume and blood temperature monitoring during haemodialysis in critically ill patients with acute kidney injury: a single-centre randomized controlled trial.	du Cheyron D., Terzi N., Seguin A., Valette X., Prevost F., Ramakers M., Daubin C., Charbonneau P., and Parienti J.J. (2013)	Prospective single center three arm randomized controlled trial	n= 74 Average Age 65, , male gender 68%, BMI 26.7, comorbidities: HTN 47%, CAD 27%, DM 100%; Cause of AKI: septic shock 43%, cardiogenic 26%, hypovolemia 11%, drug induced 8%, and other 12%; BUN 18.2 mmol/L, serum creatinine 245 μmol/L, number of sessions 4.5, number of days on RRT in ICU days 9, length of ICU stay 15 days, and mortality 42%. Inclusion criteria: AKI, $\geq$18 years with the first line of RRT as intermittent hemodialysis. Exclusion criteria: ESRD, patient requiring renal replacement therapy that was first initiated with continuous veno-venous hemofiltration, and AKI dialysis session performed with an a priori intentions for no UF. Setting: Medical ICU admission (France).	Compare the risks and benefits of HD protocols either with BV biofeedback or both BV and BT biofeedback compared to standard dialysis therapy with cool dialysate and high sodium conductivity.	No significant difference in occurrence of IDH with BVM and BVM with BTM compared to standard dialysis treatment (p = 0.99).	Further research is warranted before BVM technology is routinely used in ICU setting.	S: Included all AKI related dialysis session with UF and study design. L: Small sample size, critically ill patients are more prone to IDH versus stable ESRD patient, decreased population variety, lack of blinding to medical team, and inability to determine critical BV.	BVM was tested alone as an intervention and compared to BVM with BTM	Level I

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Do changes in relative blood volume monitoring correlate to hemodialysis-associated hypotension?	Booth J., Pinney J., and Davenport A. (2011)	Prospective Audit	n=72 36.1% diabetic patients with 20.8% with prescribed insulin, mean age 55 years, males and females (50%/50%). Exclusion criteria: Patients with implanted defibrillators and resynchronization pacemakers, patients unable to stand on the bioimpedance machine. Setting: University dialysis center (UK).	Assess the usefulness in relative BVM audited changes in relative blood volume in heathy CKD HD outpatients to determine whether there was a correlation with IDH.	Unable to determine any relationship between changes in BVM and intradialytic blood pressures.	BVM techniques solely based on hematocrit could potentially underestimate the effect of UF on plasma volume.	S: Patients refrained from eating during HD but could drink 180mL of fluid. Large sample size. L: Population study did not include IDH prone patients, audit study design, no inclusion criteria, and did not define IDH.	BVM was the manipulative variable.	Level III

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Simultaneous blood temperature control and blood volume control reduces intradialytic symptoms.	Veljančic L., Popović J., Radović M., Ahrenholz P., Ries W., Frenken L., and Wojke R. (2011)	Randomized crossover clinical trial	n= 26 Mean age 56.1 years, mean time in dialysis 6.3 years, 12 males and 14 females, comorbidities (n): HTN (12), CAD (6), LVH (6), and DM (2). Inclusion criteria: Three European countries study population, ≥18 years, thrice weekly HD treatments lasting at least 3 hours, and a history of cardiac instability during HD. Exclusion criteria: Severe instabilities with blood pressure medications, severe anemia, vascular access problems, single needle treatment, HD with varying dialysate sodium concentration or varying ultrafiltration rates. Setting: 6 European dialysis centers.	To investigate the clinical benefit of simultaneous control of BTM and BVM.	Combined use of BVM and BTM provided an average of 45% fewer intradialytic complications compared to standard HD (p = 0.024).	In a population with high incidence of IME combined application of both individualized automatic biofeedback systems is suggested as a preventative measure.	S: Sample prone to IMEs, screening phase in which individual patient critical BV was determined, and defined IME. L: Inability to distinguish the intervention that caused the significant improvements in IMEs, the intervention was not blinded by no blinding, and small sample size.	BVM was used as an intervention alongside BTM.	Level I

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Blood volume- and blood temperature-controlled hemodialysis in critically ill patients: a 6-month, case-matched, open-label study.	du Cheyron D., Lucidarme O., Terzi T., and Charbonneau P. (2010)	Prospective open label, case matched study	n=20 Historical Control: n=42. Age 61, male 43%, comorbidities: hypertension 38% and cardiomyopathy 10%. Origin medicine 86%. Cases: Age 59, male 60%, Comorbidities: hypertension 60% and cardiomyopathy 30%. Origin medicine 85%. Age 61, male 43%, Inclusion criteria: AKI in oliguric stage dialyzed exclusively by intermittent hemodialysis (IHD). Exclusion criteria: Patients with end-stage renal disease and dialysis treatments involving administration of packed red blood cells. Setting: Medical ICU (France).	Test the feasibility and safety of concurrent BV and BT monitoring during HD.	Blood volume monitoring and blood temperature monitoring proved to decrease incidence of hypotension and maintain hemodynamic stability (p = 0.03).	Simultaneous BV and BT monitoring are safe and feasible in AKI patient in the ICU.	S: Defined safe, feasibility, and hypotension. Each pair of patients and dialysis treatment had to fulfill 4 conditions: case patients should have the same age (±5 years) and the same SAPS II (±10 points) at ICU admission as historical controls; and among these pairs of patients, online monitoring dialysis sessions should have the same dialysate sodium	Manipulative variable is BVM technology.	Level II

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
							concentration (±1 mmol/l) and the same net, ultrafiltration per session (±500mL) as conventional dialysis sessions, and no statistically significant differences between the groups. L: AKI oliguric patients were the focus of the study. The treatment modality included temperature and blood volume monitoring, it remains unknown which		

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
							variable caused increased hemodynamic stability. ICU patients were the main population understudy. Small sample size. Control group used was a historical control group from 2007 treated with standard IHD.		
Improved intradialytic stability during haemodialysis with blood volume-controlled	Gabrielli D., Krystal B., Katzarski K., Youssef M., Hachache T., Lopot F., Lasseur	Open randomized crossover study	n=26 Age 69.7, mean time on RRT 4.5 years, % of males 53.8, 60, sessions with IME 47.5, Comorbidities no.: DM 15.4%, coronary heart disease 38.5%, myocardial insufficiency 15.4%, previous MI 15.4%, HF 34.6%, peripheral	Investigate differences in hemodynamic stability when compared to standard HD with BVM controlled UF.	Relative BVM biofeedback control of UF decreased the frequency of IMEs (p = 0.02) in	Use of BVM without alteration in sodium dialysate to decrease IMEs.	S: manipulative variable BVM, IME prone patients selected, eliminated variables that could	Only modified variable was BVM guided UF.	Level I

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
ultrafiltration	C., Gunne T., Draganov B., Wojke R., and Gauly A. (2009)		arteriopathy 34.9%, previous stroke 15.4%, HTN 69.2%, autonomous neuropathy 11.5%, cardiac arrhythmia requiring treatment 26.9%, and other 30.8%; 77% were on BP meds and 85% were on EPO. Inclusion criteria: 3x/week HD with at least 180 minutes of treatment time, prone to IDH, 1/3 of treatment was complicated by intradialytic morbid events (IME which are hypotension, cramps, nausea, vomiting, headache, dizziness, or other adverse symptoms requiring medical intervention). Exclusion criteria: application of blood temperature control, sodium or UF profiles, planned change in dialysate composition or dose of recombinant human erythropoietin, current intake of antihypotensive medications, frequent change in target weight, and		hypotension prone patients from 40% (during standard HD) to 32%.		affect blood volume control and intradialytic stability were eliminated and dialysis and medication prescription were kept constant. L: patient and user bias, small sample size, and BVM group had on average 2 minutes more than prescribed treatment time.		

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
			other severe medical conditions. Setting: Nine HD centers.						
Can extracellular fluid volume expansion in hemodialysis patients be safely reduced using the hemocontrol biofeedback algorithm? A randomized trial	Nesrallah G.E., Suri R.S., Thiessen-Philbrook H., Heidenheim P., and Lindsay R.M. (2008)	Open label randomized control study	n = 60 Best Clinical Practices (BCP) (31): Age 68, male 67%, race: white 87%, black 3%, native Canadian 10%; urine output >200mL/d 26%, Comorbidities: DM 24 77%, HTN 84%, cardiovascular disease 77%; Medications: Diuretics 16%, ACEI 55%, Beta blocker 61%, and other 35%. Hemocontrol Biofeedback System (HBS) (29): Age 64.1, male 55%, race: white 86%, black 0%, native Canadian 14%; urine output >200mL/d 34%, Comorbidities: DM 76%, HTN 90%, cardiovascular disease 76%; Medications: Diuretics 28%, ACEI 48%, Beta blocker 59%, and other 45%. Inclusion criteria: HD thrice weekly for at least 6 months	Examine the effects of HBS when compared to best clinical practices on ECFV and secondary outcomes in ECF expanded HD patients.	HBS did not change ECFV, however did decrease frequency of IDH (p = 0.04) compared to best clinical practices.	It is possible to use HBS software to normalize hydration status by increasing ionic mass removal to gently desalt patients. Further studies are needed.	S: Defined IDH, large sample size, study length, and baseline period. L: between group differences at baseline, selection criteria not based on frequent IDH or IME. Also, HBS used biofeedback changed dialysate and the UF rate according to RBV.	HBS is BVM technology, however, the biofeedback system changed dialysate conductivity.	Level I

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
			at the London Health Science Center, predialysis ECFV > 45% of total body water, age 18-85, blood flow rate ≥350mL/min, treatment time ≥3.5 hours, and hemoglobin 110-120 g/L. Exclusion criteria: urine output >400mL/day, treatment with hemofiltration/hemodiafiltration, blood transfusion dependence, pregnancy, hemodynamic instability due to arrhythmia, and use of alpha-adrenergic agents to prevent IDH Setting: London Health Science Center.						

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
The influence of blood volume-controlled ultrafiltration on hemodynamic stability and quality of life.	Sentveld B., Van den Brink M., Brulez H.F.H., Potter Van Loon B.J., Weijmer M.C., and Siegert C.E.H. (2008)	Prospective Multiple crossover study	n = 18 (19 enrolled 1 moved) 13 males and 6 females, mean age 64, mean time on HD 44 months, cause of RF: diabetic neuropathy (6), hypertensive nephrosclerosis (5), polycystic kidney disease (3), chronic interstitial nephritis (1), IgA nephropathy (1), Wegener's granulomatosis (1), reflux nephropathy (1), and postrenal obstruction nephropathy (1). Inclusion criteria: Patients treated 3 times weekly with 4-hr sessions Exclusion Criteria: Patients who received treatment for cardiac failure or received BV guided UF. Setting: General Dialysis department (Netherlands).	Determine whether BV controlled UF compared to conventional UF is beneficial to hemodynamic stability and quality of life.	BVM demonstrate improved hemodynamic stability (pre-treatment p = 0.003, post-treatment p = 0.018), increased ultrafiltration capacity (p = 0.049), and a decrease in dry weight (p = 0.032). But it does not demonstrate a change in quality of life.	Use of BVM in clinical setting to increase hemodynamic stability and UF capacity in heterogeneous population of HD patients.	S: determined critical BV before initiating intervention, treatment time remained unchanged, objective tool was used to determine quality of life, and IDH was defined. L: Small sample size, population did not equally represent females, sample population did not include IDH prone patients	Intervention utilized was BVM biofeedback HD.	Level II

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Blood volume monitoring.	Winkler R.E., Pätow W., and Ahrenholz P. (2008)	Descriptive clinical evaluation	n=18 11 males and 7 females mean age 56.4 Inclusion criteria: Diabetic patients with known cardiovascular disease and experienced HD related complications like cramps and IDH; age ≥18, and start of RRT 39 months Exclusion criteria: none found. Setting: not described.	BVM with regulations of UF and sodium was evaluated to describe advantages for efficacy and compatibility with HD.	BVM improved the adequacy (p single pool <0.05, p double pool <0.05) compared to SHD and removal of pure fluid (p >0.05). Also, patient can reach optimal weight (p >0.05) with reduced HD related complications (p <0.01)	BVM offers a unique possibility to treat diabetic patients according to their special needs.	S: Inclusion of IDH prone patients. L: Small sample size, BVM guided UF with sodium intervention - remains unknown which intervention proved to be effective, no sample description, and IDH not defined.	Manipulative variable in study was BVM guided UF, however it also included biofeedback of sodium.	Level II

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Automatic feedback control of relative blood volume changes during hemodialysis improves blood pressure stability during and after dialysis.	Franssen, C.F.M., Dasselaar J.J., Sytsma P., Burgerhof J.G.M, de Jong P.E., and Huisman R.M. (2005)	Prospective study	n=12 Age 64.2 years, mean time on HD 4.5 years, causes of CKD: DM (5), HTN (4), PKD (1), lupus (1), and acute RF after AAA rupture (1), AVF and AVG (11 total) and CVC (1), major cardiac comorbidity (2), BP meds (6) and prescription unchanged throughout study, residual renal function (3), hgb 7.4 mmol/L and albumin 37.7 g/L. Inclusion criteria: chronic HD for >6 months, HD 3 times/week, and symptomatic IDH requiring intervention in 50% of sessions over the past 6 weeks. Exclusion criteria: IDH caused by primary cardiac rhythm disturbances and a history of frequent transfusions of packed red blood cells (defined as >2 units/month during the past 3 months). Setting: ICHD (Netherlands).	Whether blood volume tracking (BVT) improved post dialysis BP in hypotensive prone patients and whether BVT is effective in reducing post treatment weight.	BVT is associated with better intradialytic hemodynamic stability (p <0.01) and higher systolic BP after HD (BVM with constant weight vs SHD p =0.07, BVM with reduction in weight vs SHD p = 0.15) compared to standard HD. However, it is not able to lower post HD weight (p >0.05).	BVT is effective in reducing IDH and increase systolic BP up to 16 hours post HD.	S: Defined IDH treatment interventions, defined IDH (not defined as KDOQI guidelines), and drew pre- and post- sodium level labs. L: Small sample size, adjusts both dialysate conductivity (adjusts sodium) and BVT guided UF.	Manipulative variable was BVT a form of BVM technology.	Level III

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Biofeedback controlled hemodialysis (BF-HD) reduces symptoms and increases both hemodynamic tolerability and dialysis adequacy in non-hypotension prone stable patients.	McIntyre C.W., Lambie S.H., and Fluck R.J. (2003)	Prospective study	n=15 Mean age 66, 14 males and one female. Inclusion criteria: on HD for >6 months at the beginning of BF-HD, dialyzing through an established arteriovenous fistula, considered stable based on previous history, prior to transfer to minimal care facility. Patients HD treatments complicated by systolic BP >40% (IDH) was 0.9 (0-3) episodes/patient/3- week period and significant symptoms related to IDH was 1 (0-4) episodes/patient/3-week period, and no patient had interdialytic weight gains >4kg. Exclusion criteria: None mentioned. Setting: 4 station minimal care dialysis facility within in the author's main unit (UK).	Evaluate the use of BF-HD in patients that are considered stable (representative of most chronic HD patients). Investigate BVM and its effect on tolerability, blood pressure, interdialytic weight gain, and urea clearance.	BF-HD can improve hemodynamic tolerability (p <0.001) and morbidity (p <0.001). In addition, decrease interdialytic weight gain (p = 0.009) and improve urea clearance (single pool p = 0.03, equilibrated p <0.01). . Also, decreases the amount of nursing interventions for IDH.	BF-HD may possess benefits for a larger dialysis population group than existing data suggest.	S: prescription optimization period, defined IDH, no alteration in blood flow rate, dialyzer type or size, or treatment times; and no alteration in dietary sodium intake. L: Small sample size, definition of IDH was not in accordance with KDOQI guidelines, changed UF and dialysate conductivity, more males than females in sample, and non-pone IDH population.	Manipulative variable is BF-HD is BVM technology.	Level II

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
Blood volume-controlled hemodialysis in hypotension-prone patients: a randomized, multicenter controlled trial	Santoro A., Mancini E., Basile C., Amoroso L.., Di Giulio S., Usberti M., Colasanti G., Verzetti G., Rocco A., Imbasciati, Panzetta G., Bolzani R., Grandi F., and Polacchini M. (2002)	Multicenter, prospective, randomized, crossover study	n=36 Mean age 67.1, mean time on dialysis 41.8 months, sex M/F 14/18, hgb 10.3 g/dL, hct 31.6, serum albumin 3.9 g/dL, cause of ESRD: glomerulonephritis 18.8%, interstitial nephropathy 15.6%, nephroangiosclerosis 25%, PKD 18.8%, Diabetes 18.8%. Inclusion criteria: HD 3 times/week, treatment time ≥180 minutes, stable clinical conditions with residual diuresis ≤400mL/day, stable hgb or hct, a mean interdialytic weight gain ≥1.5kg, reduced hemodynamic stability during HD (one episode of acute IDH in 20-80% of dialysis) in the last two months prior to the start of the study, and have one of the following comorbid conditions: cardiac disease, DM I/II, and arterial hypertension (already present and diagnosed for at least 6 months).	Compare blood volume tracking system to standard bicarb dialysis in respect to improvement in tolerability in a large number of IDH prone patients. Secondly, identify patient parameters to help recognize which patients draw the most benefits from continuous and automatic BVM.	BVM improved intradialytic cardiac stability (p = 0.004) with improvements in interdialytic symptoms (p <0.001). Population that seemed to respond better to this treatment were patient with an increased risk for IDH during standard HD and non-hypotensive pre-dialysis BP.	This is the first step in a physiological dialysis where treatment parameters are dynamically changed by the delivery system incorporating adaptive and logic controls.	S: Defined IDH, population predisposed to IDH, multicenter study, pre and post sodium level draws once a week. L: Small sample size compared to statistical sample analysis, 32 subjects included in statistical analysis, Kt/V is estimated, BV guided conductivity, and IDH was not defined within the parameters of KDOQI guidelines.	Manipulative variable is BVM technology.	Level I

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Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
			Exclusion criteria: The presence of a persistent intradialytic cardiac instability (IDH occurred in >80% of treatments). Setting: 10 HD centers (Italy).						
Efficacy and safety of haemodialysis treatment with the Hemocontrol biofeedback system: a prospective medium-term study	Basile C., Giordano R., Vernaglione L.., Montanaro A., De Maio P., De Padova F., Marangi A.L., Di Marco L.., Santese D., Semeraro A., and Ligorio V.A. (2001)	Multicenter, prospective, randomized cross over study	n= 35 7 males and 12 females, mean age 64.5, mean time on dialysis 80.5 months, and affected by different nephropathies including two with DM. Inclusion criteria: Maintenance standard bicarb treatment for at least 6 months and hemodynamic instability (≥20% HD sessions complicated by symptomatic IDH). Exclusion criteria: None described. Setting: 10 Italian dialysis units.	Assess whether bicarbonate treatment equipped with HBS was able to decrease cardiovascular instability and patient morbidity compared with standard bicarbonate treatment. Compare the efficacy and safety of HBS with that of standard bicarbonate treatment in the medium term.	HBS is effective in reducing IDH and other intra- and inter dialytic symptoms (p <0.02).	HBS is an effective treatment in decreasing hypovolemia related morbidity than standard treatment. Also, it is a safe treatment for medium term because the results are attained without potential harmful changes in BP, weight, and serum sodium levels.	S: Defined IDH, patients wrote down symptoms pre, intra and post HD (symptoms were rated on a 0-10 scale), blood draws in the beginning of each month (ABGs, serum urea nitrogen, creatinine, calcium, sodium, potassium, phosphate, uric acid, hemoglobin, and hematocrit),	HBS is the manipulative variable (this is a form of BVM technology).	Level I

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
							nursing staff recorded IDH and muscle cramps, BP was taken in supine position, no eating or drinking was permitted during treatment, L: Kt/V was estimated not confirmed by blood draw, two studies the medium study lacked a time control group while the short-term study included an on/off treatment schedule, it did not identify		

Study Name	Authors	Design	Sample Size, Participants, and Settings	Aim	Key Findings	Suggested Interventions	Strengths (S) & Limitations (L)	Relevance	Level of Evidence
							asymptomatic IDH, and HBS also changed dialysate conductivity.		

Reducing symptoms during hemodialysis by continuously monitoring the hematocrit.	Steuer R.R., Leypoldt J.K., Cheung A.K., Senekjian H.O., and Conis J.M. (1996)	Single sample non-randomized control trial	n=6 Sample no described. Inclusion criteria: Dialysis staff determined based on experience which patients were IDH prone. Exclusion criteria: None described. Setting: University of Utah affiliated Bonneville Dialysis Unit.	Exploit critical hematocrit threshold to design strategies to may reduce intradialytic morbidity without changing treatment times or target volume removal.	There are other symptoms correlated with hypovolemia that are not reflected by BP. BVM appears to be more useful than BP monitoring in predicting and preventing hypovolemia induced morbidity (p 0.02).	Hematocrit threshold is a valid concept that shows a two-fold reduction in hypovolemic symptoms without extending treatment time or reducing target fluid removal. Large scale studies are needed to determine what patient population would most benefit from this technique.	S: Defined IDH, no blood transfusions given, and used intradialytic symptoms as end points for intradialytic morbidity without changes in BP improved standard deviations and hematocrit thresholds. L: Small sample size, sodium concentration fluctuated during treatment, lacked wash out period, did not included asymptomatic IDH, and did not include various other symptoms that occurred during HD. Sample not described.	Crit-lines are a form of BVM technology.	Level III

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