Vena cava diameter measurement for estimation of dry weight in haemodialysis patients

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Abstract. A correct estimation of volume status and so-called dry weight in dialysis patients remains a difficult clinical problem. Clinical status and chest X-ray are not sensitive enough, while invasively measured central venous pressures are not routinely available. Recently, the sonographic determination of the diameter and collapse of the inferior vena cava (IVC) has been proposed as a noninvasive method for estimating intravascular volume. We tried to evaluate the clinical relevance of this method in dialysis patients by comparing it with central venous pressures (CVP) and atrial natriuretic peptide (ANP). To establish a normal range and to control for confounding variables, we examined a large number of healthy controls. Furthermore, the influence of tricuspid insufficiency was examined echocardiographically.

Measurements of the IVC diameters were well reproducible, with a coefficient of variation for interobserver error of 2.2%, and a coefficient of variation of 1.4% for intraobserver error. The collapse index was less well reproducible and therefore not used for further analysis.

In 86 normal controls (age 18 to 76 years), IVC diameters showed a wide variation, and they were not correlated to age, height, weight, or body surface area. However, there was a significant correlation of IVCEx to heart rate (r = 0.63, P < 0.001). Therefore, we calculated percentiles of the heart rate-IVCEx relation in normals, and compared the results in patients to these. In 10 overhydrated haemodialysis patients, CVP was closely correlated to IVCEx (r = 0.72, P < 0.001), but there was a wide interindividual variation of the slope of this relation. An IVCEx above the 95th percentile of normal was a good predictor of an elevated CVP. In another 39 stable, chronic haemodialysis patients, there was a significant correlation of the intradialytic decrease of ANP and IVCEx (r = 0.69, P < 0.001). However, this correlation existed only in patients without tricuspid insufficiency.

In summary, sonography of the inferior vena cava is a valuable tool for estimating dry weight in dialysis patients, provided that some caveats are kept in mind: (i) there is a wide variation of IVC diameters in normals, and single measurements are not helpful in individual patients; (ii) there is a significant, inverse correlation between IVC diameters and heart rate, and the precision of intravascular volume assessment is enhanced by interpreting heart rate corrected diameters; (iii) the presence of tricuspid insufficiency leads to unreliable results, as it influences IVC diameters per se. Intravascular volume changes are reflected by IVC measurements, as shown by the correlation to other indices of intravascular volume, such as CVP and x-hANP. IVC sonography is noninvasive and easily available; serial measurements allow an estimation of changes of intravascular volume in patients without cardiac filling impairment. However, unlike with body impedance, interstitial volume is not reflected by IVC diameters.

Key words: haemodialysis; dry weight; vena cava diameter; sonography

Introduction

A correct estimation of the fluid status and the determination of dry weight in dialysis patients remains a difficult clinical problem. The clinical status is insensitive, and a volume excess of several litres may escape recognition. Chest X-ray is limited by radiation exposure and cost, and the evaluation of the pulmonary vasculature is still a matter of debate, in part because of a large inter-observer variation [1]. Invasively measured central venous pressures are not routinely available, and measurements of the concentrations of atrial natriuretic peptide (ANP) or cyclic GMP are controversial [2]. Based on previous observations relating right-sided cardiac function and pressures to changes in the size of the inferior vena cava [3], the Maastricht group was the first to evaluate and propose sonography of the inferior vena cava as a noninvasive tool to estimate fluid status in patients with end-stage renal failure [4,5]. In haemodialysis patients, these authors
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found a curvilinear relation of the expiratory vena cava diameter and its collapse index during respiration and the mean right atrial pressure, and a linear relation between the vena cava diameter and the total blood volume, as determined by the radioiodinated serum albumin method. In addition, they demonstrated a linear relation between α-hANP concentrations before dialysis and vena cava diameters. According to right atrial pressures (RAP) the authors defined overhydration (mean RAP > 7 mmHg) as a vena cava diameter > 11.5 mm/m², and underhydration (mean RAP < 3 mmHg) as a vena cava diameter of < 8 mm/m². Recently, the postdialytic vena cava diameter was shown to reliably predict haemodynamic changes during dialysis [6]. It is of note, however, that all of these studies were performed in selected patient groups, in whom cardiac disease had been excluded prior to the study.

Vena cava sonography in unselected haemodialysis patients

We aimed at evaluating the clinical relevance of vena cava sonography in an unselected patient group from our chronic dialysis program [7]. Vena cava sonography was performed in the supine position with 2-dimensional guided M-mode echocardiography, using a 3.75 MHz ultrasound probe. From a subxiphoidal long axis view, the diameters were measured immediately prior to the p-wave of the ECG, in endexpiration. Valsalva-like manoeuvres were avoided.

In order to first establish a normal range and to control for confounding variables, we performed vena cava sonography in 86 healthy controls (43 women, 43 men) without a history of or evidence for cardiovascular disease, who had normal serum chemistry, blood count, urinalysis and chest X-ray (age 18–76 years, mean 39), as well as a normal echocardiogram. The mean blood pressure was 128 ± 15/80 ± 9 mmHg, the mean heart rate 71 ± 11 min⁻¹. The diameter of the vena cava varied widely (range 13–28 mm, mean 20 mm). Unexpectedly, we found no significant relation of vena cava diameters to height, weight or body surface area. However, there was a highly significant, inverse and curvilinear relation between resting heart rate and the expiratory vena cava diameter (r = —0.63, P < 0.001) (Figure 1). Vena cava diameters were well reproducible, with an inter-observer error, estimated as the coefficient of variation, of 2.24% (r = 0.98, P < 0.0001). However, the collapse index was much less reproducible, its coefficient of variation was 10.9% (r = 0.90, P < 0.001). Therefore, we abandoned the collapse index and only used diameters for analyses.

In another group of 39 chronic, stable haemodialysis patients (21 women, 18 men), we determined vena cava diameters and α-human atrial natriuretic peptide (α-hANP) simultaneously immediately before dialysis (with blood samples taken from the dialysis access needle), and directly after a haemodialysis session. The examinations were performed after a long (two-day) dialysis interval. The patients’ mean age was 56 ± 14 years, and the mean time on haemodialysis treatment was 7.9 ± 6.1 years. Hypertension was present in 22 out of 39 (56%) patients, and was treated with antihypertensive drugs in 21 patients. Coronary heart disease (previous myocardial infarction or suspected on clinical grounds and pathological ECG) was present in 14 patients (36%). Tricuspid insufficiency, as determined by pre-dialysis, color-coded Doppler echocardiography, was present in 14 patients (36%).

Contrary to the findings described by Leunissen
et al. [5], we were unable to establish a correlation between vena cava diameters and ANP concentrations, either prior to or after dialysis, in this patient population. It was only after we excluded the 14 patients with tricuspid insufficiency on pre-dialytic Doppler echocardiogram that the above mentioned linear relation of changes of vena cava diameters to changes of α-hANP became evident in the remaining 25 patients \( r = 0.70, P < 0.001 \). The patients with tricuspid insufficiency tended to be older than those without \( (62 ± 11 \) vs. \( 53 ± 15 \) years, \( P < 0.05 \)), and coronary heart disease was more frequent in these patients \( (50\% \) vs. \( 28\% \), \( P < 0.05 \)).

In 10 unselected, consecutive end-stage renal failure patients who presented with overt clinical hypervolaemia and who received a central venous (internal jugular) access for various reasons (four women, six men, mean age 61 ± 15 years), we performed serial simultaneous determinations of vena cava diameters and central venous pressures \( \text{(CVP)} \) over several days \( \text{(total of 54 measurements)} \), during which the patients were brought back to their clinically and radiologically estimated dry weight. The vena cava diameters paralleled the central venous pressures, but the large interindividual variation of this relation precluded a correct prediction of CVP based on vena cava diameters. However, this was considerably improved when we related the absolute values of vena cava diameters and resting heart rates in these patients to the percentiles of normal that we had previously calculated from the results of the normal control group. With a central venous pressure of \( > 12 \text{cmH}_2\text{O} \) as the cutoff value, an elevated CVP was detected with a sensitivity of 92\%, whereas the specificity was only 77\% due to many false positives (Figure 1).

**Pitfalls and caveats of vena cava sonography**

It is obvious that vena cava diameters are not exclusively influenced by the fluid status of a given patient, and several confounding variables have to be taken into account. As shown by the influence of tricuspid insufficiency described above, the cardiac status has to be evaluated by echocardiography in order to rule out (right-sided) heart disease, predominantly tricuspid insufficiency [8]. Vena cava sonography has not been validated in these patients, and appears to yield unreliable results in them. The possibly confounding influence of other cardiac changes that are highly prevalent in end-stage renal failure, such as left ventricular hypertrophy, require further investigation.

As is true for α-hANP, whose release is stimulated by both left and right-sided atrial stretch, only intravascular fluid status can be estimated with vena cava sonography. Thus, the important contribution of interstitial hydration status cannot be estimated by vena cava sonography. However, in a recent comparison of different techniques used to assess dry weight [2], the predictive values of both vena cava sonography and noninvasive conductivity measurements by bioimpedance with respect to haemodynamic changes during dialysis were investigated. Both methods were highly correlated, and the postdialysis fluid state predicted by these methods corresponded well to the haemodynamic and clinical findings.

In that same study, another important caveat of vena cava sonography was addressed: vena cava sonography tended to overestimate the number of underhydrated patients when compared to conductivity measurements. Vascular refilling, occurring up to several hours after the end of dialysis, affects only vena cava diameters but not conductivity measurements, which differentiate between extra- and intracellular fluid only. Thus, it is relevant at which point in time after dialysis intravascular volume is estimated by vena cava sonography. Measurements directly after dialysis, when vascular refilling from the interstitial space is not yet complete, may well underestimate the degree of (intravascular) hydration, and the same technique a few hours after dialysis may yield different results. Furthermore, this limitation is particularly important in conditions with a disproportionate relation of extra- to intracellular fluid, such as the capillary leak syndrome in sepsis and clinical situations with a very low oncotic pressure such as hepatic failure and possibly the nephrotic syndrome.

As described above [7], vena cava diameters in healthy controls were inversely correlated to heart rate, but not to any anthropometric measurements such as height, weight or body surface area. In the patients with acute hypervolaemia, the prediction of central venous pressures was only possible after adjusting vena cava diameters for heart rate. We can only speculate about the underlying mechanism. Possibilities include the level of sympathetic activity, which influences both venous tone and heart rate. The influence of venous tone and possibly venous structure has not been evaluated systematically.

**Clinical application**

Bearing the above limitations in mind, vena cava sonography is a widely available, non-invasive tool for the estimation of fluid status. In patients without obvious heart disease, a good relationship was found between vena cava sonography and conductivity measurements. Certainly, an entirely normal cardiac status will be the exception rather than the rule in the dialysis population, given the disproportionately high prevalence of heart disease in these patients. The cardiac status of the patient should be known when interpreting results of vena cava sonography, and they should be used with particular caution in patients with right-sided cardiac disease. If possible, vena cava sonography should be performed several hours after the end of dialysis, in order to allow vascular refilling to be completed. However, this may be difficult practically, especially in the outpatient setting.

Therefore, clinical markers of over- or underhydration, such as the intradialytic blood pressure profile
and the need for antihypertensive medication [9], and haemodynamic assessment during dialysis, still remain the standard against which vena cava sonography has to be evaluated. The vena cava diameter was rather constant over time in healthy individuals. Thus, follow-up determinations are probably most useful to detect changes of the fluid status in a given patient. Single measurements do not seem helpful in view of the wide variation of vena cava diameters, which renders the establishment of a normal range difficult.

References