Body composition monitoring: an emerging technology to help guide fluid management in haemodialysis patients

Elizabeth Lindley and David Keane
Departments of Renal Medicine and Medical Physics
Leeds Teaching Hospitals NHS Trust, UK

Elizabeth Lindley is a Specialist Clinical Scientist in Renal Care
David Keane is a Clinical Scientist on an NIHR Fellowship

For correspondence:
Dr Elizabeth Lindley
Department of Renal Medicine
St James's University Hospital
Beckett Street
Leeds LS9 7TF

Tel: 0113 206 4119

Summary

Haemodialysis patients with little or no urine output usually experience periods of overhydration as they accumulate fluid between treatments through intake of salt and water. Many are also dehydrated when fluid is removed during dialysis sessions. The time-averaged deviation from normal hydration will depend on the patient’s fluid status after dialysis and their interdialytic fluid gains (IDFG). Attempts to minimise the adverse effects of abnormal hydration begin by setting the patient’s ‘target’ weight to optimise their post-dialysis fluid status. However, the clinical indicators that are traditionally used to adjust target weight can be ambiguous or misleading. Body composition monitoring using multifrequency bioimpedance measurements can now provide an objective assessment of fluid status. The measurements are non-invasive and can be made in a few minutes before or after dialysis. If added to the complete clinical picture, this technology can improve outcomes and quality of life for patients on haemodialysis.

Key words

Haemodialysis, fluid overload, dehydration, bioimpedance, body composition monitoring.
**Introduction**

Haemodialysis patients usually accumulate extracellular fluid between dialysis sessions, despite restricting dietary sodium intake. This is managed by programming the dialysis machine to remove fluid by ultrafiltration so that the patient finishes dialysis at their prescribed ‘target’ weight. Getting the target weight right is a vital element in the care of haemodialysis patients. If set too high, patients will be overloaded throughout the interdialytic period leading to or worsening cardiovascular co-morbidity. On the other hand, setting the target weight too low can lead to cramps and post-dialysis fatigue, as well as accelerated loss of residual renal function (RRF) and an increased risk of a clotted fistula or graft.

There are various definitions of the target weight in the literature. Information intended for patients might say it is ‘similar to what a person with normal kidney function would weigh after urinating’ (DaVita, n.d.). Historically, publications aimed at professionals often define target weight as the lowest weight a patient can tolerate before becoming symptomatic (Henderson, 1980) or the post-dialysis weight at which the patient can remain normotensive until the next dialysis, despite retention of salt and water (Charra et al, 1996).

The historical approaches to setting target weight are based on the assumptions that there is a direct correlation between blood pressure and fluid overload, so that an increase in overload will lead to an increase in blood pressure, and that a patient will become symptomatic when their extracellular fluid volume is below normal. However, the correlation between blood pressure and fluid status is known to break down with co-morbidity such as heart failure and in some cases when blood pressure increases during dialysis. The introduction of body composition monitoring has revealed the degree of dehydration that some patients are able to tolerate, highlighting that symptoms are very patient dependent.

This unrecognised dehydration could be causing haemodialysis patients to lose residual function. In peritoneal dialysis, residual function is routinely monitored and protected (Marrón et al, 2008) but it is widely assumed that RRF is not important in haemodialysis. This may have been true in the past when bioincompatible membranes and contaminated dialysis fluid probably contributed to loss of RRF. More recently, single centre (Vilar et al, 2009) and national (van der Wal et al, 2011) studies have shown that RRF can be preserved
in haemodialysis, and that loss of RRF is a powerful a predictor of mortality (Brener et al, 2010).

With body composition monitoring to provide an objective measurement of hydration, it is possible to define target weight as the post-dialysis weight that enables the patient to remain close to normal hydration throughout the interdialytic period, with optimal control of blood pressure but without experiencing discomfort or compromising residual function.

**Bioimpedance and body composition monitoring**

The technology used in body composition monitoring is ‘bioimpedance’. This is the impedance of the body to an alternating current, usually measured between pairs of electrodes on the wrist and ankle (see figure 1). A detailed explanation is beyond the scope of this article but essentially bioimpedance depends on body size (mainly the cross sectional area of the limbs), body composition (the proportion of adipose and lean tissue) and hydration.

The challenge in bioimpedance technology has been to find a way to account for variation in impedance related to body size and composition to allow hydration to be measured. In Bioimpedance Vector Analysis, the two components of impedance (resistance and reactance) measured for a current at a frequency of 50 kHz are normalised to height and plotted on a chart that shows where males or females with different physical characteristics should appear (Piccoli 1994, see figure 2). ‘BIVA’ can provide very helpful information, especially when looking at trends rather than single measurements, but it requires the operator to make a subjective assessment of where the normally-hydrated vector would be for each patient.

The Body Composition Monitor (BCM, Fresenius Medical Care, Bad Homburg) has been designed to distinguish between abnormal and normal hydration. It uses the bioimpedance measured for currents with frequencies of 5 kHz to 1 MHz and a well established fluid model to determine the extracellular and intracellular water volumes (ECW and ICW) (Moissl et al, 2006). A second model is used to convert these volumes and the patients weight to a unique combination of lean and adipose tissue mass (LTM and ATM) which add up to the patient’s normally-hydrated weight, and either over- or under-hydration (Chamney et al, 2007) as shown in figure 3. This simple conversion is possible because the percentage of ICW and ECW in normally-hydrated lean and normally-hydrated adipose tissue seems to be very consistent across age, gender and race.
The models used in the Fresenius BCM have been extensively validated and show good agreement with the gold standards for measuring ECW, ICW, fat and fat-free mass (Wabel et al, 2007). There is no gold standard for assessing abnormal hydration against which the BCM can be compared. However after initial studies showed that making BCM-guided changes in target weight was safe and clinically effective (Ponce et al, 2009, and Macek et al, 2010), there have been many more studies showing the potential benefits of this approach to fluid management (such as Hur et al, 2013, Moissl et al, 2013 and Onofriescu et al, 2014). BCM measurements are now routinely used to characterise hydration in studies to assess the benefits of interventions to reduce fluid overload in haemodialysis patients (such as Hecking 2012, Dunlop, 2014). The BCM is also increasingly used in epidemiological studies in chronic kidney disease and peritoneal dialysis (such as Tsai et al, 2014 and Kwan et al, 2014).

**BCM-guided fluid management**

BCM measurements do not replace the regular clinical assessments that are an essential element in the management of haemodialysis patients, but they add an objective measurement of fluid status. This is especially helpful where the patient is asymptomatic or where the symptoms reported are contradictory. Many patients with fluid overload show no obvious signs of oedema and have no breathing difficulties. Heart problems can lead to low blood pressure in a patient with severe fluid overload while an inadequately blocked renin-angiotensin system can lead to high blood pressure in a patient who is dehydrated. Chest infections, left sided heart failure and anaemia can cause breathlessness in fluid depleted patients.

The most important information provided by the BCM is the ‘normally-hydrated weight’. This is the patient’s weight corrected for fluid overload or dehydration, i.e. the sum of the normally hydrated LTM and ATM (52.5 kg for the case in figure 3). It is approximately what the patient would weigh if their kidneys were working normally. Although BCM measurements are usually made pre-dialysis, the normally hydrated weight can also be obtained post-dialysis, or during in-patient admissions or clinic visits. The parameter that will differ with the timing of the measurement is the ‘overhydration’. This is the difference between measured and normal hydration in litres (or between measured and normally-hydrated weight in kg) which means that dehydration appears as negative overhydration. The
overhydration is usually positive or close to zero pre-dialysis. It is often negative post-dialysis.

The usual approach to BCM-guided fluid management is to try to select a target weight that keeps the patient within a specified hydration window at all times during the interdialytic interval. The size of the window should reflect the size of the patient, e.g. ±1.5 L around normal hydration for small patients and ±2.5 L for the very large. Within this constraint, the target weight can be adjusted to make the dialysis as beneficial and tolerable as possible. Some patients’ target weights will tend to be set at or near the normally hydrated weight displayed by the BCM. For others, a target weight above or below their normally hydrated weight will give the best clinical outcome while keeping them within the desired hydration window.

To achieve the best outcome, the BCM data should be combined with other clinical information including residual renal function, interdialytic fluid gains, blood pressure before and after dialysis, anti-hypertensive medication, intradialytic symptoms and post-dialysis recovery time. For a patient who has good urine output, dialysis should provide effective clearance of toxins and prevent accumulation of fluid without excessive dehydration. This should maintain residual function for as long as possible in chronic kidney failure and give the kidneys of patients who had an acute (or acute-on-chronic) start to dialysis the best chance of recovery. In most units, the patient (or their carer) will need to provide an estimate of urine output as this is not usually measured routinely in the haemodialysis population.

For patients with high blood pressure, correction of overhydration by removing fluid during dialysis is vital and can often allow anti-hypertensive medication to be reduced or stopped (Agarwal and Weir 2010). However, once near-normal hydration has been achieved, continuing to reduce the target weight will lead to excessive dehydration. This can cause cramps, increased post-dialysis fatigue and an increased risk of clotting in fistulae and grafts.

In general, the target weight should be set towards the lower limit of the hydration window for anuric patients with high IDFGs who tolerate dehydration or those with moderate IDFGs who feel more comfortable when slightly dehydrated than overloaded. It should be set close to the normally hydrated weight for a patient with good residual function. Patients who do not tolerate dehydration at all may need a target weight that leaves them slightly overhydrated post-dialysis. If the symptoms resolve soon after dialysis, the patient is probably a ‘poor
refiller’ and may benefit from interventions such as lower temperature dialysate and ultrafiltration profiling (Palmer and Henrich, 2008), or modification of antihypertensive medication. Dialysis tolerability can be evaluated from symptoms and the need for interventions, but it is also important to include the patient’s opinion and their assessment of post-dialysis fatigue.

Patients who cannot achieve normal hydration may also need counselling on minimising salt and fluid intake, as they can easily reach the upper limit of the fluid margin and tend to cope badly with high ultrafiltration rates.

**How will introducing BCM measurements affect patient care?**

The principles of BCM-guided fluid management described above are essentially the same as those used when only traditional clinical indicators are available. BCM measurements can help reveal where symptoms have the expected relationship to hydration and where they are misleading. Adjustment of target weight (or withholding adjustments) based on misleading clinical indicators is likely to move the patient’s fluid status away from normal.

The indicator most likely to lead to inappropriate changes in target weight is blood pressure. Whilst a trend to higher or lower blood pressures can provide important clinical information, blood pressure itself is a rather poor predictor of fluid status. The scatter plot in figure 4 shows the relationship between pre-dialysis systolic blood pressure and hydration status for the first BCM measurement made in 474 haemodialysis patients under the care of Leeds Teaching Hospitals (Lindley et al, 2011). A very similar plot was obtained in a cross-sectional study of 639 PD patients (Van Biesen et al, 2011). The expected increase in blood pressure with fluid overload is present, but only as a trend for the population. The most dehydrated patients are more likely to have high blood pressure than low and a substantial proportion of severely overloaded patients are normotensive or even hypotensive.

When the BCM was introduced in the Leeds dialysis units in 2009, 420 patients (aged 19 to 91 years, 58% male) were first measured after they had been on dialysis for at least 6 months (Lindley et al, 2012). From the first BCM measurement of normally hydrated weight it was possible to see the variation in hydration at the prescribed target weight that had been established using traditional methods (regardless of whether or not the patient achieved this target). The variation is shown in figure 5 (a). The patients are grouped according to their average daily fluid gain in the week before the measurement and their body mass index
(BMI) at normal hydration. The trend towards greater dehydration at target weight in patients with high IDFG (p<0.001) is expected when trying to avoid periods of severe fluid overload. The same trend in patients with high BMI (p<0.001) is probably due to a combination of better tolerance of dehydration and reluctance to increase target weight to reflect gains in flesh weight. At the first BCM measurement, female patients tended to be about 0.5 L more dehydrated than males (p=0.02). There was also a trend towards greater overhydration with age, probably due to decreased tolerance of dehydration, though this was not statistically significant until the hydration was normalised to ECW.

The majority of the Leeds patients were dehydrated to some degree at their prescribed target weight. This may be a centre effect, possibly associated with use of relatively low dialysate sodium (137 mmol/L) and temperature (36°C), and also blood volume monitoring to guide fluid management. However, the pre-dialysis fluid overload on the day of the patients’ first BCM as a percentage of their normally hydrated ECW was 21 ± 15%, 11 ± 13% and 3 ± 10%, for patients with BMI <18.5, 18.5 – 30 and > 30 kg/m² respectively which agrees well with the relative fluid overload measured in 244 patients in Vienna by Antlanger et al (2013).

The degree of dehydration measured in obese patients, which can be more than 4 L, has led to concerns that the BCM models used cannot be applied to this population. Antlanger’s group also measured ‘N-terminal pro-B-type natriuretic peptide’ which is a biomarker for fluid overload that is secreted in response to stretching of cardiac muscle cells (Kim and Januzzi, 2011). They found that levels of NT-proBNP were very much lower in obese compared to underweight patients. A study of bariatric surgery patients with normal kidney function showed that whilst the variation in measured hydration is greater in these patients than in the non-obese, the average deviation from normal hydration was only 0.1 L (Keane 2014, private communication). These two studies indicate that obese patients on haemodialysis do tend to be dehydrated whereas those with normal renal function do not, suggesting that the dehydration is due to excessive ultrafiltration.

Of greater concern is the degree of overhydration in patients with low BMI. This may be linked to reluctance to decrease target weight in patients who are already very underweight. The paradoxical association of lower BMI with higher mortality in dialysis patients is well-known and has already been associated with poor control of hypertension and excessive ECW in leaner patients (Agarwal 2011). Intolerance of dehydration may make it impossible
to achieve normal hydration in some patients but it is not usually beneficial to set a target weight to more than 1 kg above their normally hydrated weight.

Figure 5(b) shows hydration at the target weight prescribed after the first BCM measurement for the group of patients shown in 5(a). This narrowing of the variation in hydration is expected when BCM-guided fluid management is introduced. Reductions in target weight often need to be implemented gradually, increases can be made right away. If an increase in target weight results in a corresponding decrease in IDFG, this is an indication that the patient has good residual function and should not be dehydrated.

As with any diagnostic test, some patients are more challenging than others. The BCM relies on models that were developed using wrist-to-ankle measurements made in normal controls and dialysis patients who were lying flat and who were not at the extremes of body composition or seriously unwell. However, provided departure from the models is acknowledged by making any changes cautiously, hand-to-hand measurements can be used to guide fluid management in bilateral amputees and to check for generalised overhydration in patients with severe lower limb oedema (Keane and Lindley, 2014). The BCM cannot measure lung water, but it can help minimise the extra burden of interdialytic fluid overload in patients with left heart failure. BCM measurements may also help identify interventions to mobilise fluid in patients with poor vascular refilling capacity and and/or localised oedema. Further research is needed to realise the full contribution that this low-cost, patient-friendly tool can make to renal care.

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Key Points

- Traditional clinical indicators of fluid status, particularly blood pressure, can be misleading.

- The Body Composition Monitor (BCM) is a well validated and can provide an objective measurement of hydration status in a few minutes.

- The ‘normally-hydrated weight’ determined from BCM measurements should be combined with regular clinical assessments to guide fluid management.

- In BCM-guided fluid management, excessive dehydration and overhydration are avoided but target weight is still individualised to minimise discomfort.

- Prevention of inappropriate dehydration can help preserve residual renal function and support recovery of the kidneys after acute injury.

- Further research is needed to realise the full contribution that BCM measurements can make to renal care.
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Figure 1: The standard ‘wrist-to-ankle’ (or ‘hand-to-foot’) electrode configuration used for whole body bioimpedance measurements. [Image used with permission from LTHT Medical Illustration Department.]
Figure 2: Nomogram used for interpreting single frequency bioimpedance measurements. The outer ellipse encloses 95% of readings for normal subjects. Typical vectors for a patient with average build when (a) normally-hydrated, (b) slightly overloaded and (c) severely overloaded.
Figure 3: The BCM ‘body model’ converts intracellular and extracellular water volumes and weight to normally hydrated lean and adipose tissue and, in this case, excess fluid.
Figure 4: Pre-dialysis systolic blood pressure vs hydration status for the first BCM measurement made in 474 haemodialysis patients under the care of the Leeds Teaching Hospitals (reproduced from Lindley et al, 2011)
Figure 5: ‘Overhydration’ at prescribed target weight for 420 haemodialysis patients under the care of the Leeds Teaching Hospitals. (a) using traditional clinical indicators only and (b) after the first adjustment guided by BCM measurement.