Review

Davide Bolignano, Aderville Cabassi, Enrico Fiaccadori, Ezio Ghigo, Renato Pasquali, Andrea Peracino*, Alessandro Peri, Mario Plebani, Antonio Santoro, Fabio Settanni and Carmine Zoccali

Copeptin (CTproAVP), a new tool for understanding the role of vasopressin in pathophysiology

Abstract: Arginine vasopressin (AVP) plays a key role in many physiologic and pathologic processes. The most important stimulus for AVP release is a change in plasma osmolality. AVP is also involved in the response and adaptation to stress. Reliable measurement of AVP is hindered by several factors. Over 90% of AVP is tightly bound to platelets, and its estimation is influenced by the number of platelets, incomplete removal of platelets or pre-analytical processing steps. Copeptin (CTproAVP), a 39-aminoacid glycopeptide, is a C-terminal part of the precursor pre-provasopressin (pre-proAVP). Activation of the AVP system stimulates CTproAVP secretion into the circulation from the posterior pituitary gland in equimolar amounts with AVP. Therefore CTproAVP directly reflects AVP concentration and can be used as a surrogate biomarker of AVP secretion. In many studies CTproAVP represents AVP levels and its behavior represents changes in plasma osmolality, stress and various disease states, and shows some of the various physiologic and pathophysiologic conditions associated with increased or decreased AVP. Increased CTproAVP concentration is described in several studies as a strong predictor of mortality in patients with chronic heart failure and acute heart failure. Autosomal polycystic kidney disease (ADPKD) patients have both central and nephrogenic defects in osmoregulation and CTproAVP balance. A possibility raised by these clinical observations is that CTproAVP may serve to identify patients who could benefit from an intervention aimed at countering AVP.

Keywords: chronic heart failure; copeptin; CTproAVP; diabetes insipidus; hyponatremia; osmoregulation; vasopressin.

DOI 10.1515/cclm-2014-0379
Received April 7, 2014; accepted May 14, 2014

***Corresponding author: Andrea Peracino,** Fondazione Giovanni Lorenzini Medical Science Foundation, Milan, Italy and Houston, TX, USA, E-mail: andrea.peracino@lorenzinifoundation.org
Davide Bolignano and Carmine Zoccali: CNR-Institute of Clinical Physiology and Department of Nephrology, Urology and Renal Transplantation Unit, United Hospitals, Reggio Calabria, Italy
Aderville Cabassi: Internal Medicine, Cardiorenal Research Unit, Department of Clinical and Experimental Medicine, University of Parma, Parma, Italy
Enrico Fiaccadori: Clinical and Experimental Medicine Department, Renal Failure Unit, Parma University Medical School, Parma, Italy
Ezio Ghigo: Department of Medical Sciences, School of Medicine, University of Turin, Turin, Italy
Renato Pasquali: Division of Endocrinology, S. Orsola-Malpighi Hospital in Bologna, Bologna, Italy
Alessandro Peri: Endocrine Unit, Department of Experimental and Clinical Biomedical Sciences "Mario Serio", University of Florence, Center for Research, Transfer and High Education on Chronic, Inflammatory, Degenerative and Neoplastic Disorders for the Development of Novel Therapies (DENOThe), Florence, Italy
Mario Plebani: Department of Laboratory Medicine, University-Hospital of Padua, Padua, Italy
Antonio Santoro: Nephrology, Dialysis and Hypertension Department, Azienda Ospedaliero-Universitaria of Bologna, Policlinico S. Orsola-Malpighi, Bologna, Italy
Fabio Settanni: Laboratory of Endocrinology, Division of Endocrinology, Diabetology and Metabolism, Department of Medical Science, Turin University San Giovanni Battista Hospital, Città della Salute e della Scienza, Turin, Italy

Introduction

Arginine vasopressin (AVP), also known as antidiuretic hormone, plays a key role in many physiologic and pathologic processes. Both AVP and its closely related peptide oxytocin are highly conserved and appear to precede the divergence of vertebrate and invertebrate families. The main role of AVP is to induce water conservation by the kidney, thus contributing to osmotic and cardiovascular

homeostasis. It also has hemostatic, endocrine and central nervous effects.

AVP is a nine-amino acid peptide with a disulfide bridge between two cysteine amino acids. It is produced primarily in the magnocellular neurons of the hypothalamus, and is stored and secreted by granules within the posterior lobe of the pituitary, primarily as a response to high plasma osmolality, low plasma volume, and/or low blood pressure. To a lesser extent, it is also produced in other tissues including the sympathetic ganglia, adrenal glands, and the testis [1].

The synthesis of AVP involves precursor peptides (pre-proAVP and proAVP) that are enzymatically cleaved by a four-enzyme cascade into the components vasopressin, copeptin (CTproAVP) and neurophysin II. These three cleavage products are all released into the circulation in equal ratios.

The most important stimulus for AVP release is a change in plasma osmolality. This occurs via peripheral receptors whose afferent stimuli ascend via the vagus nerve through the medulla to the hypothalamic nuclei. A small change, of even 1%, in plasma osmolality is sufficient to change AVP concentration. Normal AVP concentrations in healthy individuals are between 1 and 5 pg/mL.

AVP is also an important factor of the response and adaptation to stress. Stressful stimuli evoke complex endocrine, autonomic, and behavioral responses that are extremely variable and specific depending on the type and nature of the stressors. Adaptation to stress stimuli, either acute or chronic, largely depends on the activation of the hypothalamic-pituitary-adrenal (HPA) axis and the catecholaminergic system [2]. Appropriate regulatory control of the HPA stress axis is essential to health and survival. The outflow of the HPA axis is therefore a summation of integrated inputs from several forebrain regions. In the hypothalamic areas, the cascade is in turn chiefly regulated by the corticotropin releasing hormone (CRH) and AVP. Hyperactivation of the sympathetic nervous system (SNS) also plays a partnership role in the body's response to both acute and chronic stress [3]. AVP is particularly produced in response to stress or acute life-threatening events (physical stress conditions), and is involved in changes in blood pressure and volume.

AVP produced under these circumstances greatly exceeds the physiological range with exponential levels 100- or 1000-fold times the normal concentration. AVP exerts its effects on three different receptors. The V1a receptors mediate strong arteriolar vasoconstriction and are localized primarily on vascular smooth muscle cells, hepatocytes, platelets, and cells in the brain and uterus. V2 receptors mediate antidiuretic effects, and are highly expressed in the kidneys, and in endothelial cells and vascular smooth muscle. Upon stimulation, V2 receptors activation is associated with an increased intracellular level of cAMP, which in turn triggers the insertion of aquaporin-2 water channels in the apical membrane of tubular cells of the distal nephron, leading to water reabsorption into the interstitium. V3 receptors (also known as V1b receptors), found in the anterior pituitary, brain, pancreas, and heart are involved in ACTH secretion, neuromodulation, insulin synthesis and release, temperature and memory control [1, 4–7].

The plasma half-life of AVP is quite short, of about 5–20 min. Clearance of AVP usually occurs by the kidney or liver, with renal clearance estimated at approximately 50%–70% of total clearance [1]. AVP can also be degraded by several endothelial and circulating endo- and amino peptidases. Clearance is proportional to plasma levels of AVP and reaches 600 mL/min at a concentration of 10 pg/mL in humans. Urinary clearance is about 5% of the total clearance [1].

AVP action has been linked to liver glycogenolysis via V1a receptors and insulin and glucagon secretion via V1b receptors. AVP levels are markedly increased in patients with poorly controlled diabetes mellitus [8] and AVP infusion leads to increased blood glucose levels in healthy subjects [9]. AVP predicts diabetes mellitus independently of a broad range of established diabetes risk factors [10].

Finally, AVP has been suggested to regulate hypermetabolic pathways of fat in V1a receptor knockout mice [11] and promote thermogenic adipokines in brown adipose tissue [12], which imply a potential role of the AVP system in the regulation of energy expenditure and balance which, in turn, may interfere with the water balance.

CTproAVP (copeptin) in physiological conditions

Reliable measurement of AVP is hindered by several factors. Over 90% of AVP is tightly bound to platelets, and its estimation is influenced by the number of platelets, incomplete removal of platelets or pre-analytical processing steps [4]. In addition, AVP is also highly unstable in isolated plasma – even when stored at –20 °C.

CTproAVP (copeptin), a 39-aminoacid glycopeptide, is a C-terminal part of the precursor pre-provasopressin (pre-proAVP). Activation of AVP system stimulates CTproAVP secretion into the circulation from the posterior pituitary gland in equimolar amounts with AVP. Therefore, CTproAVP directly reflects AVP concentration and can be

used as surrogate biomarker of AVP secretion. Even mild to moderate stress situations contribute to the release of CTproAVP. These reasons have led to several different lines of research in various disease states.

To overcome some of these disadvantages, CTproAVP can be used as a surrogate for AVP since it is very stable in plasma and during storage. Unlike AVP, it does not require any pre-analytical processing and can be easily determined with several manual and automated assays.

A large study using healthy volunteers recruited from a local heart failure screening showed that the median CTproAVP levels are slightly, but significantly higher in males compared to females [4.3 (0.4–44.3) vs. 3.2 (1.0–14.8) pmol/L]. There is a stronger correlation of CTproAVP with the estimated glomerular filtration rate (eGFR) in males compared to females and left atrial size correlated with higher CTproAVP levels [13].

Levels of CTproAVP are not strongly correlated with age [13, 14], however, strenuous exercise causes a moderate increase in CTproAVP [14].

Studies have shown that CTproAVP mirrors AVP levels under diverse physiologic and pathophysiologic conditions such as changes in plasma osmolality, stress and various disease states [15–17]. The measurement of CTproAVP can be used to reflect AVP concentrations as it is produced in equimolar amounts as AVP and released into the circulation at the same time as AVP secretion [15].

Vasopressin and CTproAVP in pathogenetic conditions

Diabetes insipidus

Diabetes insipidus (DI) is a clinical syndrome characterized by polyuria due to a defect in the urinary concentrating mechanism [18]. There is also an associated compensatory polydipsia. The prevalence in the general population is estimated at 1 per 25–35,000. The syndrome comprises three main types central, nephrogenic and gestational, and a related syndrome, primary polydipsia [19].

Central (neuro-hypophyseal) DI is associated with impaired production or secretion of AVP, such as in pituitary injury after head trauma or surgery. It is estimated that 20%–30% of pituitary operations are associated with transient central DI, and that 2%–10% lead to permanent disease [20, 21].

Central DI is also sometimes observed in course of infection or malignancy. The other type of central DI is due to a very rare congenital condition, i.e., as familial neuro-hypophyseal DI associated with autosomal dominant, recessive or X-linked recessive mutation of the AVP gene.

Nephrogenic DI is characterized by impaired AVP-induced water adsorption [19]. Acquired nephrogenic DI is most commonly associated with electrolyte abnormalities (such as hypokalemia or hypercalcemia) or the therapeutic use of drugs, such as lithium or cisplatin.

Gestational DI, is due to an increased degradation of AVP from vasopressinase, a placental enzyme [22, 23]. Although it is not very commonly observed, it can be under diagnosed, as polyuria is considered normal during pregnancy.

DI should be differentiated from primary polydipsia. The latter differs from DI as it is not associated with variants of AVP secretion or activity – but rather from excessive fluid intake over extended periods of time. However, CTproAVP may help in the differential diagnosis of primary polydipsia and DI, although further studies are needed in the area.

An accurate differentiation of the underlying pathology is necessary for effective treatment of DI. If the patient has central diabetes insipidus, the AVP concentration will not increase – even though there has been a significant decrease in body weight or increase in plasma osmolarity. However, if the patient has nephrogenic DI, AVP will appropriately increase in parallel to dehydration status progression and the increase in plasma osmolarity. Desmopressin (an exogenous synthetic vasopressin analog) is commonly administered as a challenge after water deprivation to see if there is a further change in urine osmolality.

CTproAVP has been used in several recent studies as a novel approach for the diagnosis of DI [24–26]. This method evaluates osmotically stimulated CTproAVP after an 8-h water withdrawal period. The first blood sample is able to aid in the distinction between central complete and nephrogenic DI by comparing the plasma levels of CTproAVP. Concentrations of CTproAVP that are <2.6 pmol/L indicate central DI complete whereas concentrations >20 pmol/L indicate nephrogenic DI. Patients with intermediate values between 2.6 and 20 pmol/L undergo a further 8 h of fluid deprivation.

A CTproAVP index is derived by the following equation:

$$\frac{\text{Delta CTproAVP [8–16 h]} \times 1000 \text{ [pmol/L/mmol/L]}}{\text{S-Na+ [16 h]}}$$

Patients with a CTproAVP index of <20 are classified as having partial central DI whereas patients with values >20 have primary polydipsia [16].

Hyponatremia and SIADH (SIAD)

Hyponatremia, defined as serum sodium levels <135 mmol/L [27], is the most frequent electrolyte disorder occurring in 15%–30% of hospitalized patients. Severe hyponatremia is often defined as levels of serum sodium <125 mmol/L and represents 1%–4% of patients. However, the incidence can rise dramatically for certain patient groups. For example, institutionalized geriatric patients have incidences of 7%–53% [28] and it is estimated that as many as 40%–75% of patients have hospital-acquired hyponatremia.

Although many cases are asymptomatic, acute severe hyponatremia is associated with substantial morbidity and mortality risk. Treatment is also complicated, as overly rapid correction can lead to severe permanent neurological deficits and death. Even mild chronic hyponatremia is associated with clinical consequences, such as gait disturbances and falls, increased risk of fractures and reduced bone mineral density and attention deficits [27, 29].

A recent meta-analysis showed that a moderate reduction of serum sodium concentration is associated with an increased risk of death in different pathologic conditions [30].

The syndrome of inappropriate antidiuretic hormone secretion (SIADH) refers to disorders related to water and sodium balance characterized by the impairment of urinary dilution and hypotonic hyponatremia in the absence of renal disease or other identifiable non-osmotic stimuli known to activate the release of AVP [31]. It is a frequent cause of hyponatremia in the clinical setting with a wide range of clinical manifestations, ranging from asymptomatic to life threatening.

The underlying pathological basis for SIADH is an absolute increase in body water in relation to sodium pool due to osmoregulatory dysfunctions. SIADH can be further subdivided according to the different underlying osmoregulatory dysfunctions. Type A, is characterized by high basal AVP levels with random fluctuations in the hyponatremic state. This type of SIADH is commonly associated with tumors and is due to excessive AVP secretion. Type B is also characterized by high AVP (but with levels often lower than type A). Type B is often related to injury of the neuro-hypophysis causing generalized osmoregulatory dysfunction. Type C is thought to be due to a "downward reset" of the osmoregulatory system, while Type D, in which AVP is undetectable, has been associated with mutation in V2 receptors [32]. This discovery led to the proposal to rename SIADH with the new acronym SIAD, for syndrome of inappropriate antidiuresis.

Endogenous conditions that can cause SIAD include: 1) conditions that can increase hypothalamic (eutopic) production of AVP; 2) conditions associated with ectopic production (such as malignancies); 3) potentiation of AVP effects; and 4) nephrogenic syndrome of inappropriate antidiuresis (NSIAD), which is characterized by gain-of-function mutations of the V2 receptor gene.

SIAD can occur in different pathologic conditions, such as infections, thrombosis or subarachnoid or subdural hemorrhage, neuropsychiatric disorders, various cerebral diseases (HIV, Guillan-Barre', multiple sclerosis), pulmonary diseases and severe nausea or post-surgical pain. SIAD can be also induced by many drugs, such as chemotherapeutics, antipsychotics, antidepressants, opiates, and non-steroidal anti-inflammatory drugs.

CTproAVP has also been used in the differential diagnosis of hyponatremia. Fenske et al. found that while isolated measurements of CTproAVP had only limited value for identification of patients with polydipsia, a combination of CTproAVP and urinary sodium gave superior performance to the reference standard in discriminating volume depleted from normovolemic hyponatremic disorders [16].

Unlike true hyponatremia, *pseudohyponatremia* is a condition represented by low serum sodium concentration resulting from volume displacement by massive hyper-lipidemia or hyper-proteinemia, or by hyperglycemia. Therefore, reduced sodium concentration in pseudo-hyponatremia does not entail a true hypotonic disorder. The correct identification of pseudo-hyponatremia is essential to avoid unnecessary and dangerous treatments aiming at restoring normal sodium values.

Heart failure

Heart failure is commonly associated with hyponatremia, and is also characterized by increased concentrations of basal AVP and CTproAVP [33–35]. In addition to plasma osmolality, non-osmotic factors, such as intra-cardiac pressures, intra-arterial pressures, angiotensin II, pain, and adrenergic ($\alpha 2$) central nervous stimuli can also influence AVP secretion [36]. Although non-osmotic mechanisms do not usually play an important role in healthy individuals, edematous states are characterized by a shift in regulation towards predominance of non-osmotic over the physiological osmotic stimuli. In addition, AVP through its V1 and V2 receptor-mediated effects, seems to contribute to the progression of left ventricular dysfunction by worsening systolic and diastolic wall stress and by stimulating both ventricular hypertrophy and myocardial remodeling.

Several studies have shown that increased CTproAVP concentration is a strong predictor of mortality in patients

with chronic heart failure, acute heart failure and heart failure caused by acute myocardial infarction [33, 37–39].

CTproAVP values are higher in non-survivors compared to survivors for patients with advanced heart failure, as well as acute heart failure. The typical range of CTproAVP for patients with chronic or acute heart failure is between 10 and 50 pmol/L compared to the normal values of 4–7 pmol/L. These clinical observations and the previously discussed physiological and pathophysiological effects suggest that CTproAVP may be an interesting prognostic biomarker to be measured and monitored in patients with heart disease.

CTproAVP levels predict mortality in outpatients with chronic heart failure independently from clinical variables, such as plasma sodium. It also predicts the combined endpoint of hospitalization or death independent of NTproBNP [38]. Results from the BACH study also showed that patients with elevated CTproAVP and the lowest levels of sodium had the highest mortality at 90 days. Combined end points of mortality, readmissions and emergency department visits were also associated with higher CTproAVP [37, 40].

If patients at high short-term mortality risk are prospectively selected, adequate power for interventional studies may be obtainable with much smaller trials [39].

Renal disorders

Accruing evidence over the last several years suggests that AVP plays an important role in the initiation and progression of chronic kidney disease, kidney transplantation and as well as specific roles in disorders, such autosomal polycystic kidney disease (ADPKD) [5, 41–43].

In population-based cohorts, the annual decline in eGFR has been inversely correlated to 24-h fluid intake and urine volume. Independent studies also have correlated CTproAVP concentration and albuminuria with renal decline in kidney transplant recipients [44].

Although there are many, still open, questions regarding the underlying pathophysiology, there is strong evidence that AVP modifies vascular tone in renal microvessels. AVP acting via the V2 receptors may also reduce the efficiency of sodium and urea excretion and thus increase glomerular filtration rate thus imposing increased energetic demands on the kidney. In addition, AVP promotes mitogenesis and proliferation of mesangial cells via the V1 receptors, which mediate AVP-induced cell contraction. In part, this may also be due to AVP stimulation of endothelin-1, a vasoactive peptide with mitogenic effects. Studies have shown that addition of AVP to cultured mesangial cells increases in a dose dependent manner the synthesis and release of matrix proteins, such as type I and IV collagen, fibronectin and transforming growth factor. All these may interfere with the normal contractile, immunologic and endocrine actions of mesangial cells, which are crucial for the maintenance of glomerular health [5]. AVP may be especially important in ADPKD.

CTproAVP is correlated with the severity of the disease and recent evidence suggests that ADPKD patients have both central and nephrogenic defects in osmoregulation and CTproAVP balance [45–47]. AVP has a direct influence on cysts, by stimulating the formation of cAMP, a potent stimulator of cyst growth, particularly of cysts that originate from the distal nephron segments that express V2 receptors. The CRISP study showed that ADPKD patients with relatively well-preserved renal function that had higher 24-h urine osmolality at baseline were at higher risk of a faster decline of eGFR. These results confirm preclinical and experimental findings [48] that blocking the endogenous activity of AVP on V2R might counteract the cystic phenotype. Tolvaptan, a selective V2R-antagonist, slowed the increase in total kidney volume and the progression toward kidney failure in patients with ADPKD but was associated with a higher rate of adverse events in the TEMPO 3:4 trial [48]. High water intake decreases plasma and urine osmolarity and suppresses AVP release from CNS. As a result, there is no or little renal V2R stimulation by AVP, reduced cAMP synthesis and slower cyst growth. This approach was successful in reducing the cystic phenotype in experimental models [49].

In pilot studies in humans, a short course of high water diet was effective in reducing urinary cAMP in ADPKD patients [50, 51]. An intriguing possibility raised by clinical observations is that CTproAVP may serve to identify patients who may benefit from an intervention aimed at countering AVP.

Summary

The main role of AVP is to induce water conservation by the kidney, and contribute to osmotic and cardiovascular homeostasis. Reliable measurement of AVP is hindered by several factors. CTproAVP can be used instead as a surrogate to provide insight on AVP, as it is produced at the same time, has high plasma stability and is easy to measure.

In many studies CTproAVP represents AVP levels and its behavior represents changes in plasma osmolality, stress and various disease states, showing some of the various physiologic and pathophysiologic conditions associated with increased or decreased AVP.

Several studies have shown that increased CTproAVP concentration is a strong predictor of mortality in patients with chronic heart failure, acute heart failure and heart failure caused by acute myocardial infarction. ADPKD patients have both central and nephrogenic defects in osmoregulation and CTproAVP balance.

CTproAVP represents a prognostic biomarker for acute illness and has been shown to correlate with clinical outcome in various critical diseases. The evaluation of chest pain patients is critical and involves several clinical specialities. The utility of combining CTproAVP to troponin may provide additional value in ruling-out or -in patients in life-threatening emergencies [52].

For a biomarker to be considered useful in clinical practice [53], four criteria should be met: 1) accuracy, i.e., the ability to reliably identify individuals at excessive risk of adverse clinical outcome of interest; 2) simplicity, such as ease of measurement; cost, as biomarkers should be reasonably cost-effective; 3) relevance of the information provided by the biomarker, as this information should be additive to that conveyed by established risk factors; and finally 4) biomarkers need to be tested in a proper randomized clinical trial where a clinical policy based on the biomarker of interest is compared with the traditional, standard clinical policy applied in the patients' population of interest.

Larger clinical trials to evaluate the feasibility and long-term effects of this approach are currently ongoing. An intriguing possibility raised by these clinical observations is that CTproAVP may serve to identify patients who may benefit from an intervention aimed at countering AVP.

The open question on the use of CTproAVP in the diagnosis and treatment of hyponatremia [54] seems to receive a promising answer.

Conflict of interest statement

Authors' conflict of interest disclosure: The authors stated that there are no conflicts of interest regarding the publication of this article.
Research funding: None declared.
Employment or leadership: None declared.
Honorarium: None declared.

References

1. Laycock JF. Introduction to vasopressin. In: Perspectives on vasopressin. London: World Scientific Publishing Company, Imperial College Press, 2010;1–16.
2. Dedovic K, Duchesne A, Andrews J, Engert V, Pruessner JC. The brain and the stress axis: the neural correlates of cortisol regulation in response to stress. Neuroimage 2009;47:864–71.
3. Kvetnansky R, Sabban EL, Palkovits M. Catecholaminergic systems in stress: structural and molecular genetic approaches. Physiol Rev 2009;89:535–606.
4. Morgenthaler NG, Struck J, Jochberger S, Dünser MW. Copeptin: clinical use of a new biomarker. Trends Endocrinol Metab 2008;19:43–9.
5. Bolignano D, Zoccali C. Vasopressin beyond water: implications for renal diseases. Curr Opin Nephrol Hypertens 2010;19:499–504.
6. Holmes CL, Landry DW, Granton JT. Science review: vasopressin and the cardiovascular system part 1 – receptor physiology. Crit Care 2003;7:427–34.
7. Holt NF, Haspel KL. Vasopressin: a review of therapeutic applications. J Cardiothorac Vasc Anesth 2010;24:330–47.
8. Zerbe RL, Vinicor F, Robertson GL. Plasma vasopressin in uncontrolled diabetes mellitus. Diabetes 1979;28:503–8.
9. Spruce BA, McCulloch AJ, Burd J, Orskov H, Heaton A, Baylis PH, et al. The effect of vasopressin infusion on glucose metabolism in man. Clin Endocrinol (Oxf) 1985;22:463–8.
10. Enhörning S, Wang TJ, Nilsson PM, Almgren P, Hedblad B, Berglund G, et al. Plasma copeptin and the risk of diabetes mellitus. Circulation 2010;121:2102–8.
11. Hiroyama M, Aoyagi T, Fujiwara Y, Birumachi J, Shigematsu Y, Kiwaki K, et al. Hypermetabolism of fat in V1a vasopressin receptor knockout mice. Mol Endocrinol 2007;21:247–58.
12. Küchler S, Perwitz N, Schick RR, Klein J, Westphal S. Arginine-vasopressin directly promotes a thermogenic and pro-inflammatory adipokine expression profile in brown adipocytes. Regul Pept 2010;164:126–32.
13. Bhandari SS, Loke I, Davies JE, Squire IB, Struck J, Ng LL. Gender and renal function influence plasma levels of copeptin in healthy individuals. Clin Sci (Lond) 2009;116:257–63.
14. Morgenthaler NG, Struck J, Alonso C, Bergmann A. Assay for the measurement of copeptin, a stable peptide derived from the precursor of vasopressin. Clin Chem 2006;52:112–9.
15. Balanescu S, Kopp P, Gaskill MB, Morgenthaler NG, Schindler C, Rutishauser J. Correlation of plasma copeptin and vasopressin concentrations in hypo-, iso-, and hyperosmolar states. J Clin Endocrinol Metab 2011;96:1046–52.
16. Fenske W, Störk S, Blechschmidt A, Maier SG, Morgenthaler NG, Allolio B. Copeptin in the differential diagnosis of hyponatremia. J Clin Endocrinol Metab 2009;94:123–9.
17. Blanchard A, Steichen O, De Mota N, Curis E, Gauci C, Frank M, et al. An abnormal apelin/vasopressin balance may contribute to water retention in patients with the syndrome of inappropriate antidiuretic hormone (SIADH) and heart failure. J Clin Endocrinol Metab 2013;98:2084–9.
18. Robertson GL. Diabetes insipidus. Endocrinol Metab Clin North Am 1995;24:549–72.
19. Moeller HB, Rittig S, Fenton RA. Nephrogenic diabetes insipidus: essential insights into the molecular background and potential therapies for treatment. Endocr Rev 2013;34:278–301.
20. Fenske W, Allolio B. Clinical review: current state and future perspectives in the diagnosis of diabetes insipidus: a clinical review. J Clin Endocrinol Metab 2012;97:3426–37.
21. Nemergut EC, Zuo Z, Jane JA, Laws ER Jr. Predictors of diabetes insipidus after transsphenoidal surgery: a review of 881 patients. J Neurosurg 2005;103:448–54.

22. Aleksandrov N, Audibert F, Bedard MJ, Mahone M, Goffinet F, Kadoch IJ. Gestational diabetes insipidus: a review of an underdiagnosed condition. J Obstet Gynaecol Can 2010;32:225–31.
23. Kalelioglu I, Kubat Uzum A, Yildirim A, Ozkan T, Gungor F, Has R. Transient gestational diabetes insipidus diagnosed in successive pregnancies: review of pathophysiology, diagnosis, treatment, and management of delivery. Pituitary 2007;10:87–93.
24. Szinnai G, Morgenthaler NG, Berneis K, Struck J, Müller B, Keller U, et al. Changes in plasma copeptin, the c-terminal portion of arginine vasopressin during water deprivation and excess in healthy subjects. J Clin Endocrinol Metab 2007;92:3973–8.
25. Katan M, Morgenthaler NG, Dixit KC, Rutishauser J, Brabant GE, Müller B, et al. Anterior and posterior pituitary function testing with simultaneous insulin tolerance test and a novel copeptin assay. J Clin Endocrinol Metab 2007;92:2640–3.
26. Fenske W, Quinkler M, Lorenz D, Zopf K, Haagen U, Papassotiriou J, et al. Copeptin in the differential diagnosis of the polydipsia-polyuria syndrome – revisiting the direct and indirect water deprivation tests. J Clin Endocrinol Metab 2011;96:1506–15.
27. Verbalis JG, Goldsmith SR, Greenberg A, Korzelius C, Schrier RW, Sterns RH, et al. Diagnosis, evaluation, and treatment of hyponatremia: expert panel recommendations. Am J Med 2013;126:S1–42.
28. Miller M, Morley JE, Rubenstein LZ. Hyponatremia in a nursing home population. J Am Geriatr Soc 1995;43:1410–3.
29. Kinsella S, Moran S, Sullivan MO, Molloy MG, Eustace JA. Hyponatremia independent of osteoporosis is associated with fracture occurrence. Clin J Am Soc Nephrol 2010;5:275–80.
30. Corona G, Giuliani C, Parenti G, Norello D, Verbalis JG, Forti G, et al. Moderate hyponatremia is associated with increased risk of mortality: evidence from a meta-analysis. PLoS One 2013;8:e80451.
31. Esposito P, Piotti G, Bianzina S, Malul Y, Dal Canton A. The syndrome of inappropriate antidiuresis: pathophysiology, clinical management and new therapeutic options. Nephron Clin Pract 2011;119:c62–73.
32. Feldman BJ, Rosenthal SM, Vargas GA, Fenwick RG, Huang EA, Matsuda-Abedini M, et al. Nephrogenic syndrome of inappropriate antidiuresis. N Engl J Med 2005;352:1884–90.
33. Stoiser B, Mörtl D, Hülsmann M, Berger R, Struck J, Morgenthaler NG, et al. Copeptin, a fragment of the vasopressin precursor, as a novel predictor of outcome in heart failure. Eur J Clin Invest 2006;36:771–8.
34. Morgenthaler NG. Copeptin: a biomarker of cardiovascular and renal function. Congest Heart Fail 2010;16(Suppl 1):S37–44.
35. Yalta K, Yalta T, Sivri N, Yetkin E. Copeptin and cardiovascular disease: a review of a novel neurohormone. Int J Cardiol 2013;167:1750–9.
36. Finley JJ, Konstam MA, Udelson JE. Arginine vasopressin antagonists for the treatment of heart failure and hyponatremia. Circulation 2008;118:410–21.
37. Maisel A, Xue Y, Shah K, Mueller C, Nowak R, Peacock WF, et al. Increased 90-day mortality in patients with acute heart failure with elevated copeptin: secondary results from the biomarkers in acute heart failure (BACH) study. Circ Heart Fail 2011;4:613–20.
38. Balling L, Kistorp C, Schou M, Egstrup M, Gustafsson I, Goetze JP, et al. Plasma copeptin levels and prediction of outcome in heart failure outpatients: relation to hyponatremia and loop diuretic doses. J Card Fail 2012;18:351–8.
39. Peacock WF, Nowak R, Christenson R, Di Somma S, Neath SX, Hartmann O, et al. Short-term mortality risk in emergency department acute heart failure. Acad Emerg Med 2011;18:947–58.
40. Di Somma S, Magrini L, Travaglino F, Lalle I, Fiotti N, Cervellin GF, et al. Opinion paper on innovative approach of biomarkers for infectious diseases and sepsis management in the emergency department. Clin Chem Lab Med 2013;51:1167–75.
41. Meijer E, Bakker SJ, van der Jagt EJ, Navis G, de Jong PE, Struck J, et al. Copeptin, a surrogate marker of vasopressin, is associated with disease severity in autosomal dominant polycystic kidney disease. Clin J Am Soc Nephrol 2011;6:361–8.
42. Dünser MW, Schmittinger CA, Torgersen C. Copeptin and the transplanted kidney: friends or foes? Transplantation 2009;88:455–6.
43. Boertien WE, Meijer E, Li J, Bost JE, Struck J, Flessner MF, et al. Relationship of copeptin, a surrogate marker for arginine vasopressin, with change in total kidney volume and GFR decline in autosomal dominant polycystic kidney disease: results from the CRISP cohort. Am J Kidney Dis 2013;61:420–9.
44. Bankir L, Bouby N, Ritz E. Vasopressin: a novel target for the prevention and retardation of kidney disease? Nat Rev Nephrol 2013;9:223–39.
45. Boertien WE, Meijer E, Zittema D, van Dijk MA, Rabelink TJ, Breuning MH, et al. Copeptin, a surrogate marker for vasopressin, is associated with kidney function decline in subjects with autosomal dominant polycystic kidney disease. Nephrol Dial Transplant 2012;27:4131–7.
46. Zittema D, Boertien WE, van Beek AP, Dullaart RP, Franssen CF, de Jong PE, et al. Vasopressin, copeptin, and renal concentrating capacity in patients with autosomal dominant polycystic kidney disease without renal impairment. Clin J Am Soc Nephrol 2012;7:906–13.
47. Ho TA, Godefroid N, Gruzon D, Haymann JP, Maréchal C, Wang X, et al. Autosomal dominant polycystic kidney disease is associated with central and nephrogenic defects in osmoregulation. Kidney Int 2012;82:1121–9.
48. Torres VE, Chapman AB, Devuyst O, Gansevoort RT, Grantham JJ, Higashihara E, et al. Tolvaptan in patients with autosomal dominant polycystic kidney disease. N Engl J Med 2012;367:2407–18.
49. Torres VE, Bankir L, Grantham JJ. A case for water in the treatment of polycystic kidney disease. Clin J Am Soc Nephrol 2009;4:1140–50.
50. Barash I, Ponda MP, Goldfarb DS, Skolnik EY. A pilot clinical study to evaluate changes in urine osmolality and urine cAMP in response to acute and chronic water loading in autosomal dominant polycystic kidney disease. Clin J Am Soc Nephrol 2010;5:693–7.
51. Wang CJ, Creed C, Winklhofer FT, Grantham JJ. Water prescription in autosomal dominant polycystic kidney disease: a pilot study. Clin J Am Soc Nephrol 2011;6:192–7.
52. Lippi G, Plebani M, Di Somma S, Monzani V, Tubaro M, Volpe M, et al. Considerations for early acute myocardial infarction rule-out for emergency department chest pain patients: the case of copeptin. Clin Chem Lab Med 2012;50:243–53.
53. Manolio T. Novel risk markers and clinical practice. N Engl J Med 2003;349:1587–9.
54. Spasovski G, Vanholder R, Allolio B, Annane D, Ball S, Bichet D, et al, on behalf of the Hyponatraemia Guideline Development Group. Clinical practice guideline on diagnosis and treatment of hyponatraemia. Eur J Endocrinol 2014;170:G1–47.

Davide Bolignano graduated in Medicine from the University of Messina, Italy in 2004 and obtained the post-graduate specialization in nephrology in 2009, both cum laude. He currently works as clinical researcher of the Italian National Research Council (CNR) at the Institute of Clinical Physiology (IFC) based in Reggio Calabria, Italy. He has participated in several national and international scientific congresses and courses focusing on epidemiology, biostatistics, physiology and pathophysiology of kidney diseases. In 2012 he joined the Cochrane Renal Group (Sydney, Australia) as an honorary research fellow, learning skills in systematic reviews, meta-analysis, literature searching and guidelines-making processes. Up to now, Dr. Bolignano is co-author of over 80 scientific papers published on national and international peer-reviewed journals and over 70 official interventions at national and international congresses on nephrology, metabolism, cardiovascular and laboratory medicine. His main fields of research are epidemiology and pathophysiology of chronic and acute kidney diseases, renal biomarkers, cardiovascular risk, vasopressin system, medullar and systemic effects of erhytropoietin and stem cells in uremia.

Aderville Cabassi graduated in Medicine and Surgery (1990) from the University of Parma Medical School. He is a specialist in Internal Medicine and Cardiology, Head of the Medical Physiopathology ward and Cardiorenal Research Unit of the Department of Clinical and Experimental Medicine, and Assistant Professor of Internal Medicine and Research Fellow (1996–1998) at the Research Group on Autonomic Nervous System in the Department of Physiology, University of Montreal Medical School, under the guidance of Prof. Jacques de Champlain. He is Project Coordinator at the Laboratory of Clinical Physiology (1999–2001) of Clinica Medica e Nefrologia della Università di Parma headed by Prof. Alberico Borghetti. From 2001 to 2009 he was responsible of the Cardiovascular Physiopathology Unit. Research interests are both fundamental and clinical in nature, including using microdialysis techniques in experimental pathological models (arterial hypertension, heart failure, renal failure) on the interaction between oxygen- and nitrogen-free radical species, renin-angiotensin, sympathetic nervous system, and the arginine-vasopressin system. In particular, he is interested in the study of heart failure in experimental models by analyzing neurohormonal activation and the interactions with sodium, water balance and osmolarity.

Enrico Fiaccadori, MD, PhD is Associate Professor at the Clinical and Experimental Medicine Department of the Parma University Medical School. He is the Head of the Acute and Chronic Renal Failure Unit and the Renal Intensive Care Unit of the Parma University Hospital. His main topics of research are acute kidney injury in the ICU, nutrition in renal failure, electrolyte and acid-base disorders, and heart failure. He has authored 100 peer-reviewed papers.

Ezio Ghigo is Professor of Endocrinology and Chair of the Division of Endocrinology, Diabetes and Metabolism, the Postgraduate Schools of Endocrinology and Metabolism, Sport Medicine, and the Department of Medicine, at the Health and Science City Hospital for the University of Turin, Italy. He is Dean of the School of Medicine and Vice Rector for Healthcare at the University of Turin, President of the Italian Society of Endocrinology and Vice President of the European Society of Endocrinology. He was Editor-in-Chief of the *Journal of Endocrinological Investigation* and has been a member of the editorial boards of many other international endocrine journals. Professor Ghigo's scientific research has focused on the clinical and experimental basis of neuroendocrine diseases. He has authored more than 400 original papers and various patents. His career in endocrinology was recognized with the Lifetime Achievement Award from the Italian Society of Endocrinology in 2001 and he was awarded the Geoffrey Harris Prize by the European Society of Endocrinology in 2011.

Renato Pasquali is full Professor of Endocrinology and Director of the Division of Endocrinology of the S. Orsola-Malpighi Hospital in Bologna, Italy. Moreover, he heads the School of Specialization in Endocrinology and Metabolism, University Alma Mater Studiorum of Bologna, Italy. He is a member of numerous national and international scientific societies and of the editorial boards of international journals. His scientific activity pertains to: 1) the pathophysiology and treatment of the polycystic ovary

syndrome; and 2) the endocrinology of obesity (sex hormones, the hypothalamic-pituitary-adrenal axis, and the endocannabinoid system). He has authored 250 original papers and review articles published in international journals (PubMed) and 20 chapters in international textbooks (HI 50).

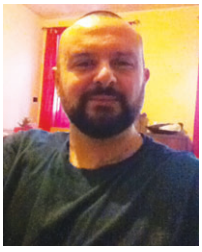
Andrea P. Peracino, MD obtained his degree in Medicine, Magna cum Laude, at the University of Turin, Italy, in 1959. He is member of the Ordine dei Medici di Torino with n. 6304. Andrea Peracino is Vice President, and Member of Scientific Committee, of the Giovanni Lorenzini Medical Science Foundation (Milan, Italy-Houston, TX, USA). His professional carrier had the following inverse-time development: 7 years as Aufsichtsratsmitglied (supervisory board member) in BRAHMS AG, Berlin, Germany, ending on 2006. He spent 17 years in Hoechst Group in R&D in Germany, and UK, and as Member of the Board in Italy: ending on 1998 as Vice President in Hoechst Marion Roussel SpA, President of Hoechst Farmaceutici SpA, and President of Istituto Behring SpA. He spent 28 years in university hospitals in Italy, Finland, and Denmark in the Research, Pathology and Medicine Laboratory areas: ending in 1981 as Director of Research Laboratories and Medical Director of Scientific Institute and University Hospital San Raffaele, Milan, Italy. He has expertise in anatomical pathology (PhD), laboratory medicine (PhD), forensic medicine (PhD), skin diseases (PhD), clinical trials, health organization, health technology assessment, hospital organization and management. His main fields of experience: anatomical pathology, histopathology, immunochemistry, laboratory management and automation, forensic medicine, molecular medicine, infections, diabetes, informatics, clinical pharmacology, cyber communication, hospital organization and management, health economics, business economics, health policy, health technology assessment, and translational medicine. He taught at the following universities: Turin, Ancona, Padua, Bologna, Milan, Copenhagen, Helsinki, Marburg, Frankfurt, and London; and at the following hospitals or health organizations: Ancona, Milan, Paris, Lille, London, Milton Keynes, Marburg, Frankfurt, Berlin, Copenhagen, Helsinki, Vienna, and Seattle.

Alessandro Peri, MD, PhD received a degree in Medicine in 1989, Visiting Fellow at the Human Genetics Branch, NICHD, NIH, Bethesda (MD) from 1991 to 1994, received a PhD in Endocrinology in 1995, and Specialty in Endocrinology in 1999. In 1997, he was Assistant Professor of Endocrinology at the University of Florence and in 2004 Associate Professor. He is a member of several national and international endocrine societies. In 1999 he was the winner of a Travel Grant awarded by the Endocrine Society (USA) and in 2014 the winner of the highest award (entitled to Prof. Aldo Pinchera) of the Italian Endocrine Society. He is Editor (Basic Endocrinology) of the *Journal of Endocrinological Investigation* and reviewer for international scientific journals. He undertakes clinical work at the Careggi University Hospital, Florence, is coordinator of the Week Hospital section of the Endocrine Unit, and teaches at the University of Florence, School of Medicine and School of Biotechnology. He is author of more than 100 articles in international journals, more than 100 communications at national and international scientific meetings, and also an invited speaker. His scientific production encompasses several areas, i.e., neurohypophyseal hormones and electrolyte disorders, endocrine and endocrine-related tumors, hormone-mediated neuroprotection, pathophysiology of reproduction, and stem cell differentiation.

Mario Plebani obtained his medical degree summa cum laude from the Medical School of the University of Padua in 1975. He completed residency training and specialization in laboratory medicine (1978), and subsequently in gastroenterology (1983), at the same university. He is full Professor of Clinical Biochemistry and Clinical Molecular Biology at the University of Padua, School of Medicine, Chief of the Department of Laboratory Medicine at the University-Hospital of Padua, and Chief of the Center of Biomedical Research (a specialized center for quality in laboratory medicine for the Veneto region). Currently, he is also Director of the Post-graduate School in Clinical Biochemistry at the Medical School of the Padua University and President of the Course for Medical Technologists at the same medical school. He served as President of the International Society of Enzymology (ISE) for 4 years (2004–2008) and as President of the Italian Society of Clinical Biochemistry and Molecular Clinical Biology for 5 years (in 2003 and from 2007 to 2009). He is the Chairman of the IFCC Working group on "Laboratory errors and patient safety" (WG LEPS) and in 2008 received the AACC Award for *Outstanding Clinical Laboratory Contributions to Improving Patient Safety.* Dr. Plebani is Editor in Chief of *Clinical Chemistry and Laboratory Medicine*, and Associate Editor of *CRC Clinical Laboratory Sciences*, and *International Journal of Biological Markers*. His main areas of research are quality in laboratory medicine, biomarkers in cancer and cardiovascular diseases, and in vitro allergy diagnostics.

Antonio Santoro is the Director of Nephrology, Dialysis and Hypertension Unit, Policlinico S.Orsola-Malpighi, Bologna, Italy. He is Professor of Nephrology and Intensive Care School, University Bologna,

Chairman of Dialysis and Transplantation Registry of the Emilia-Romagna, and expert for the European Pharmacopea (Brussels) for medical devices and drugs linked to renal replacement therapy. His major research interests include aspects of cardiovascular disease and hypertension in renal diseases from their outset to replacement therapies. Another sphere of interest concerns bioengineering and dialysis technology. In the last few years his scientific output has been focused on kinetics and dialysis modeling, cardiovascular aspects and hypertension of a patient with CKD, extracorporeal purification therapies in non-renal diseases, and intensive care nephrology.



Fabio Settani in 2004 received a degree in Biological Sciences in Turin University and the professional qualification of biologist. He completed post-graduate studies in clinical biochemistry in 2009 and received a PhD in medical pathophysiology in 2013 at Turin University. Since April 2004 he has been employed in the Division of Endocrinology and Metabolism, Department of Medical Sciences at University of Turin. His particular fields of interest are clinical biochemistry applied to endocrinology, diabetology and metabolism, but also molecular and cellular endocrinology, and has contributed to 18 original articles and 20 including oral communications and posters in national and international congresses.

Carmine Zoccali is Team Leader of the Clinical Epidemiology of Renal Diseases and Hypertension Unit of the National Research Council (Consiglio Nazionale delle Ricerche, CNR) – IBIM at Riuniti Hospital, Reggio Calabria. Dr. Zoccali's research interests cover hypertension, cardiovascular complications in chronic renal failure, renal disease progression and the epidemiology of chronic renal failure. He has contributed over 500 PudMed indexed publications in peer-reviewed journals and has a Hirsh Index of 69. He is Chief Editor of *Nephrology, Dialysis and Transplantation* and an editorial board member of *Journal of American Society of Nephrology*, *Clinical Journal of American Society of Nephrology*, *Nephrology Dialysis Transplantation*, *Hypertension*, *European Journal Clinical Investigation* and *Clinical Nephrology* and several other internal medicine and nephrology journals. He has chaired the European Renal Association-European Dialysis and Transplant Association (ERA-EDTA) Registry of Dialysis and Transplantation from 2003 until May 2009. He is a member to 10 national and international societies of nephrology and hypertension, and has received international awards by the American Kidney Foundation and the Borelli Foundation. Dr. Zoccali is Fellow of the American Society of Nephrology (FASN), ERA-EDTA (FERA), American Kidney Foundation (FNKF) and honorary Member of the Spanish Society of Nephrology and the Polish Society of Nephrology.