Review

Ultrasonography: Ariadne's Thread in the Diagnosis of the Cardiorenal Syndrome

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Key Words

Acute renal failure • Chronic renal failure • Heart failure • Ultrasonography

Abstract

The term cardiorenal syndrome (CRS) describes a broad spectrum of clinical conditions with four combinations of acute and chronic heart and kidney failure. Based on the pathophysiological primum movens, the actual classification recognizes five CRS types: in type I and II CRS, the initiating event is heart failure (acute or chronic), while it is kidney failure in type III and IV CRS; type V is linked to systemic diseases. Ultrasound techniques (echocardiography and ultrasonography of the kidney, inferior vena cava and chest) can be extremely helpful in establishing a prompt diagnosis and a correct CRS classification. Basic echocardiography allows evaluation of ventricular diastolic and systolic functions, investigates pulmonary congestion and pericardial effusion, and describes volume overload. On the other hand, renal ultrasound helps clinicians to distinguish between acute and chronic renal failure, excludes urinary tract dilation or pathological bladder repletion, and provides crucial information regarding kidney volume or echogenicity. Applying basic knowledge of echocardiography and renal ultrasound, nephrologists may be in a better position for patient treatment and management, bearing in mind that doctors can properly use a stethoscope although not being a cardiologist.

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Introduction

According to the recent definition of the Acute Dialysis Quality Initiative Group, the term cardiorenal syndrome (CRS) has been used to define different clinical conditions in which heart and kidney dysfunction overlap [1]. The heart and the kidney are mutually involved in the dialogue between physiology and disease. The heart delivers nourishing, oxygen-rich fluids to all body areas, while the kidney is responsible for maintaining fluid and electrolyte balance, acid-base homeostasis, erythropoietin synthesis and vitamin D activation. In this respect, tissue oxygenation and fluid control are amazing examples of the evolutionary path taken by the human body.

The complexity of CRS renders an exhaustive evaluation of its pathogenesis, epidemiology and prognosis difficult. Lack of knowledge about CRS prevalence and incidence, as well as about some aspects of its pathogenesis, do not allow correct formulation of primary and secondary prevention in healthcare and sanitary politics. Actually, the term CRS is rarely mentioned as final diagnosis in medical records while a majority of observed cases is reported under single voices, e.g. acute renal failure complicated by the coronary syndrome.

At present, both a clear classification of CRS and its wide, correct application are required, presenting an important challenge for nephrologists and cardiologists who have to work together. These specialists have to osmotically ‘contaminate’ their own fields, thus creating modern common frontiers between nephrology and cardiology to provide a holistic, complete picture of their patients.

In practice, the definition of CRS has been often used to describe only chronic renal failure due to chronic heart failure. Actually, this misunderstanding reflects the partial approach to the problem, obliterating complete analysis of all clinical situations in which cardiac and renal dysfunction overlap.

An effective classification has been proposed in a Consensus Conference by the Acute Dialysis Quality Group [1] in 2008 (table 1). This classification divides CRS in two principal groups, the cardiorenal and the renocardiac syndrome, on the basis of *primum movens* of the disease. Further subdivision in each group defines it as acute or chronic, according to the onset modalities of the disease.

It is important to stress then that cardiac disease related to chronic renal failure (CRS type IV) is only one of the 5 types of CRS. There are at least three other forms that are completely different from this one. These CRS types are due to primary cardiac diseases (acute or chronic, CRS type I and II) or acute renal disease (CRS type III).

Finally, the 5th group integrates all CRS induced by systemic diseases, which presents a confounding category in our opinion.

Ultrasound Imaging in the Diagnosis of CRS

CRS is a wide field of application for ultrasound imaging techniques. Such techniques, elective in the diagnosis of main cardiovascular and nephrological clinical conditions, elucidate morphological and functional difficulties playing a crucial role in the diagnosis of CRS and correct distinction among different types.

The nephrologist who is able to directly manage ultrasound imaging makes use of a non-invasive, low-cost, effective, easily available technology.

In addition to an ultrasonographic monitor, preferably with harmonic detection, two probes are required: convex probes from 3 to 5 MHz to study the abdomen and a sectorial one from 3 to 3.5 MHz to study the chest and perform echocardiography. Using a linear probe from 7 to 10 MHz, neck, arm and leg vessels can be visualized, thus providing more

Table 1. CRS classification according to the Acute Dialysis Quality Initiative Group

Type	Denomination	Description	Example
I	Acute cardiorenal	Heart failure leading to acute renal failure	Acute coronary syndrome leading to acute heart and kidney failure
II	Chronic cardiorenal	Chronic heart failure leading to renal failure	Chronic heart failure
III	Acute nephrocardiac	Acute renal failure leading to acute heart failure	Uremic cardiomyopathy – related to acute kidney disease
IV	Chronic nephrocardiac	Chronic kidney disease leading to heart failure	Left ventricular hypertrophy and diastolic heart failure due to kidney failure
V	Secondary	Systemic disease leading to heart and kidney failure	Sepsis, vasculitis, diabetes mellitus

details of the area of study. These devices are durable and present a good investment in terms of costs and productivity.

Common ultrasound devices with three probes (described above), harmonic fusion software and pulsed wave Doppler allow complete evaluation of the kidneys, large vessels, and abdominal and pleural effusion, ‘thoracic comet’ research, and basic echocardiographic evaluation. Echocardiography represents one of the most expanding techniques in cardiological practices, since it is a valuable supplement to the bedside examination of patients.

Recording only a restricted number of parameters, it is possible to obtain an echocardiographic picture of the heart according to the cardiological definition of basic echocardiography, including:

- (1) diameters of the aortic root, ascending tract and aortic arch;
- (2) diameters, areas or volumes of the cardiac chambers;
- (3) wall thickness;
- (4) ejection fraction, and
- (5) evaluation of pericardial effusion.

With little effort, the nephrologist will learn to make Doppler measurements and M-mode recordings, thus making it possible to accomplish the examinations with:

- (6) transmitral, transtricuspid and transaortic flow, and
- (7) tricuspid annulus plane systolic excursion.

Abdominal examination not only clarifies the morphology of the kidneys, bladder, liver and aorta, but also visualizes inferior vena cava dynamics and the absence/presence of effusions.

Many of these data are extremely helpful in the differential diagnosis of renal diseases (i.e. to be able to discern among the different cardiac/renal aspects of CRS).

In a patient with suspected CRS, a brief ultrasonographic cardiorenal examination may elucidate the main part of the dilemma.

A typical form of *CRS type I* (acute cardiac disease inducing acute renal failure) is related to the acute coronary syndrome. Goldberg et al. [2] reported that the incidence of acute renal failure in patients hospitalized for acute myocardial infarction is about 2–4%. It is important to underline how, in this study, acute renal failure is not only predictive of short-term mortality (during hospitalization), but also strongly amplifies the risk of developing congestive heart failure and long-term mortality (in the years following hospitalization for an acute coronary event). Consequently, it is important to promptly recognize this form of CRS and treat cardiological and nephrological aspects of the syndrome.

Fig. 1. Left ventricular hypertrophy in stage III chronic kidney disease.

Fig. 2. Left atrium dilation in acute heart failure.

In this CRS form, ultrasonography may help to detect CRS at an early stage and to monitor the following parameters during follow-up:

- (1) abnormal myocardial kinetics (indicating an ischemic condition) and left ventricular hypertrophy (fig. 1);
- (2) valvular stenosis and insufficiency (particularly in case of rapid deterioration, e.g. valvular endocarditis or valvular rupture);
- (3) pericardial effusions;
- (4) normal inspiratory collapse of the inferior vena cava (excluding severe hypovolemia), and
- (5) aortic aneurysms or dissection.

In case of *CRS type II*, a chronic, cardiorenal syndrome, the patient typically suffers from chronic congestive heart failure, which occurs in about 2% of the adult population worldwide, as recently stated in the American Registry of Congestive Heart Failure. According to these data, it has been estimated that about 3% of patients hospitalized for congestive heart failure concomitant with renal failure, with a mortality rate of 22% [3–6]. Even small increases in serum creatinine indicate a worse clinical outcome in these patients independent of preexisting chronic renal failure and the degree of left ventricular dysfunction [3–6].

In another cohort of patients with congestive heart failure, glomerular filtration rate has been estimated to be <30 ml/min in 39% of patients in NYHA class IV and in 31% of patients in NYHA class III [6], suggesting that in patients with congestive heart failure, in addition to ejection fraction and NYHA functional class, glomerular filtration rate also has a predictive value [6, 7].

In these patients, CRS is insidious, and patients are rarely treated in specialized units but rather in general wards. Due to the coexistence of several pathologies, it is not easy to clearly diagnose them all. In this group of patients, it may be difficult to reach a definitive diagnosis. Ultrasonographic examination will provide information regarding:

- (1) renal ultrasonographic parameters of ‘chronicity’;
- (2) high atrial volumes or areas as indices of volume overload (fig. 2);
- (3) decreased ejection fraction;
- (4) right chamber dilation and decreases in estimated pulmonary arterial pressure and tricuspid annulus plane systolic excursion as parameters of congestive heart failure, pulmonary hypertension or decreased ejection fraction;
- (5) pericardial effusion (fig. 3), and
- (6) chronic valvular pathology, giving particular attention to valvular calcifications.

Fig. 3. Severe pericardial effusion in end-stage renal failure.

Fig. 4. Kidney in end-stage renal disease (marked hyperechogenicity of the renal cortex and decreased corticomedullary ratio).

Probably these patients are those that mostly appreciate the presence of a good ‘cardio-nephrologist’, who is interested in ultrasonography and has particular knowledge on the prescription of dialysis fluids, angiotensin-converting enzyme inhibitors, angiotensin receptor blockers, aldosterone antagonists, diuretics and erythropoietin.

CRS type III, the acute and renocardiac syndrome, is a quite frequent event in the nephrological emergency setting in our experience. In these clinical patterns, volume overload due to acute renal failure leads to acute heart failure, and echocardiography may be of limited value in this insidious and silent disease.

Kidney size and echogenicity provide primary features to discern between acute and chronic nephropathies. Physicians who perform ultrasound evaluation should remember how kidney volume and longitudinal diameters correlate with patient height and body surface [16, 17] and that chronic renal failure does not exclude normal or enlarged kidneys (e.g. early stages of diabetic nephropathy, HIV-related glomerulonephritis or cast nephropathy).

A hyperechogenic renal cortex with medullary hypoechogenicity and low corticomedullary ratio is predictive of chronic nephropathy [16, 17] (fig. 4, 5). On the other hand, cortical hyperechogenicity can also present in acute tubular necrosis (fig. 6) or systemic lupus erythematosus nephritis [16, 17]. In these cases, enlarged renal parenchyma may suggest a condition of edema in the acute setting.

Doppler and color Doppler evaluation can be crucial in the diagnosis and prognosis in the acute setting, mainly in relation with diastolic flow evaluation in interlobar arteries [18].

Renal ultrasound is a crucial step in the differential diagnosis of obstructive nephropathies.

In this patient group, ultrasonographic examination depicts:

- (1) increases in atrial volumes or areas as indices of volume overload;
- (2) pleural or pericardial effusion;
- (3) lung comets;
- (4) renal parenchymal echogenicity;
- (5) renal volume;
- (6) urinary tract dilation, and
- (7) inversed diastolic flow at interlobar renal arteries.

CRS type IV is the most common CRS type diagnosed clinically in patients with available epidemiological data. The literature clearly indicates how patients with chronic renal failure very frequently develop cardiovascular disease with fatal outcomes. In about 50% of

Fig. 5. End-stage renal disease with marked reduction in the corticomedullary ratio.

Fig. 6. Ultrasound pattern of acute tubular necrosis.

cases of end-stage renal disease, cardiovascular events are the cause of death, i.e. 10–20 times more frequent than in the general population [3–6].

In these cases, ultrasonography may help to detect dyspnea in uremic patients [19, 20], evaluates the effects of changes in vascular access on hemodialysis and right cardiac chambers and then guides policy management of dry weight and vascular access [21].

In group IV, ultrasonographic examination will verify particularly the presence of:

- (1) increased atrial volumes or areas as indices of volume overload (fig. 2);
- (2) pleural or pericardial effusion (fig. 3);
- (3) lung comets;
- (4) valvular calcifications, and
- (5) possible right heart dysfunction (high pulmonary artery pressure, low tricuspid annulus plane systolic excursion or right chamber dilation).

CRS type V represents an agglomeration of different chronic pathologies causing CRS, ranging from sepsis (either due to cardiorenal or renocardiac acute events) to type 2 diabetes mellitus or associated diseases.

In the above-listed conditions, the physician will find it comfortable to analyze every clinical picture, label it as acute or chronic, renocardiac or cardiorenal, and then continue as described previously.

A particular field of study is finally the patient on renal replacement therapy. This procedure induces peculiar, drastic fluctuations in volemia and cardiac parameters, which may be reflected by ultrasonographic data and indicate potentially increased risks (e.g. intracardiac diameters or volumes, or inferior vena cava collapse with inspiration). Nephrologists, cardiologists and critical care physicians should be able to interpret these parameters in a 'holistic' view and bear in mind that every single medical parameter may be clinically significant.

Conclusion

In our opinion, physicians should aim to gain experience in ultrasonography, and therefore colleagues with more experience in the field should confirm clinical observations and the diagnosis of inexperienced ultrasonographers. This working behavior is crucial to build

up experience and acquire familiarity with an indispensable tool, in order to accrue critical information.

Echocardiography is employed in nephrology units for some years, and we are well aware of the criticisms regarding alleged borders between specialties. In our opinion, overlapping specialties can be an opportunity to employ the same tool in a different way. Due to the parallel, widespread ability to properly interpret an ECG enables a clinician to refer the patient with cardiac dysfunction in need of treatment in time to the cardiologist, and no one is accused of violating borders in doing this.

We are confident that nephrologists will be able to accept these new challenges, trying to conform with the requests of the patients and the community, and taking a new look at our beloved specialty.

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