Paraneoplastic endocrine syndromes

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Abstract

The majority of neoplasms are responsible for symptoms caused by mass effects to surrounding tissues and/or through the development of metastases. However, occasionally neoplasms, with or without endocrine differentiation, acquire the ability to secrete a variety of bioactive substances or induce immune cross-reactivity with the normal tissues that can lead to the development of characteristic clinical syndromes. These syndromes are named endocrine paraneoplastic syndromes when the specific secretory components (hormones, peptides or cytokines) are unrelated to the anticipated tissue or organ of origin. Endocrine paraneoplastic syndromes can complicate the patient's clinical course, response to treatment, impact prognosis and even be confused as metastatic spread. These syndromes can precede, occur concomitantly or present at a later stage of tumour development, and along with the secreted substances constitute the biological 'fingerprint' of the tumour. Their detection can facilitate early diagnosis of the underlying neoplasia, monitor response to treatment and/or detect early recurrences following successful initial management. Although when associated with tumours of low malignant potential they usually do not affect long-term outcome, in cases of highly malignant tumours, endocrine paraneoplastic syndromes are usually associated with poorer survival outcomes. Recent medical advances have not only improved our understanding of paraneoplastic syndrome pathogenesis in general but also enhanced their diagnosis and treatment. Yet, given the rarity of endocrine paraneoplastic syndromes, there is a paucity of prospective clinical trials to guide management. The development of well-designed prospective multicentre trials remains a priority in the field in order to fully characterise these syndromes and provide evidence-based diagnostic and therapeutic protocols.

Key Words

- ▶ endocrine tumours
- ▶ paraneoplastic syndromes
- ▶ SIADH
- ▶ hypercalcaemia
- ▶ Cushing's syndrome
- ▶ acromegaly
- ▶ hypoglycaemia

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Introduction

The term paraneoplastic syndrome (PNS) was first described in the 1940s when it was recognised that certain neoplasms may cause various symptoms that are not solely attributable to direct tumour invasion, compression and/or the development of metastases (Guichard *et al.* 1949). Such neoplasms present or acquire in time the ability to

secrete a variety of biologically-active substances that can lead to the development of distinctive clinical syndromes. These syndromes are termed paraneoplastic because the secretory components responsible for their development are not derived from the anticipated organ or tissue of origin. PNS can be the product of tumour-secreted peptides,

Table 1 Criteria for defining ectopic hormonal (paraneoplastic) syndromes.

Endocrine or metabolic disturbance in a patient with a tumour
Remission after successful treatment
Return of endocrine syndrome with tumour recurrence
Abnormally regulated elevated hormone levels
Significant gradient between hormone concentration in the venous effluent from the tumour and arterial hormone levels
Extracts from tumour exhibit bio- and/or immunoreactive hormone
Relevant hormone mRNA can be identified in tumour tissue
Synthesis and secretion of relevant hormone by tumour cells <i>in vitro</i>

amines or cytokines, or immune cross-reactivity between neoplastic and normal tissues, and can originate from either endocrine or non-endocrine neoplasms (Pelosof & Gerber 2010). The occurrence of PNS is influenced by the histology of the underlying neoplasm, and while such behaviour can often be explained in tumours of endocrine origin, it is not as yet fully understood in cases of non-endocrine neoplasms. The criteria for the diagnosis of endocrine PNS are shown in Table 1.

PNS can develop during different phases of the evolution of the neoplastic process, with an estimated prevalence of approximately 8% among all malignant neoplasms (Baijens *et al.* 2006). In some cases, PNS can manifest itself before the diagnosis of the underlying malignancy and may facilitate diagnosis at an early and potentially reversible disease stage (Tarin 2013). Furthermore, the presence of PNS and measurement of the related aetiological factor can be used to monitor response to treatment and/or detect recurrence of the tumour following initial successful treatment. Effective and prompt diagnosis and treatment of the PNS may substantially improve overall clinical outcomes. However, occasionally, in the presence of highly aggressive tumours or extensive disease burden, management of these syndromes may be difficult and their presence can contribute to the morbidity and mortality of the underlying disease (Kaltsas *et al.* 2010). As currently available therapies for a number of neoplasms evolve and highly specific diagnostic modalities become widely used, patients with tumours will live longer, and thus the prevalence of PNS will likely also increase (Oberg *et al.* 2016). In the present review only endocrine PNS will be considered, excluding those related to different pathophysiological processes and/or exhibiting manifestations in other systems.

Paraneoplastic endocrine syndromes

Paraneoplastic endocrine syndromes mostly result from the production of bioactive substances from neoplastic cells, of endocrine or neuroendocrine origin, that are

widely distributed throughout the lungs, gastrointestinal tract, pancreas, thyroid gland, adrenal medulla, skin, prostate and breasts (Agarwala 1996, Modlin 2008). A distinctive feature of endocrine PNS is that related symptoms cannot be attributed to the presence of a secreting neoplastic lesion related to the originating anatomic site, and thus the secretion of peptides, amines or other bioactive substances is regarded as *ectopic* (Kaltsas 2010). This is particularly relevant as neoplasms without endocrine differentiation may also acquire the ability to synthesise and secrete these bioactive substances, leading to clinically similar endocrine tumour-derived PNS (Table 2).

The clinical manifestations of these ectopic hormonal secretion syndromes may be clinically indistinguishable to those encountered when the neoplastic lesion is found in the expected site of origin (eutopic hormonal secretion), thus causing diagnostic dilemmas (Keffer 1996, Kaltsas *et al.* 2010). Neoplasms that cause endocrine PNS exhibit a wide range of malignant potential, ranging from being essentially of benign or low malignant potential to highly malignant tumours. However, the development of PNS does not always correlate with tumour stage, malignant potential and/or overall prognosis (Spinazze *et al.* 2006).

A number of histopathological classification systems of endocrine tumours originating from different endocrine tissues, such as gastrointestinal neuroendocrine tumours (GI-NETs), lung NETs, adrenomedullary and adrenocortical tumours, skin and thyroid tumours, have emerged providing information regarding the malignant potential of such tumours. In contrast, the great majority of endocrine PNS produced from non-endocrine neoplasms are found in highly malignant tumours mainly involving the lungs, breasts, prostate, ovaries, skin, colon and certain forms of haematological malignancies; however, tumours arising from virtually any tissue have been implicated, albeit rarely (Lorch *et al.* 2007, Nimalasena *et al.* 2008, Gilmore *et al.* 2009, Nella *et al.* 2014, Dimitriadis *et al.* 2015, Thajudeen *et al.* 2016).

Table 2 Ectopic Cushing's syndrome (CS): differences in clinical, laboratory and radiological features compared to eutopic secretion.

Syndrome	Mediator	Tumour	Clinical/biochemical	Endocrine testing	Radiological
Cushing's syndrome (CS)	ACTH and (rarely) CRH	SCLC Carcinoid tumour Thymus, mediastinum Thyroid (MTC) PICT Pheochromocytoma GI Head Abdomen (paraganglioma, ovary, other)	Hypokalaemia/cachexia Cushingoid phenotype	↑ACTH (isoforms) HDDSST (–), CRH (DDAVP test) (–)	Pituitary MRI (–) BIPSS (–) ¹¹¹ In Octreotide SRS (+) ¹⁸ F-FDG-PET (+) ¹⁸ F-DOPA-PET (+) ⁶⁸ Ga-PET DOTATATE (+) ¹²³ I-MIBG (+)

¹¹¹In SRS, ¹¹¹Indium somatostatin receptor scintigraphy; ¹⁸F-DOPA-PET, flu-dihydroxyphenylalanin positron emission tomography; ¹⁸F-FDG-PET, fludeoxyglucose positron emission tomography; ⁶⁸Ga-PET DOTATATE, gallium positron emission tomography; ACTH, adrenocorticotrophic hormone; BIPSS, bilateral inferior petrosal sinus sampling; CRH, corticotrophin-releasing hormone; DDAVP, desmopressin; GI, gastrointestinal; SCLC, small cell lung cancer; HDDSST, high dose dexamethasone suppression test; MIBG, metaiodobenzylguanidine; MTC, myeloid thyroid cancer; PICT, pancreatic islet cell tumours.

Prompt endocrine PNS recognition may facilitate the diagnosis of an underlying unsuspected neoplasm, avoid extensive investigations to identify a presumptive eutopic hormonal-secreting neoplasm, and will allow for the monitoring of the clinical course and response to treatment of the underlying tumour (Pierce 1993, Bollanti 2001).

Pathogenesis

Although several attractive hypotheses have been proposed for the pathogenesis of endocrine PNS, the exact events that lead to their development are still elusive (Spinazze *et al.* 2006). It is well known that all human cells carry the same genetic information of which only part is expressed through their life span. However, under certain conditions specific alterations of gene function may activate genes that regulate hormonal synthesis, particularly in the context of an underlying neoplastic process, leading to the development of endocrine PNS (Granot & Fridlender 2015). Inappropriate gene expression heralds the unscheduled appearance of a gene product at an unusual time of life or in an atypical cell, tissue or organ leading to a PNS, as encountered in many different animal species (Tarin 2013). However, the precise mechanism that initiates ectopic hormonal synthesis and release during the neoplastic transformation at a specific time point stills remains to be defined (Kaltsas *et al.* 2010).

Ectopically produced bioactive substances from endocrine and non-endocrine neoplasms leading to endocrine PNS are mostly peptides and hormones, and

less commonly biogenic amines, steroids or thyroid hormones (Kaltsas *et al.* 2010, Dimitriadis *et al.* 2016). The symptoms are produced following the direct secretion of these substances from the tumour to the circulation, although they may also exert paracrine and autocrine effects. When symptoms develop, ectopically related hormones are found in large quantities in the serum. In a minority of patients, there may be different types of pancreatic NET hormone secretion which may also alter over time (Crona *et al.* 2016). Occasionally, the synthesis and/or processing of these compounds may be different from that of the eutopically secreted hormone leading to diagnostic uncertainty (Newell-Price 2003). In addition, as the secretion of these hormones is usually aberrantly regulated, the response to endocrine testing is different to that anticipated if eutopically secreted (Kaltsas *et al.* 2010).

Diagnostic methods for detecting endocrine PNS

Suspicion of an endocrine PNS can direct relevant diagnostic investigations accordingly. Non-endocrine tumours associated with endocrine PNS mainly involve the lung, breast, prostate, skin, colon and haematological malignancies. The majority of lung tumours are either small or large cell (SCLC or LCLC), or tumours of squamous origin (Nauck *et al.* 2007). Squamous cell tumours are usually large and can be detected using conventional cross-sectional imaging (computerised tomography, CT) with a sensitivity and specificity of

89% and 93%, respectively, in one series (Toyoda *et al.* 2008); in cases of a suspected lesion without radiological confirmation, ^{18}F -FDG-PET shows 79% sensitivity and 91% specificity (Benjamin *et al.* 2003). Magnetic resonance imaging (MRI) is increasingly used in the diagnosis for both *in situ* and invasive forms of breast tumours (Behrendt *et al.* 2014) with >90% sensitivity but only 72% specificity (Menezes *et al.* 2014). Multiparametric MRI is widely used for prostate cancer detection with 88% sensitivity and 74% specificity, respectively (De Rooij *et al.* 2014). Most imaging modalities for malignant skin neoplasms exhibit low sensitivity and specificity, although molecular pathways/targets are currently being explored (Hong *et al.* 2008). Various imaging methods are employed for the diagnosis of colorectal tumours, yet the 'gold standard' remains optical colonoscopy (OC). Other modalities include CT colonoscopy with very high sensitivity (100%), while MRI has 84% sensitivity and 95% specificity when evaluating lesions >1 cm (Kekelidze *et al.* 2013). In the case of haematological malignancies, CT is the modality of choice (Shankland *et al.* 2012). PET scanning with ^{18}F -FDG-PET CT is increasingly being used in the management of lymphomas with 80% sensitivity and 90% specificity; however, PET scans are most widely used to assess responsiveness to therapy (Shankland *et al.* 2012).

Various radiological modalities are utilised for the diagnosis of endocrine tumours. Functional imaging aims at demonstrating the presence of somatostatin receptors (sstr) and uptake mechanisms on their surface (Kwekkeboom *et al.* 2009). The reported overall sensitivity of somatostatin receptor scintigraphy (SRS) for well-differentiated (grade 1 and 2) GI-NETs is >80%. The sensitivity of SRS is lower in tumours with a diameter generally <1 cm, due to insufficient tumour-to-background uptake ratios of radioactivity, and is also low in NETs with a high Ki-67 index or neuroendocrine carcinomas (NECs), reflecting dedifferentiation and loss ofsstr expression (Sundin *et al.* 2012). ^{68}Ga -DOTATATE or ^{68}Ga -DOTATOC is superior to SRS SPECT-CT showing higher sensitivities for lesion detection (>90%), particularly due to better resolution orsstr affinities (Wild *et al.* 2013). Radioiodinated MIBG, ^{123}I -MIBG, is a guanethidine analogue that shares structural features with noreadrenaline and is used for imaging of pheochromocytomas, paragangliomas and neuroblastomas (Jacobson *et al.* 2010). However, ^{123}I -MIBG scintigraphy has lower sensitivity than SRS for GI-NETs (50%) and pancreatic NETs (<10%) (Kaltsas *et al.* 2001). Fluorine-18-L-3,4-dihydroxyphenylalanine (^{18}F -DOPA) PET/CT showed the highest sensitivity (98%) as compared

with SRS and ^{11}C -5-hydroxy-L-tryptophan (^{11}C -5-HTP) PET for the detection of GI-NETs, but not pNETs (Van Essen *et al.* 2014). ^{11}C -5-HTP is a radiolabelled precursor in the serotonin synthesis: ^{11}C -5-HTP PET showed the highest sensitivity (96%) for the detection of pNETs as compared with CT, SRS or ^{18}F -DOPA PET (Gotthardt *et al.* 2010). Cholecystokinin₂ (CCK2) receptor expression has been demonstrated in NETs with ^{111}In -DOTA-CCK, $^{99\text{m}}\text{Tc}$ -demogastrin and ^{111}In -DOTAMG11. ^{68}Ga -DOTAminogastrin radiopharmaceuticals have shown 97% sensitivity for the detection of tumour deposits in patients with medullary thyroid carcinoma (MTC) (Froberg *et al.* 2009). Another radiopeptide used for targeting the GLP1R is (Lys(40)(Ahx-HYNIC- $^{99\text{m}}\text{Tc}$ /EDDA)NH₂)-exendin-4, GLP1R imaging using this compound has been studied in MTCs (Pach *et al.* 2013).

There is currently a paucity of reliable biomarkers to aid the diagnostic process in cases of non-endocrine neoplasia. This is partially due to the pathobiological diversity of non-endocrine neoplasia and its generally more aggressive biological behaviour (Oberg *et al.* 2016). In endocrine neoplasia, particularly in NETs, certain markers developed based on specific tumour-secreted compounds can improve chances of tumour detection (Oberg *et al.* 2016). Besides traditional biomarkers developed for the detection of endocrine malignancy, there is currently a considerable interest in areas such as blood transcript analysis, circulating tumour cells (NetTest) and miRNA measurement, although yet there are significant limitations before application into general clinical practice is likely (Modlin *et al.* 2016).

Common endocrine PNS secondary to the secretion of peptide hormones

Hypercalcaemia

The hypercalcaemia of malignancy is one of the most common endocrine PNS occurring in up to 10% of all patients with advanced tumours, and conveys a poor prognostic factor as the 30-day mortality can reach 50% (Ralston *et al.* 1990, Lumachi *et al.* 2008). Paraneoplastic hypercalcaemia occurs in the absence of metastases or altered parathyroid gland function and can be caused by a variety of humoral substances that exert different effects on calcium homeostasis. Although ectopic parathyroid hormone (PTH) or 1–25-dihydroxy (OH)₂ vitamin D₃ secretion have been associated with the humoral hypercalcaemia of malignancy (HHM), in the majority of cases (>80%) it results from the secretion of parathyroid

hormone-related protein (PTHrP) (Stewart 2005, Van den Eyden *et al.* 2007).

Parathyroid hormone is composed of 84 amino acids, whereas PTHrP comprises of 139–173 amino acids; although they exhibit different C-terminal portions they share the first 13 N-terminal amino acids (Stewart 2005, Van den Eyden *et al.* 2007). PTHrP folds into a configuration that can bind to the PTH receptor, although it can also bind to other receptors, via which it exerts different effects from PTH (Van den Eyden *et al.* 2007). It has effects upon tissues other than bone, including the skin, anterior pituitary and mammary gland, and causes more widespread symptoms than elevated PTH although there is some overlap (Lumachi *et al.* 2008). It can be produced as four different alternatively-spliced messenger RNA transcripts, and at least two peptide isoforms are known to exist. Hypomethylation of the promoter has been implicated as a mechanism of its aberrant gene expression (Strewler 2000).

PTHrP-related hypercalcaemia occurs most commonly with squamous cell tumours and SCLC (Donovan *et al.* 2015), but it is also seen with endocrine tumours including GI-NETs (Stewart 2005, Van den Eyden *et al.* 2007). In two lung squamous cell carcinoma xenograft models of hypercalcaemia, the inhibition of autocrine epidermal growth factor receptor (EGFR) signalling has been shown to reduce plasma PTHrP and total calcium concentrations (Lorch *et al.* 2007). Amphiregulin stimulation of EGFR resulted in high levels of PTHrP gene expression in squamous cell carcinomas (Gilmore *et al.* 2009). Furthermore, the reconstitution of the amphiregulin-EGFR signalling system in a squamous cell carcinoma line led to HHM and rapid osteolytic growth in animal models (Gilmore *et al.* 2009). This is a potential mechanism of non-endocrine neoplasia induced hypercalcaemia. Breast and testicular malignancies, and certain haematological malignancies including multiple myeloma, lymphomas and chronic lymphocytic leukaemia, can cause hypercalcaemia via this mechanism, at least in part (other mechanisms may also be involved) (Shionoiri *et al.* 2000, Stewart 2005, Kampfenkel *et al.* 2010). Other malignancies can also be associated with PTHrP-related hypercalcaemia. A recent review identified 29 cases of malignant colorectal tumours causing PTHrP-mediated hypercalcaemia. Most patients were middle-aged men with advanced metastatic cancer and severe hypercalcaemia (62% with Ca >14 mg/dL, 3.5 mmol/L) and were associated with high mortality and a short median survival (Galindo *et al.* 2016).

PTHrP-related hypercalcaemia is currently considered as the most common mechanism of endocrine

tumour-related hypercalcaemia and can be encountered in GI-NETs, pheochromocytomas and carcinoid tumours (Mantzoros *et al.* 1997, Abraham *et al.* 2002, Brzozowska *et al.* 2009, Kaltsas *et al.* 2010). Pancreatic NETs were initially considered to be a relatively common group of tumours associated with ectopic PTHrP secretion, but a recent single centre study identified this to be a relatively rare event (Kamp *et al.* 2014).

Rarely, hypercalcaemia may result from ectopic 1,25-dihydroxy(OH)₂ vitamin D secretion, particularly in association with certain haematological malignancies (lymphomas) and NETs, or from ectopic PTH secretion (Stewart 2005, Van den Eyden *et al.* 2007). Another mechanism of HHM may be mediated by granulocyte colony-stimulating factor (G-CSF), as a long-term exposure to G-CSF results in the stimulation of osteoclastic bone resorption and/or an increase in osteoclast progenitors (Hiraki *et al.* 2004). The over-secretion of macrophage inflammatory protein 1a (MIP-1a) has also been implicated in a myeloma case simultaneously secreting PTHrP and MIP-1α (Shimizu *et al.* 2011). Cases of hypercalcaemia attributed to true ectopic PTH secretion are rare. In a recent literature review, 32 patients with tumours originating from the head and neck (7), thorax (8), GI-pelvis (11) and gynaecological (5) neoplasms, including a number of endocrine and NETs, were reported causing hypercalcaemia secondary to PTH secretion (Kandil *et al.* 2011).

Symptom severity depends not only on the degree of hypercalcaemia (calcium levels >3 mmol/L), but also on the rapidity of onset and the patient's baseline neurologic and renal function (Stewart 2005). The optimal approach to paraneoplastic hypercalcaemia is the treatment of the underlying tumour. In cases of intractable hypercalcaemia, treatment directed against the elevated calcium levels should be undertaken as per recent guidelines (including bisphosphonates and possibly denosumab), while cinacalcet has been shown to be particularly efficacious in cases of PTHrP-related hypercalcaemia (Collins *et al.* 1998, Takeuchi *et al.* 2016).

Syndrome of inappropriate anti-diuretic hormone secretion (SIADH)

The syndrome of inappropriate anti-diuretic hormone secretion (SIADH) is characterised by hypo-osmotic, euvoletic hyponatraemia in the absence of plasma hypotonicity, and it occurs in 1–2% of all patients with malignant tumours (Castillo *et al.* 2012, Thajudeen *et al.* 2016). SIADH is most commonly found in SCLC

although it can also result from LCLC (Raftopoulos 2007, Castillo *et al.* 2012, Thajudeen *et al.* 2016). SIADH is also seen in 2–4% of non-SCLC patients, including those suffering from prostate, breast, adrenal cancer and lung carcinoids (Raftopoulos 2007, Castillo *et al.* 2012, Thajudeen *et al.* 2016). In SCLC, SIADH has been associated with a higher propensity for central nervous system metastases, poor response to chemotherapy and advanced stage of cancer (Thajudeen *et al.* 2016). There appears to be no clinical and/or biochemical features distinguishing the origin of the tumour although most severe symptoms are encountered in patients with highly aggressive tumours (Selmer *et al.* 2016); hyponatraemia grade at short-term follow-up was also predictive for long-term survival (Shepshelovich *et al.* 2015). In primary care patients, all levels of hyponatraemia are associated with increased all-cause mortality, whereas hyponatraemia *per se* is linked to an increased risk of being diagnosed with any malignancy, particularly pulmonary and head-and-neck malignancies (Selmer *et al.* 2016).

Inappropriate action of anti-diuretic hormone (ADH, vasopressin), and nearby secreted oxytocin, have been identified in related neoplasms, being also implicated in tumour growth, exhibiting autocrine and paracrine signalling activities (De Lellis & Xia 2003). The relation between SIADH and ectopic ADH production by tumour cells has also been demonstrated in *in vitro* studies as high concentration of immune-reactive ADH has been found in tumour extracts of patients with SIADH (Thajudeen *et al.* 2016). Northern blot and S₁-nuclease analysis demonstrated the production of ADH mRNA in tumours and tumour cell lines from patients with SCLC and hyponatraemia. Similarly, ADH has also been detected in SCLC tumours by radioimmunoassay and bioassay of anti-diuretic activity. Tissue cultures derived from ADH-producing SCLC demonstrated the presence of ADH in only a fraction of cells. Evidence for the production of ADH by only selected cells is also supported by the finding of persistent SIADH in patients who had a marked decrease in tumour size (Grohe *et al.* 2015).

The symptoms of SIADH depend on the degree and rapidity of hyponatraemia onset. Serum sodium levels <125 mmol/L, particularly if developing within 48 h, manifest as altered mental status, seizures, coma, respiratory collapse and death (Ellison & Berl 2007). When hyponatraemia develops during a longer time frame, neurologic complications may not occur (Raftopoulos *et al.* 2007). The optimal therapy for paraneoplastic SIADH is

related to the treatment of the underlying tumour, which if successful normalises sodium level in weeks. It has been suggested that in patients with malignancy the use of an ADH receptor antagonist could improve hyponatraemic symptoms even in patients on palliative care. More studies are required to address the potential safety concerns of chronic use, because tolvaptan, a V₂-receptor antagonist, is an excellent choice, especially in patients with lung malignancies (Grohe *et al.* 2015, Thajudeen *et al.* 2016). It has recently been shown that prompt endocrine input improved time for the correction of hyponatraemia and shortened length of hospitalisation, and the widespread provision of endocrine input should be considered (Verbalis *et al.* 2014, Grant *et al.* 2015, Tzoulis *et al.* 2016).

Cushing's syndrome (CS)

Approximately 10% of Cushing's syndrome (CS) cases are considered to be of paraneoplastic origin with approximately 50% being secondary to lung NETs (bronchial carcinoids, SCLC and rarely LCLC) (Barbosa *et al.* 2005, Teves *et al.* 2005, Morandi *et al.* 2006). Less commonly, paraneoplastic CS (PN-CS) may develop from neuroendocrine cells of the thymus, MTC, pancreas or chromaffin cell tumours (phaeochromocytomas, paragangliomas and neuroblastomas) (Ilias *et al.* 2005, Isidori *et al.* 2006). In a recent study performed by Kamp and coworkers looking at a large cohort of patients with thoracic and GEP-NETs, the reported prevalence of PN-CS was 3.2% (Kamp *et al.* 2016).

It can also rarely arise from NE cells originating from the ovary or prostate (Nimalasena *et al.* 2008). Paraneoplastic CS occurs secondary to tumour secretion of adrenocorticotrophic hormone (ACTH) or very rarely of corticotrophin-releasing hormone (CRH) (Newell-Price *et al.* 1998, Newell-Price *et al.* 2006). The ectopic ACTH syndrome is caused by abnormal expression of the POMC gene product arising from non-pituitary tumours in response to ectopic activation of the pituitary-specific promoter of this gene. Methylation of the CpG islands in the promoter region is associated with silencing of some genes. Using bisulphite sequencing and hypomethylation in five thymic carcinoid tumours resected from patients with ectopic ACTH syndrome, its presence correlated with POMC over-expression and the ectopic ACTH syndrome (Ye *et al.* 2005). Methylation near the response element for the tissue-specific POMC activator PTX1 diminishes POMC expression, implying that the methylation and expression patterns are likely to be set early or prior to

neoplastic transformation and that targeted *de novo* methylation might be a potential therapeutic strategy (Newell-Price 2003).

Endocrine and neuroendocrine tumours producing PN-CS are in the majority of low malignant potential although this may change during the course of the disease (Ilias *et al.* 2005, Isidori *et al.* 2006, Li *et al.* 2016). Well differential lung NETs (typical and atypical carcinoids) account for the majority of PN-CS, approximately 36–46%, producing a clinical and biochemical syndrome resembling pituitary dependent CS (Li *et al.* 2016, Zhang & Zhao 2016). Symptoms and biochemical manifestations typically evolve gradually and usually do not produce a severe CS phenotype (Li *et al.* 2016). Although a variety of invasive and non-invasive endocrine and imaging studies may be utilised, a number of these tumours may still elude localisation or become apparent later during the course of the disease (Hofland & Lamberts 2001). In such cases medical treatment of hypercortisolaemia and regular imaging studies to identify such lesions is usually advocated (Nieman *et al.* 2015). Paraneoplastic CS syndrome due to ACTH secretion from MTC appears to be relatively rare as it was only detected in 10/1640 patients with MTCs (0.6%) (Barbosa *et al.* 2005). Pheochromocytomas secreting ACTH are considered to be even rarer, accounting for approximately 5.2% of all cases of ectopic ACTH related CS (Ballav *et al.* 2012). Pancreatic NETs associated with PN-CS account for up to 10% of ectopic CS. In a recent study of 10 pNETs causing PN-CS, the mean age at diagnosis was 42 years, whereas the 5 and 10 year overall survival rate was 35% and 16.2%, respectively (Maragliano *et al.* 2015). Thymic NETs associated with PN-CS are also relatively rare and are usually associated with a worse outcome, but ectopic ACTH is a fairly common manifestation of thymic carcinoids and may occur in association with MEN-1 (Jia *et al.* 2017). In a study of 12 patients the median age at presentation was 21 years, median tumour diameter 5 cm, while urinary free cortisol levels were found to be grossly elevated (Neary *et al.* 2012). Six recurrent patients developed metastatic disease and died 57 months following initial thymectomy (Neary *et al.* 2012). Figure 1 illustrates a thymic carcinoid tumour which secreted ACTH intermittently to cause periodic Cushing's syndrome (Trott *et al.* 2016).

Paraneoplastic CS from NETs has occasionally been attributed to CRH secretion such as carcinoids, MTCs and chromaffin cell tumours (Ilias *et al.* 2005, Isidori *et al.* 2006). In such cases, endocrine testing may be difficult to interpret as there is interplay between the findings

Figure 1

Thorax computerised tomography (CT) demonstrating a 24 mm anterior mediastinal thymic carcinoid. Reproduced under the terms of the original CC BY licence, from Trott *et al.* (2016).

of ectopic and eutopic production of these compounds, although usually there is a co-secretion of both ACTH and CRH (Howlett *et al.* 1986, Oldfield *et al.* 1991, Chrysoulidou *et al.* 2008).

Approximately 8–20% of PNS-CS is related to SCLC, although the secretory potential of ectopically produced ACTH of these tumours is much higher than that encountered in NETs (Ilias *et al.* 2005, Isidori *et al.* 2006, Kaltsas *et al.* 2010). In contrast to patients with PN-CS derived from NETs, patients with SCLC do not generally exhibit the classical symptoms of gradually evolving endogenous hypercortisolaemia with the exception of being exposed to high levels of cortisol (Bollanti *et al.* 2001, Ilias *et al.* 2005, Isidori *et al.* 2006). The symptoms/signs of the underlying malignancy along with weight loss, electrolyte and metabolic abnormalities are commonly encountered (Bollanti *et al.* 2001, Ilias *et al.* 2005, Isidori *et al.* 2006). The diagnosis is usually suspected on the basis of the rapidity of symptom development, relevant history of excessive smoking and radiological findings (Rueda-Camino *et al.* 2016). The severity of PN-CS can occasionally be so excessive that it may lead to cardio-respiratory failure (von Stempel *et al.* 2013). The impact of PN-CS in SCLC patients has been evaluated in a recent study (Nagy-Mignotte *et al.* 2014). Among 383 patients with SCLC, 23 had PN-CS, 56 other PNS (OtherPNS) and 304 had no PNS (NoPNS). After comparison of the three groups, PN-CS patients had more extensive disease, greater weight loss ($\geq 10\%$) and a reduced objective response to first-line treatment (47.6% vs 74.1% vs 71.1%) and poorer sensitivity to first-line treatment (19% vs 38.9% vs 48.6%), respectively. On relapse, the PN-CS group had no objective response to second-line treatment vs 25%

and 42.8% in OtherPNS and NoPNS groups, respectively (Nagy-Mignotte *et al.* 2014). The median survival of PN-CS patients was 6.6 months vs 9.2 months for otherPNS and 13.1 months for noPNS patients. It was concluded that PN-CS is a prognostic factor of early demise (hazard ratio, 2.31) (Nagy-Mignotte *et al.* 2014).

Small cell carcinoma (SCC) of the prostate is an uncommon condition but there are a very few cases in which presenting symptoms are consistent with CS (Rueda-Camino *et al.* 2016). It may be suspected when laboratory features appear in patients diagnosed with prostatic adenocarcinoma with metastases that becomes resistant to specific therapy; prostatic-specific antigen levels are usually normal. The prognosis is very poor as 2- and 5-year survival rates are 27.5 and 14.3%, respectively (Rueda-Camino *et al.* 2016). Ectopic ACTH secretion associated with CS can also be rarely due to pancreatic acinar cell carcinoma (ACC) and pancreatoblastoma, rare tumour types with morphologic features sometimes overlapping those of pNETs (Maragliano *et al.* 2015).

Several studies have attempted to provide clinical, biochemical and radiological features aiming at distinguishing the origin of PN-CS in respect to the malignant potential of the tumour (Table 3).

PN-CS treatment focuses on the management of the severe metabolic disruptions followed by rapid resolution of the hypercortisolaemia, and subsequent confirmation of the cause. Emergency lowering of the elevated serum cortisol when the syndrome is severe is most rapidly achieved with oral metyrapone and/or ketoconazole; if parenteral therapy is required then intravenous etomidate is rapidly effective in almost all cases (Preda *et al.* 2012), but all measures require careful supervision. If medical treatments fail, bilateral adrenalectomy should be performed in the shortest possible time span to prevent the debilitating complications of uncontrolled hypercortisolaemia (Nieman *et al.* 2015).

PNS hypoglycaemia

Tumour-associated or paraneoplastic hypoglycaemia occurs rarely and is caused by insulin-producing non-islet cell tumours and tumours secreting substances that can induce hypoglycaemia by non-insulin mediated mechanism (Iglesias & Diez 2014). However, the majority of cases are the result of tumour-associated hypoglycaemia without excess insulin secretion secondary to the secretion of peptides capable of causing

Table 3 Endocrine and non-endocrine tumours causing paraneoplastic syndromes.

Paraneoplastic syndrome	Tumour types
Common	
Humoral hypercalcemia of malignancy (HHM)	Squamous cell (head and neck, lung, skin), breast, genitourinary (ovary, testis), lymphomas, renal, multiple myeloma, chronic lymphocytic leukaemia, lung (SCLC), colorectal, GI-NETs
Syndrome of inappropriate anti-diuretic hormone secretion (SIADH)	Lung (squamous, SCLC, LCLC, bronchial carcinoids), prostate, breast, adrenal, GI
Cushing's syndrome	Lung (SCLC, bronchial carcinoids, LCLC), thymus, MTC, pNET, pheochromocytomas, paragangliomas, neuroblastomas
Less common	
Non-islet cell tumour hypoglycaemia (NICTH)	Mesenchymal tumours (sarcomas, GIST), renal, ovary, NETs
Gynaecomastia/virilisation (β -hCG)	Lung (SCLC, bronchial carcinoids), GCT (seminomas, teratomas, choriocarcinomas, yolk sac), pNETs
Rare	
Acromegaly	pNETs, lung (bronchial carcinoids), choristomas, hamartomas, gliomas, gangliocytomas
Hypertension	Lung (SCLC, bronchial carcinoids), paragangliomas, renal, DSRCT
Ovarian hyperstimulation syndrome/PCOS like	pNETs, lung (bronchial carcinoids)
Hyperprolactinaemia	Lung (SCLC), mesenchymal tumours
Hyperthyroidism	Ectopic pituitary adenomas, struma ovarii
Secretory diarrhoea	Lung (SCLC), MTC, pheochromocytoma, renal
Tumour induced osteomalacia (TIO)	Mesenchymal tumours, prostate, colon
Ileus	Glomus tumours (skull base)
Acute inflammatory reaction/pyrexia	Pheochromocytomas, mesenchymal tumours, angiomatoid fibrous histiocytoma

β -hCG, beta-human chorionic gonadotrophin; DSRCT, desmoplastic round cell tumours; GI-NETs, gastrointestinal neuroendocrine tumours; GIST, gastrointestinal stromal tumours; LCLC, large cell lung carcinoma; MTC, myeloid thyroid carcinoma; PCOS, polycystic ovary syndrome; pNETs, pancreatic neuroendocrine tumours; SCLC, small cell lung carcinoma.

glucose utilisation by different mechanisms such as insulin-like growth factor 2 (IGF2) precursors, IGF1 and glucagon-like peptide-1 (Kaltsas *et al.* 2010, Iglesias & Diez 2014). Tumour autoimmune hypoglycaemia may also occur secondary to insulin receptor auto-antibody production, whereas excessive tumour burden with glucose consumption, massive tumour liver infiltration, and pituitary or adrenal gland destruction by the tumour are the other mechanisms in cases of large and aggressive neoplasias (Iglesias & Diez 2014).

Non-islet cell tumour hypoglycaemia (NICTH) presents as recurrent or constant hypoglycaemic episodes and mostly affects elderly patients with advanced tumours (Teale & Wark 2004, Dimitriadis *et al.* 2015). Occasionally, these hypoglycaemic episodes can predate the diagnosis of the underlying tumour (Nayar *et al.* 2006, Kim *et al.* 2016). The majority of cases of NICTH are usually caused by tumour cell production of IGF2 (Iglesias & Diez 2014). NICTH is characterised by low serum insulin and C-peptide levels, low growth hormone (GH) and IGF1 levels, normal or elevated IGF2 levels and an elevated IGF2:IGF1 ratio (Teale & Wark 2004, Nayar *et al.* 2006, Iglesias & Diez 2014). In some cases of NICTH, expression of 'big' IGF2 has been reported and rarely there is expression of pro-IGF2 (Beckers *et al.* 2003, Hamberg *et al.* 2006). High concentrations of pre-pro-IGF2 levels that are not properly glycosylated result in the high molecular weight 'big' IGF2 that has a significantly higher affinity to the insulin receptor, and a lower affinity to its binding protein (IGFBP3), leading to increased bioavailability, enhanced peripheral glucose consumption and suppressed hepatic glucose production (de Groot *et al.* 2007, Rikhs *et al.* 2009). The majority of tumours associated with NICTH are mesenchymal and epithelial tumours although a number of NETs have also been described (de Groot *et al.* 2007, Kaltsas *et al.* 2010). In a recent review, 32 cases of IGF2 secreting tumours with hypoglycaemia that underwent radical surgery were identified; in 19 patients, hypoglycaemia was reversed and there was no subsequent recurrence. The remaining 13 patients experienced tumour recurrence or metastasis an average of 43 months after initial tumour resection (Otake *et al.* 2015). Although mTOR pathway blockade may represent a possible target regarding the management of malignant insulinoma-induced NICTH, an interesting case of an adrenocortical carcinoma secreting IGF2 not responding to everolimus was recently reported by Korevaar and coworkers (Korevaar *et al.* 2014). It appears that either IGF2 does not cause hypoglycaemia by activation of the insulin receptor, which is improbable, or that the mode of

action of everolimus in this situation was not downstream of the insulin receptor. It is possible that the IGF1R and insulin receptor A or B may form receptor hybrids when co-expressed on the same cell (Korevaar *et al.* 2014).

A case of ectopic insulin secretion by a renal cell carcinoma with positive ⁶⁸Ga-DOTANOC imaging and *ex-vivo* immunoreactivity for insulin has recently been reported (Ramkumar *et al.* 2014), along with an ovarian tumour of mixed neuroendocrine and yolk origin secreting insulin, leading to paraneoplastic hypoglycaemia (Battocchio *et al.* 2015).

Acromegaly

Acromegaly unrelated to a pituitary GH-secreting adenoma is very rare, accounting for less than 1% of cases (Melmed *et al.* 2006). Since the discovery of growth hormone-releasing hormone (GHRH) 30 years ago, it became apparent that the majority of these cases are GHRH-related as this peptide can be synthesised and expressed in multiple extrapituitary tissues (Christofides *et al.* 1984, Melmed *et al.* 2006). In a recent review, only 74 published cases were identified and except for a recent French series of 21 cases most were case reports (Garby *et al.* 2012). Tumours secreting GHRH are mainly NETs, usually well-differentiated and of pancreatic or bronchial origin accounting for approximately 2/3 of cases (Fainstein *et al.* 2007, Butler *et al.* 2012, Lock *et al.* 2014). The clinical presentation is variable with features similar to those caused from a somatotroph adenoma. These tumours are usually large and easy to localise whereas the pituitary imaging may be normal or enlarged and difficult to interpret, especially in multiple endocrine neoplasia type-1 (MEN1) cases. Plasma GHRH measurement has an excellent specificity for the diagnosis, using a threshold of 250–300 ng/L, and is a good tool for the follow-up of patients after treatment. These tumours have a good overall prognosis although approximately 50% develop metastases (Borson-Chazot *et al.* 2012). Single cases of NETs causing acromegaly have been described from the duodenum (Colak Ozbey *et al.* 2009), liver (Furrer *et al.* 2001) and pancreatic tumours in the context of MEN1 (Biermasz *et al.* 2007, Weiss *et al.* 2011, Sala *et al.* 2013). Hypothalamic tumours, including hamartomas, choristomas, gliomas and gangliocytomas, may also produce excessive GHRH resulting in acromegaly (Di Lorgi *et al.* 2007). Ectopic secretion of GH has only been described in single cases (Melmed *et al.* 2006, Fainstein *et al.* 2007) and represents approximately 0.1%

of paraneoplastic acromegaly cases (Melmed *et al.* 2006, Fainstein *et al.* 2007).

Less common endocrine PNS secondary to the secretion of peptide hormones

Ectopic renin secretion Cases of extra-renal renin-producing tumours are particularly rare, mostly related to NETs (paragangliomas and carcinoids) and SCLC leading to a hypertensive PNS (Dayal *et al.* 1986). Other extremely rare cases of renin-secreting tumours including desmoplastic round cell tumours (DSRCT) secreting ectopic renin (Lee *et al.* 2014). Cases of renin secretion from renal or pulmonary carcinomas have also been described (Ganguly *et al.* 1973). The renin-secreting tumour triad consists of hypertension, hypokalaemia and elevated plasma renin activity (PRA). Tumour resection is the therapeutic option of choice with various cases of chemo-sensitive tumours responding well to chemotherapeutic regimes. Adjuvant use of various anti-hypertensives, spironolactone or rarely aliskiren has proven to be helpful in offering temporary symptom relief (Rosei *et al.* 2015).

Ectopic β -human chorionic gonadotrophin (bhCG production) Gynaecomastia is a relatively rare PNS associated with tumour-secreted bhCG. There are several reports of paraneoplastic gynaecomastia secondary to thoracic (mainly SCLCs, carcinoids and extragonadal germ cell tumours) clinically associated with gynaecomastia in men, menstrual irregularity and virilisation in women, and precocious puberty in children (Braunstein *et al.* 1972, DeLellis & Xia 2003, Yaturu *et al.* 2003, Mehta *et al.* 2008, Dimitriadis *et al.* 2017). Rarely, secretion of bhCG results from clear cell renal tumours (Mohammed *et al.* 2008) or liver carcinomas (Teniola & Ogunleye 1994). A bhCG-like protein is also found in a variety of normal tissue, and there is evidence to suggest that the ahCG subunit may exert a paracrine effect on the growth of tumour cells (Rivera *et al.* 1989); bhCG may also act as a growth factor in SCLCs (Szturmowicz *et al.* 1995). Treatment is tumour resection or multi-agent chemotherapy in cases of chemo-sensitive malignancies such as SCLC.

Ectopic gonadotrophin production A handful of cases of ectopic gonadotrophin-secreting tumours leading to PNS are reported in the literature. In cases of the ectopic secretion of follicle stimulating hormone (FSH), patients may present with ovarian hyperstimulation syndrome

(Roberts *et al.* 2005, Burgos *et al.* 2009, Miras *et al.* 2015). Ectopic secretion of luteinising hormone (LH) has also been described presenting with phenotypic characteristics resembling the polycystic ovary syndrome (PCOS, Brignardello *et al.* 2004, Piaditis *et al.* 2005). Definitive treatment for these rare tumour cases remains the resection of the primary site.

Other ectopic pituitary hormone secretion Ectopic secretion of prolactin secondary to a SCLC has been reported (Turkington 1971). Another case of hyperprolactinaemia secondary to a low-grade malignant mesenchymal tumour of the uterus with positive SRS has also been described (Simsir *et al.* 2012). Following successful removal of the mass, the hyperprolactinaemia which was previously refractory to dopamine agonist treatment was resolved, but immunohistochemistry for prolactin was negative (Simsir *et al.* 2012). Anecdotal cases of ectopic TSH secretion have been mentioned in the literature; ectopic TSH-secreting pituitary adenomas have occasionally been described (Bollanti *et al.* 2001, Pasquini *et al.* 2003).

Ectopic gut hormone secretion Paraneoplastic syndromes associated with ectopic secretion of gut peptides are very rare. Cases of vasoactive intestinal polypeptide (VIP) secretion causing typical watery diarrhoea has been described secondary to SCLC, MTC, phaeochromocytoma and NETs arising from the kidney (Said & Faloona 1975, Tischler *et al.* 1984). Glucagon-like peptides (GLP) 1 and 2 are hormones derived from the post-translational processing of pro-glucagon in the intestinal L cells that influence intestinal motility and small bowel growth, respectively. A case of a GLP1 and somatostatin-secreting NET has been reported presenting with reactive hypoglycaemia and hyperglycaemia subsequently cured by surgery (Todd *et al.* 2003). Another case of a well-differentiated NET of unknown primary origin presenting with diffuse metastases, constipation and nocturnal itching with positive immunostaining for GLP1, GLP2 and polypeptide YY (PYY) has been described. Jejunal biopsy demonstrated marked intestinal mucosal hypertrophy. High-performance liquid chromatography (HPLC) analysis combined with radioimmunoassay (RIA) of tumour and serum extracts revealed that the tumour was secreting and releasing GLP1 and GLP2, as well as PYY (Byrne *et al.* 2001). Ectopic secretion of ghrelin, in the serum of a patient with a pNET has been reported, as well as a carcinoid of the stomach

albeit without clinical symptoms (Corbetta *et al.* 2003, Tsolakis *et al.* 2004). Somasundaram and coworkers report the case of an ACTH-secreting thymic carcinoid causing Cushing's syndrome, with histopathological features of gastrin over-secretion and Zollinger–Ellison syndrome (Somasundaram *et al.* 2013).

Other rare peptide hormones Ectopic calcitonin over-secretion is rare. A case of a SCLC presenting with dual PNS including over-secretion of ACTH and calcitonin has been described (Coners *et al.* 2011). Presenting symptoms included metabolic alkalosis with hypokalaemia, hypocalcaemia, hypomagnesaemia, hypophosphataemia, hyperglycaemia and profound diarrhoea (Coners *et al.* 2011). There are several other cases of ectopic calcitonin secretion by SCLC, LCLC or lung carcinoids (Kelley *et al.* 1994, Machens *et al.* 2000, Cvijovic *et al.* 2013).

Tumour-induced osteomalacia (TIO) is a rare PNS manifested with bone and muscular pains, bone fractures, and sometimes loss of height and weight (Dadoniene *et al.* 2016). The first evidence of a circulating factor that could cause phosphate wasting in humans was described when a tumour transplanted into nude mice caused hypophosphataemia (Miyauchi *et al.* 1988). Fibroblast growth factor FGF23 is secreted by the bones and was first identified as the phosphaturic agent when mutations in FGF23 gene were linked to autosomal dominant hypophosphataemic rickets (ADHR) (White *et al.* 2001). In cases of TIO, FGF23 (FGF23/Klotho system) secretion is much higher leading to dysregulation of the FGF23 degradation pathway (Hannan *et al.* 2008). Tumours usually bearing the ability to over-secrete FGF23 are generally of mesenchymal origin, but there are cases of an adenocarcinoma of the colon and prostate (Ramon *et al.* 2011, Mak *et al.* 2012, Leaf *et al.* 2013). FGF23 measurements combined with ¹⁸F FDG PET/CT SCAN can be a decisive tool in cases of TIO, and is likely going to be of considerable importance for facilitating early diagnosis and follow-up (Dupond *et al.* 2005). Current management of TIO involves tumour resection. However, the development of a humanised anti-FGF23 antibody for adult patients with X-linked hypophosphataemic rickets (XLHR) may be useful for patients with TIO with similar pathogenesis to that of XLHR (Kinoshita & Fukumoto 2014).

Hypertrophic osteoarthropathy (HOA) is a syndrome characterised by proliferative changes in the skin and skeleton. In addition, it may also comprise of proliferative periostitis of the long bones, oligo- or polysynovitis

and digital clubbing (Dubrey *et al.* 2016). There are two types of hypertrophic osteoarthropathy: primary and secondary. Only 3–5% of patients have primary HOA while the remaining 95–97% have secondary HOA, commonly associated with many disease conditions of the cardiovascular system and hepatobiliary gastrointestinal system as well as in malignancies, including neuroendocrine carcinomas of the oesophagus and lungs (El Bakkal *et al.* 2011, Saif & Vethody *et al.* 2016). Current evidence favours a pathology based on inadequate uptake or metabolism of prostaglandin E2.

Ectopic oxytocin secretion is a very rare PNS but has been reported in cases of SCLC (Shigetomi *et al.* 1980, Wilson & Ngsee 1980). A case of an SCLC tumour cell line from a patient with PN hyponatraemia was shown to ectopically produce, process and secrete ANP in the same immunoreactive form as the biologically active molecule. It apparently contained an enzyme that could cleave precursors at the same amino acid sequences needed to produce ANP-(S99-Y126) from pro-ANP (Johnson *et al.* 1997). The recent demonstration of human placental lactogen (hPL) in serum samples of 12 patients with testicular malignancy and highly elevated levels of hCG (mean: 42.490 ng/mL) suggest an auto/paracrine function of this molecule (Madersbacher *et al.* 1998). Cases of SCLCs and pheochromocytoma have also been reported secreting hPL (Kaltsas *et al.* 2010).

There is evidence that glomus tumours of the skull base (head-and-neck paragangliomas) may secrete neuropeptides, such as cholecystokinin, in addition to catecholamines (Jackson *et al.* 1989). High circulating levels of cholecystokinin associated with these tumours may be responsible for the unexplained phenomenon of prolonged post-operative ileus (Jackson *et al.* 1989).

Endocrine paraneoplastic syndromes secondary to the secretion of non-peptide agents

Cytokines In recent years, increasing evidence has been adduced that pheochromocytomas are capable of secreting cytokines, mainly interleukin-1 (IL1) (Bornstein *et al.* 1996, Liu *et al.* 2000), IL6 (Shimizu *et al.* 2001), tumour necrosis factor- α (TNF α) and interferon- γ (IFN γ) (Tirone *et al.* 1989). In such cases marked inflammatory reactions and pyrexia were improved on either non-steroidal anti-inflammatory drugs (NSAIDs) or corticosteroids, but subsided after adrenalectomy (Minetto *et al.* 2003). Non-endocrine tumours producing cytokines are usually of mesenchymal origin; a recent case

reported an angiomatoid fibrous histiocytoma presenting with severe inflammatory symptoms, being immunohistopathologically positive for IL-6 and Tyr705-phosphorylation of signal transducer and activator of transcription 3 (STAT3) (Akiyama *et al.* 2015). The EWSR1-CREB1 fusion gene detected in the tumour led to continuous activation of CREB1 and IL6 production because the promoter region of IL6 has a CREB binding site (Akiyama *et al.* 2015).

Steroid and other endocrine PNS related compounds A number of mesenchymal cells can differentiate into steroidogenic cells following ectopic expression of nuclear factor (NR) 5A subfamily proteins, steroidogenic factor-1 and liver receptor homolog 1 (Yazawa *et al.* 2016). The ability of certain cells to differentiate into others may represent one of the mechanisms accounting for the development of PNS. This could be the underlying reason for the rare cases of steroid-secreting hormones leading to PNS from tissues other than the adrenal and the gonads (Yazawa *et al.* 2016).

Paraneoplastic hyperaldosteronism has been described in a patient with ovarian cancer and also in cases of Non-Hodgkin's lymphoma (NHL) (Todesco *et al.* 1975, Mulatero *et al.* 2001). It has been suggested that paraneoplastic hyperaldosteronism could be secondary to the expression of the *CYP11B2* gene (Mulatero *et al.* 2001). In a patient with NHL and unexplained hypertension, RNA extraction from a lymph node demonstrated increased *CYP11B2* mRNA expression, confirming that hyperaldosteronism was paraneoplastic (Mulatero *et al.* 2001). Struma ovarii is a rare subtype of ovarian cancer representing <1% of all ovarian malignancies (Lara *et al.* 2016). It represents a monodermal teratoma composed of mature thyroid tissue; thyroid tissue must comprise more than 50 percent of the overall ovarian tissue to be classified as a struma ovarii. The diagnosis is usually made on clinical presentations including symptoms of overactive thyroid function. The rate of recurrence is high and in the majority of patients with malignant struma ovarii adjuvant chemotherapy is necessary. The mechanism underlying the functioning status of the tumour is still unclear, but the presence of thyroid stimulating hormone receptor (TSHr) is thought to play a role. It represents the only known malignancy that secretes ectopic TSH (Lara *et al.* 2016). Gestational trophoblastic diseases comprise hydatidiform moles, invasive moles, choriocarcinomas and placental site trophoblastic tumours. Hydatidiform moles and

choriocarcinomas that secrete high amounts of hCG can cause hyperthyroidism (Kopp 2010).

Conclusions

As the incidence of several types of neoplasms and in particular NETs increases, and as these patients live longer, the incidence of PNS will most probably increase. These syndromes affect the presentation, clinical course and treatment of such patients. As a result of recent diagnostic and therapeutic advances, many PNS are currently well defined, and some effective treatment options are evolving. The ability to recognise and treat PNS may have a substantial effect on clinical outcomes, ranging from earlier cancer diagnosis, to improved quality of life, to increased delivery of tumour-directed therapy. Furthermore, on-going research into these disorders may shed light on mechanisms of tumour development, maintenance and proliferation. However, as the exact prevalence of PNS is still a matter of debate, registration of these syndromes seems imperative to help identify their exact aetiology and their effect on the disease process.

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G K D, A A, M O W and H S R declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of this review. G K and A G have received advisory board and lecture fees from pharmaceutical companies.

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The authors of this manuscript contributed equally to its creation.

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