Effect of hormone secretory syndromes on neuroendocrine tumor prognosis

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Abstract

The treatment of hormone hypersecretory syndromes caused by neuroendocrine tumors (NETs) can be a major challenge. NETs originating from the small intestine often secrete serotonin causing flushing, diarrhea and valve fibrosis, leading to dehydration or heart failure in severe cases. NETs from the pancreas can secrete a wider variety of hormones, like insulin, glucagon and gastrin leading to distinct clinical syndromes. Historically mortality in patients with functioning NETs was high due to the complications caused by the hypersecretion of hormones. This has been reduced with several drugs: proton-pump inhibitors decrease acid secretion caused by gastrinomas. Somatostatin analogs can inhibit the secretion of multiple hormones and these are now the cornerstone for treating patients with a gastroenteropancreatic NET. However, peptide receptor radionuclide therapy (PRRT) with radiolabeled somatostatin analogs and everolimus can also decrease symptoms of hypersecretion and increase progression-free survival. Several factors affect the survival in patients with a functioning NET. Complications of hypersecretion negatively impact survival; however, secretion of hormones is also often a sign of a well-differentiated NET and due to the symptoms, functioning NETs can be detected in an earlier stage suggesting a positive effect on prognosis. The effect on survival is also dependent on the type of hormone being secreted. This review aims to study the effect of hormone secretion on the prognosis of NETs with the contemporary treatments options available today.

Introduction

Neuroendocrine tumor (NETs) are often best known for causing hypersecretory syndromes, through the hormones they secrete, which is mainly determined by the cell of origin (Kaltsas et al. 2004). More than 15 individual neuroendocrine cell types have been identified, and they all secrete different hormones, causing different kinds of syndromes (Kidd et al. 2015). These syndromes of hormone excess are diagnosed when the clinical presentation fits a certain syndrome, and this is confirmed by demonstrating that corresponding hormone levels are elevated (Kaltsas et al. 2004). When patients present without a specific syndrome or without elevated hormone levels, they are diagnosed with a non-functioning, or non-syndromic, NET. Small intestinal NETs almost exclusively secrete serotonin, and when metastasized causing the carcinoid syndrome with symptoms of flushing, diarrhea...
Table 1  Overview of the most common neuroendocrine tumor syndromes: origin and incidence.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Cell</th>
<th>Location</th>
<th>Tumor</th>
<th>Incidence (per million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serotonin</td>
<td>EC</td>
<td>Stomach, pancreas, duodenum, small intestine, colon, appendix, rectum</td>
<td>Carcinoid</td>
<td>0.2–0.6</td>
</tr>
<tr>
<td>Insulin</td>
<td>B</td>
<td>Pancreas</td>
<td>Insulinoma</td>
<td>1–3</td>
</tr>
<tr>
<td>Gastrin</td>
<td>G</td>
<td>Duodenum</td>
<td>Gastrinoma</td>
<td>0.5–2</td>
</tr>
<tr>
<td>Glucagon</td>
<td>a</td>
<td>Pancreas</td>
<td>Glucagonoma</td>
<td>0.02–0.06</td>
</tr>
<tr>
<td>VIP</td>
<td>VIP</td>
<td>Pancreas, sympathetic ganglia</td>
<td>VIPoma</td>
<td>0.05–0.2</td>
</tr>
<tr>
<td>ACTH</td>
<td>Various</td>
<td>Lung, adrenals, thyroid, pancreas</td>
<td>ACTHoma</td>
<td>Rare</td>
</tr>
<tr>
<td>PTH</td>
<td>Various</td>
<td>Lung, pancreas</td>
<td>PTH-like-oma</td>
<td>Rare</td>
</tr>
<tr>
<td>Somatostatin</td>
<td>D</td>
<td>Pancreas, stomach, duodenum, colon, rectum, appendix</td>
<td>Somatostatinoma</td>
<td>Rare</td>
</tr>
</tbody>
</table>

and carcinoid heart disease. Pancreatic NETs show a much larger variation in hormonal secretion and are capable to secrete insulin, glucagon, gastrin and other hormones (Table 1). Arising from different neuroendocrine cell types and causing different symptomology, survival differs between these syndromes as well. Strong predictors of survival are the grade, based on the Ki67-index, and the WHO/ENETS staging (Klimstra et al. 2010). The biomarkers chromogranin A and neuron-specific enolase are predictors of survival as well. Serum chromogranin A is a marker for tumor burden, and elevated serum chromogranin A is associated with a shorter survival (Arnold et al. 2008, Han et al. 2015). Neuron-specific enolase was long thought to be a predictive biomarker not only in poorly differentiated NET and small cell carcinomas but also in low-grade NETs, an elevated serum neuron-specific enolase is a negative predictor of survival (van Adrichem et al. 2015). The influence of hormone hypersecretion on survival in patients with NETs remains unclear.

Historically, the slow growth of NETs often resulted in survival not being limited by tumor burden but by complications caused by the hypersecretion of hormones (Thorson et al. 1954). However, many steps have been made in treatment of these patients mainly with the discovery of somatostatin and the subsequent development of octreotide, allowing the inhibition of hormone secretion and thus reduction of clinical symptoms and morbidity (Kvols et al. 1986). Long-acting somatostatin analogs can now be administered only once a month vs three times daily for octreotide subcutaneously, once more improving quality of life for patients (Rinke et al. 2009, Caplin et al. 2014). Also peptide receptor radionuclide therapy (PRRT) with radiolabeled somatostatin analogs and tumor-targeted therapy (everolimus and sunitinib) are now available for the treatment of metastatic NETs (Kwekkeboom et al. 2008, Raymond et al. 2011, Yao et al. 2016). Also, simply decreasing acid secretion with PPIs in gastrinoma patients strongly reduces the incidence of peptic ulcer disease (Hirschowitz et al. 2005). It is without question that before all these contemporary options were available, patients with a hypersecreting NET had a worse prognosis, due to the complications of hormone hypersecretion. On the other hand, hormone secretion is often a sign of a well-differentiated NET with, theoretically, a better survival (Wang et al. 2011). Also symptoms caused by the secreting NET could allow for detection of the NET in an earlier stage. In this review, we will study available literature, questioning the influence of hormonal secretion on NET prognosis in the current era, focusing on NETs originating from the pancreas and the gut.

Serotonin and the carcinoid syndrome

The histological diagnosis of a ‘Karzinoide’ was first described early in the twentieth century and the first cases of carcinoid syndrome were described from 1927 onward (Oberndorfer 1907, Postma 1927, Cassidy 1930). Patients presented with diarrhea and flushing and post-mortem examination revealed tumors in the ileum, liver metastases and tricuspid valve stenosis, but the link connecting these findings remained unknown (Cassidy 1931, Scholte 1931). In the 1950s, several discoveries were made, significantly advancing the knowledge of the carcinoid syndrome. Serotonin was identified by Page and in a case series published in 1954, Thorson and coworkers linked flushing, diarrhea and right-sided heart failure to carcinoids in the small intestine and identified serotonin secretion as a possible cause of the syndrome (Page 1954, Thorson et al. 1954). Survival varied from over ten years when patients first complained of abdominal pain or flushing, to weeks when presenting with heart failure.

Nowadays the carcinoid syndrome is a well-known entity. Text books clearly describe the symptomatology of flushing, diarrhea, bronchospasm and eventually...
valvular heart disease, but this typical presentation is rare (Pape et al. 2008). It is a clinical diagnosis, made when these symptoms are present and when there is evidence for increased serotonin secretion. Serotonin levels can be measured in several ways, but excretion of 24-h urinary 5-hydroxyindoleacetic acid (5-HIAA), the degradation product of serotonin, is most validated in diagnosis and follow-up of NETs (O’Toole et al. 2009). In the near future, plasma 5-HIAA will probably play a more prominent role (Tellez et al. 2013). Occasionally, NETs from organs like the lung, ovaries and pancreas can cause the carcinoid syndrome, but it is most frequently associated with NETs from the embryological midgut and so our knowledge on the carcinoid syndrome is mainly based on these tumors. The midgut NETs arise from enterochromaffin cells in the intestine and when the tumor is limited to the abdomen (ENETS Stage I–IIIb), secreted serotonin is efficiently metabolized in the liver and therefore localized disease rarely causes symptoms. But liver, bone and retroperitoneal or distant node metastases as well as lung and ovary primaries directly secrete serotonin and other mediators into the systemic circulation, and this causes the carcinoid syndrome (Grozinsky-Glasberg et al. 2015). This factor is of great importance because this influences incidence of carcinoid syndrome in different centers and it confounds the influence of the carcinoid syndrome on prognosis.

In epidemiological studies, incidence of midgut NETs varies between regions. Current incidence is estimated to be around 0.3–1.1 cases annually per 100,000 persons and seems to be increasing in recent years (Modlin et al. 2003, Yao et al. 2008, Ellis et al. 2010, Landerholm et al. 2010). Whether this is due to a true increase in incidence or to increased imaging procedures or both remains to be elucidated. The incidence of the carcinoid syndrome in these patients is highly dependent on the selected population. In nationwide surveys or cancer registries, 3–19% of patients with a small intestinal NET have the carcinoid syndrome, but incidence has been reported as high as 71% in specialized centers, treating more patients with advanced disease (Bax et al. 1996, Janson et al. 1997, Soga 2003, Niederle et al. 2010, Halperin et al. 2017).

When surgery, chemotherapy and radiotherapy were the only options for the treatment of metastatic small intestinal NETs, the prognosis was mediocre and overall 5-year survival rate was approximately 50–60% for all stages combined (Barclay & Schapira 1983, Zollinger 1986). Also patients with a functioning NET had a shorter median survival. In a study by Norheim and coworkers in 1987, median survival from the time of histologic diagnosis was 14 years but 8 years from the time of onset of the carcinoid syndrome (Norheim et al. 1987). With new options for treatment becoming available for patients with a NET in the past two decades, there has been a large improvement in the quality of life and prognosis.

Patients with the carcinoid syndrome almost exclusively have extensive disease but curative surgery should still be the first option to consider. Unfortunately, this is not feasible in many patients and palliative therapy should be started to control symptoms and tumor growth (Pavel et al. 2016). This is best achieved with a somatostatin analog (SSA). The first studies with these drugs revealed significant reduction of symptoms by reducing serotonin secretion, measured with 24-h urinary 5-HIAA excretion (Modlin et al. 2010). Subsequently, this was confirmed in randomized controlled trials. Two well-known, landmark trials have shown that SSAs increase progression-free survival (PFS). Lanreotide was found to increase PFS in patients with non-functioning neuroendocrine tumors (gastrinomas were included) (Caplin et al. 2014). In the PROMID trial, median PFS increased from 6.0 months with placebo to 14.3 months when treated with octreotide LAR and in this study 36% of patients had the carcinoid syndrome at baseline (Rinke et al. 2009). Treatment effect was equal in patients with a functioning or non-functioning tumor and while PFS was shorter in patients with a functioning tumor, this did not reach significance (HR 1.38; 95% CI: 0.81–2.37). Second-line options include peptide receptor radionuclide therapy (PRRT) and everolimus (van der Zwan et al. 2015). PRRT with $^{177}$Lu-DOTATate resulted in a longer PFS in patients with midgut NETs. After 20 months, 65.2% of these patients were without tumor progression (RECIST) as compared to 10.8% in the control group using a doubled dose (60mg) of octreotide LAR every 4 weeks in the NETTER-1-study (HR for progression 0.21; 95% CI: 0.13–0.33) (Strosberg et al. 2017). Furthermore, PRRT can reduce symptoms (pain, fatigue and carcinoid-related symptoms) in selected patients (Kam et al. 2012, Seregni et al. 2013). Everolimus is specifically tested in patients with the carcinoid syndrome, but no direct comparison was made with non-functioning tumors, as these were studied in a different trial (Pavel et al. 2011, Yao et al. 2016). Compared to octreotide LAR alone, treatment with everolimus resulted in a larger reduction of urinary 5-HIAA excretion in the RADIANT-2 trial, but the effects on symptoms of carcinoid syndrome or quality of life were not studied (Pavel et al. 2011). With all these contemporary medical options, 5 year survival for stage IV midgut NETs has been described as being 54% to as
Table 2  Overall survival and peri-operative mortality in surgical series on carcinoid heart disease.

<table>
<thead>
<tr>
<th>Study</th>
<th>5 year: Survival</th>
<th>Median survival:</th>
<th>Peri-operative mortality</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robiolio et al. (1995)</td>
<td>25%</td>
<td>2.6 years</td>
<td>62.5% (&lt;1995)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9% (1995–2000)</td>
<td>43</td>
</tr>
<tr>
<td>Mokhles et al. (2012)</td>
<td>43%</td>
<td></td>
<td>5.7% (1993–2010)</td>
<td>19</td>
</tr>
<tr>
<td>Bhattacharyya et al. (2010)</td>
<td></td>
<td></td>
<td>18% (2006–2010)</td>
<td>22</td>
</tr>
<tr>
<td>Connolly et al. (2015)</td>
<td>35%</td>
<td></td>
<td>20% (&lt;1990)</td>
<td>10</td>
</tr>
<tr>
<td>Edwards et al. (2016)</td>
<td></td>
<td>69%</td>
<td>16.4% (1990–1999)</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.2% (2000–2009)</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.7% (2010–2012)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13% (2005–2015)</td>
<td>32</td>
</tr>
</tbody>
</table>

Peri-operative mortality: mortality rate the first 30 days after surgery for carcinoid heart disease.

Table 3  Overall survival in patients with carcinoid syndrome vs non-functional midgut NET.

<table>
<thead>
<tr>
<th>Study</th>
<th>Hazard ratio (95% CI)</th>
<th>2-year survival</th>
<th>5-year survival</th>
<th>10-year survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jann et al. (2011)</td>
<td></td>
<td></td>
<td>96.9% vs 97.6%</td>
<td></td>
</tr>
<tr>
<td>Janson et al. (1997)</td>
<td>2.9 (1.4–6.0)</td>
<td></td>
<td>85.6% vs 93.7%</td>
<td></td>
</tr>
<tr>
<td>Formica et al. (2007)</td>
<td>1.18 (0.7–1.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halperin et al. (2017)</td>
<td>1.10 (1.02–1.20)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS: not significant.

high as 84.8% (Quaedvlieg et al. 2001, Yao et al. 2008, Jann et al. 2011).

Treatment of carcinoid heart disease has also vastly improved. In the nineties over a quarter of patients died of carcinoid heart disease, and this was almost 50% of disease-related death (Makridis et al. 1997). There is strong evidence that serotonin plays an important role, so reduction of secretion with SSAs and telotristate could potentially reduce the risk of developing carcinoid heart disease, but no studies, with these drugs, show the effect on the incidence of carcinoid heart disease or overall survival due to the slow progressive character of NETs (Pavel et al. 2015). Also increasing experience in valve replacement surgery in patients with carcinoid heart disease has resulted in a sharp reduction of peri-operative mortality to approximately 4–10% with an overall survival approaching that of non-syndromic patients (Table 2). However, this might be biased by selecting patients for surgery in an earlier stage. Regular screening on carcinoid heart disease and optimal timing of cardiac valve replacement are important factors that determine the ultimate outcome.

Altogether treatment of the carcinoid syndrome has clearly advanced and with that, its influence on prognosis is diminishing. Historically symptomatic patients, on average, have a shorter survival. Simply looking at the urinary 24-h 5-HIAA excretion indeed shows that patients with elevated excretion have a shorter survival (Turner et al. 2006, Formica et al. 2007, van der Horst-Schrijvers et al. 2007). But after correction for metastases (ENETS Stage IV) and tumor burden (with chromogranin A), urinary 5-HIAA excretion is no longer a predictor for survival (Janson et al. 1997, Zandee et al. 2016). Few studies have purely compared survival of functional and non-functional midgut NETs. Often urinary 5-HIAA excretion is used as marker for the carcinoid syndrome, but this does not always correlate with the clinical symptoms, which are used to define carcinoid syndrome (Zuetenhorst et al. 2004). Only limited number of studies have been published on the effect of carcinoid syndrome on survival (on the basis of clinical symptoms) (Table 3). Halperin and coworkers and Janson and coworkers demonstrated a shorter survival for functional NETs (HR 1.10 and HR 2.9) in a respective cohort-study (SEER database) and a center-based study (Janson et al. 1997, Halperin et al. 2017). However, after correction for liver burden and other biomarkers by Janson and coworkers, survival no longer differs between patients with and without carcinoid syndrome. Halperin and coworkers could not correct for tumor burden, due to the limitations in the data collection. In contrast to these studies, two other studies did not demonstrate a significant influence of carcinoid syndrome on survival (Formica et al. 2007, Jann et al. 2011).

Much less is known of the influence of carcinoid syndrome in pancreas NETs because this is a rare phenomenon, occurring in about only 1% of pNETs (Modlin et al. 2005, Soga 2005, Bilimoria et al. 2007,
La Rosa et al. 2011). However, its influence on survival seems to mimic that of the midgut NETs. Serotonin secretion has a negative influence on survival, but it occurs mainly in patients with metastasized disease and bulky tumors. After correcting for this fact, serotonin secretion no longer influenced survival (Zandee et al. 2017).

It is clear that the mortality of the carcinoid syndrome is decreasing due to reduction of serotonin secretion with potent drugs and improved valve surgery. At the same time, survival has increased for both functional and non-functional NETs, due to the anti-proliferative effect of SSAs, tumor-targeted therapy and PRRT. Unfortunately mortality for patients with the carcinoid syndrome remains relatively high, but this is probably due to extensive tumor load and not due to the effects of serotonin secretion.

### Pancreatic neuroendocrine tumors

Neuroendocrine tumors originating from the pancreas can produce a wide variety of hormones like insulin and glucagon. Currently, it is not recommended to screen for hormone secretion unless symptoms fit a certain functioning tumor syndrome (Falconi et al. 2016). Unlike the carcinoid syndrome in patients with midgut tumors, pNETs do not need to metastasize before symptoms arise. For example, 90% of insulinomas are smaller than 4 cm and limited to the pancreas at diagnosis (Mehrabi et al. 2014). Non-functioning pNETs mostly present either with an incidentaloma or with abdominal pain, and it is suggested that thereby these patients present more frequently with advanced disease (Cheema et al. 2012, Crippa et al. 2014).

In many studies, comparing survival of non-functioning pNETs with their functional counterpart, functional pNETs are described as a group with no sub-selection for the type of hormone. Therefore, we will first discuss these studies, followed by a focus on the prevalent syndromes.

After diagnosis of a pNET according to guidelines, curative surgery is the first consideration (Falconi et al. 2016). A small number of studies are published on observation only, for non-functioning pNETs smaller than 2 cm. Results are promising, but no long-term data is available yet (Sadot et al. 2016). Due to the symptomology of functioning pNETs observation is often not preferred except for selected patients with a gastrinoma. Only Cubilla and coworkers report a worse prognosis for patients with functional tumors but values for significance are not reported (Cubilla & Hajdu 1975). Most surgical series show a better prognosis for patients with a functional tumor, but after correction for other

### Table 4  Reported 5-year survival, comparing functional and non-functional pancreatic neuroendocrine tumors.

<table>
<thead>
<tr>
<th>Surgical series</th>
<th>Functional (%)</th>
<th>Non-functional (%)</th>
<th>P value</th>
<th>Number of patients</th>
<th>Functioning (insulinoma %)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phan et al. (1998)</td>
<td>77</td>
<td>52</td>
<td>0.025</td>
<td>125</td>
<td>64 (55)</td>
<td>Surgical, ( P = 0.14 ) in metastatic NET</td>
</tr>
<tr>
<td>Sarmiento et al. (2002)</td>
<td>100</td>
<td>70</td>
<td>0.08</td>
<td>29</td>
<td>9 (33.3)</td>
<td>Surgical</td>
</tr>
<tr>
<td>Jarufe et al. (2005)</td>
<td>82.5</td>
<td>55.0</td>
<td>0.41</td>
<td>44</td>
<td>24 (66.6)</td>
<td>Surgical curative</td>
</tr>
<tr>
<td>Vagefi et al. (2007)</td>
<td>89</td>
<td>78</td>
<td>0.16</td>
<td>168</td>
<td>70 (33.3)</td>
<td>Surgical series all stages, ( P = 0.03 ) in multivariate</td>
</tr>
<tr>
<td>Bilimoria et al. (2008)</td>
<td>67.7</td>
<td>60.0</td>
<td>&lt;0.001</td>
<td>3851</td>
<td>619 (20.7)</td>
<td>Surgical treatment all stages</td>
</tr>
<tr>
<td>Gao et al. (2010)</td>
<td>77</td>
<td>74</td>
<td>0.225</td>
<td>112</td>
<td>47 (60.0)</td>
<td>Surgery stage IV, including palliative and no resection</td>
</tr>
<tr>
<td>Partelli et al. (2015)</td>
<td>71</td>
<td>57</td>
<td>0.148</td>
<td>166</td>
<td>15 (26.7)</td>
<td></td>
</tr>
<tr>
<td>Cohort studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DSS, all stages, center based</td>
</tr>
<tr>
<td>Wang et al. (2011)</td>
<td>96.8</td>
<td>71.6</td>
<td>0.008</td>
<td>93</td>
<td>39 (71.7)</td>
<td>Not significant in multivariate</td>
</tr>
<tr>
<td>Martin-Perez et al. (2013)</td>
<td>83.6</td>
<td>73.4</td>
<td>0.185</td>
<td>483</td>
<td>171 (44.4)</td>
<td>Population based</td>
</tr>
<tr>
<td>Chu et al. (2002)</td>
<td>48</td>
<td>30</td>
<td>0.27</td>
<td>55</td>
<td>21 (28.5)</td>
<td>All stages</td>
</tr>
<tr>
<td>Halfdanarson et al. (2008)</td>
<td>47.6</td>
<td>31.3</td>
<td>&lt;0.001</td>
<td>1483</td>
<td>137 (27.0)</td>
<td>All stages, SEER database ( P = 0.004 ) in multivariate</td>
</tr>
</tbody>
</table>
factors like stage, often no significant difference is found (Table 4 and 5). Phan and coworkers have reported a higher probability of survival for functional pNETs, but at baseline, patients with non-functional NETs had, on average, a larger primary tumor and more often metastatic disease. A subgroup analysis in malignant NETs (node or hepatic metastases) showed no significant difference in survival for functionality. Only Bilimoria and coworkers report a significant difference in uni- and multivariate analyses between functional and non-functional pNETs in patients undergoing pancreatic surgery, including metastasized pNETs (Bilimoria et al. 2008). In the subgroup analysis of this study, a better prognosis for gastrinomas is reported (HR 0.52, 95% CI: 0.30–0.92), while other syndromes did not have a significant longer survival. Several center-wide or cohort studies report a better survival for functional tumors (Ekeblad et al. 2008, Halfdanarson et al. 2008, Wang et al. 2011, Yang et al. 2015). Including all stages of disease and all types of treatment, functional tumors have a better prognosis; however, in multivariate analyses, only Halfdanarson and coworkers report higher survival rates for functional NETs (HR 0.71; 95% CI: 0.57–0.89). Wang and coworkers have studied 93 pNET patients and reported a higher five-year survival in functioning NETs. However, at baseline, the non-functioning NETs were significantly more poorly differentiated and were also more often metastasized to lymph nodes. Ekeblad and coworkers and Yang and coworkers also reported higher survival probabilities in functional NETs, but in multivariate analyses, correcting for stage and differentiation, this was no longer significant. So in this broad spectrum, patients with a functional pNET have a better prognosis than their non-functioning counterparts; however, this is often biased by stage and differentiation. Correction for these factors almost always results in comparable prognosis for functional and non-functional pNETs, so once again, the difference in prognosis between functioning and non-functioning NETs is probably explained by tumor burden and differentiation and not by hormone secretion.

Insulinomas

The first patient with the typical presentation of an insulinoma was described in 1927 by Wilder (Wilder et al. 1927). This patient turned out to have a malignant insulinoma with liver metastases. Insulinomas present mainly with hypoglycemia resulting in episodes of confusion, loss of consciousness, sweating or dizziness and body weight increases (Stefanini et al. 1974, Fajans & Vinik 1989). The diagnosis of an insulinoma is based on Whipple’s triad: neuroglycopemia with a proven hypoglycemia and elevated circulating insulin levels with resolving of symptoms after normoglycemia is established (Whipple 1938, de Herder et al. 2006, Cryer et al. 2009). Some patients suffer from convulsions or abnormal behavior resulting in long neurological or psychiatric treatment before the insulinoma is diagnosed. These disabling symptoms might bear an advantage: almost 90% of patients present with localized disease with tumors smaller than 5 cm restricted to the pancreas. Prognosis is excellent in these patients. Overall survival and curation rates are often near 100% after enucleation or (partial) pancreatectomy, higher than most series on non-functioning pNETs (Tsutsumi et al. 2013, Mehrabi et al. 2014).

Once metastasized, insulinomas form a unique clinical challenge. With its recurrent hypoglycemias, it causes major comorbidity and, if uncontrolled, mortality as well. In this often palliative setting, symptom control is the major treatment goal in these patients. Diazoide is often used to prevent hypoglycemia by reducing insulin secretion through its effect on ATP-sensitive potassium channels (Altszuler et al. 1977). Fluid retention and hirsutism are the most common side effects (Gill et al. 1997). If the insulinoma expresses somatostatin receptors

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**Table 5** Reported survival (either hazard ratio or median survival) comparing functional and non-functional pancreatic neuroendocrine tumors.

<table>
<thead>
<tr>
<th></th>
<th>Hazard ratio for functioning pNET (95% CI)</th>
<th>Median survival (functional vs non-functional)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubilla and Hajdu (1975)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venkatesh et al. (1990)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hochwald et al. (2002)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panzuto et al. (2005)</td>
<td>0.9 (0.38–2.15)</td>
<td>2.8 years vs 4.3 years</td>
<td>P value not reported</td>
</tr>
<tr>
<td>Ekeblad et al. (2008)</td>
<td>0.63 (0.48–0.83)</td>
<td>45.2 vs 40.4 months</td>
<td>NA</td>
</tr>
<tr>
<td>Yang et al. (2015)</td>
<td></td>
<td>152 vs 110 months</td>
<td>&gt;0.2</td>
</tr>
<tr>
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lanreotide or octreotide LAR can potentially reduce insulin secretion as well. However, if somatostatin receptor-expression is low, these drugs can also increase the number of hypoglycemia by decreasing glucagon secretion, more than they decrease insulin secretion. A short clinical trial with short-acting octreotide is, therefore, recommended when starting with somatostatin analogs (de Herder et al. 2011).

PRRT with radiolabeled somatostatin has also been reported to be effective in reducing hypoglycemia in patients with metastatic insulinoma. Treatment results in long-lasting euglycemia and can stabilize tumor growth (van Schaik et al. 2011). Other effective options for metastasized insulinoma include chemotherapy (streptozotocin and 5-fluorouracil) or everolimus (Moertel et al. 1980, Kulke et al. 2009, Bernard et al. 2013).

As metastasized insulinomas are rare, no large series are available on prognosis. The few series with more than 10 patients report a median survival of approximately 2–3 years, but survival of over 30 years has been described in single patients (Danforth et al. 1984, Hirshberg et al. 2005, Starke et al. 2005). All these series have been published before PRRT or tumor-targeting therapy was available and thereby probably underestimate current prognosis as for example van Schaik and coworkers report a median progression-free survival of 27 months in five patients after treatment with PRRT, which is a vast improvement compared to these historical cohorts. Median survival of metastatic non-functioning pNET in the period before 2005 is 2–3 years as well (Solorzano et al. 2001, Wang et al. 2011, Yang et al. 2014).

So it seems that insulinomas have a better prognosis than non-functioning pNETs when resectable, but metastatic disease has not been reported to have a better survival. It remains unclear if the better prognosis of insulinomas is due to the early detection because of hypoglycemia or whether this is related to a more indolent course of disease caused by other factors like different genetic mutations in line with evidence in non-functioning pNETs (Sadanandam et al. 2015).

Gastrinoma

Gastrin secreted in large amounts by a gastrinoma causes severe peptic ulcer disease through acid hypersecretion and is known as the Zollinger–Ellison Syndrome (ZES) (Zollinger & Ellison 1955). ZES is diagnosed when an inappropriate high gastrin is demonstrated, but the diagnosis is challenging because of proton-pump inhibitors (PPIs) being widely used nowadays (Falconi et al. 2016). Discontinuing PPIs can aid the diagnostic process, but in patients with ZES, peptic complications can rapidly arise, so this should only be done cautiously (Poitras et al. 2012). Gastrinomas are most often localized in the duodenum or the pancreas (gastrinoma triangle), but are not always found with pre-operative imaging. Fortunately, this does not influence the outcome and should not withhold patients from surgery (Alexander et al. 1998, Norton et al. 2012). A sharp decrease in peptic complications in ZES has been established since the introduction of PPIs leading to a discussion if surgery is indicated for ZES (Hirschowitz et al. 2005, Wilcox et al. 2011). Treatment strategy is also highly dependent on the presence or absence of the multiple endocrine neoplasia 1 (MEN-1) syndrome. Several studies have shown the benefit of surgical resection for sporadic gastrinoma. A large amount of patients have lymph node metastases at the time of first resection, so removal of peritumoral nodes is advised (Norton et al. 2012, Giovinazzo et al. 2013). This results in curement of approximately half of patients after surgery and an excellent 10-year survival of over 90% in patients with a localized gastrinoma, higher than non-functional pNETs (Thompson et al. 1988, Weber et al. 1995, Bilimoria et al. 2008, Norton et al. 2012). For MEN-1-associated gastrinomas, only medical treatment with PPIs can be started in most cases. Due to the multifocal nature of gastrinomas in MEN-1, curement rates are much lower in MEN-1 patients, but on the other hand, prognosis is better, also justifying an observational strategy (Weber et al. 1995, Jensen et al. 2012). Although local lymph node metastases do not seem to influence prognosis too much, survival does decrease once liver metastases occur. Then 5-year survival decreases to 30–46% with 10-year survival of 16–30% (Weber et al. 1995, Yu et al. 1999). This seems to be slightly better in MEN-1 with reported 15-year survival of over 50%. Mainly when diffuse liver metastases are diagnosed survival is significantly reduced in MEN-1 (Yu et al. 1999). Then palliative treatment should be considered in the form of SSAs, PRRT with radiolabeled somatostatin analogs or sometimes debulking, always in combination with a PPI. PRRT with radiolabeled somatostatin resulted in a partial response in 45% of patients with a gastrinoma, but time to progression was shorter than that in non-functioning pNETs (Kwekkeboom et al. 2008, Grozinsky-Glasberg et al. 2011).

So while 60% of gastrinomas are classified as being malignant because of peritumoral lymph node metastases, this is not reflected in survival. Even with only 50% cure after local resection, survival is high in the absence of liver metastases. Median survival of metastatic non-functioning pNET is much longer than non-functional pNETs (Thompson et al. 1988, Weber et al. 1995, Bilimoria et al. 2008, Norton et al. 2012). For MEN-1-associated gastrinomas, only medical treatment with PPIs can be started in most cases. Due to the multifocal nature of gastrinomas in MEN-1, curement rates are much lower in MEN-1 patients, but on the other hand, prognosis is better, also justifying an observational strategy (Weber et al. 1995, Jensen et al. 2012). Although local lymph node metastases do not seem to influence prognosis too much, survival does decrease once liver metastases occur. Then 5-year survival decreases to 30–46% with 10-year survival of 16–30% (Weber et al. 1995, Yu et al. 1999). This seems to be slightly better in MEN-1 with reported 15-year survival of over 50%. Mainly when diffuse liver metastases are diagnosed survival is significantly reduced in MEN-1 (Yu et al. 1999). Then palliative treatment should be considered in the form of SSAs, PRRT with radiolabeled somatostatin analogs or sometimes debulking, always in combination with a PPI. PRRT with radiolabeled somatostatin resulted in a partial response in 45% of patients with a gastrinoma, but time to progression was shorter than that in non-functioning pNETs (Kwekkeboom et al. 2008, Grozinsky-Glasberg et al. 2011).
metastases, and in surgical cases, survival is higher than that for patients with non-functional pNETs.

**Glucagonoma**

Patients with a glucagonoma usually present with diabetes mellitus and typical skin lesions named necrolytic migratory erythema. Other clinical features include glossitis, anemia, weight loss and venous thrombosis (Soga & Yakuwa 1999a). First described in 1966 by McGravan, current incidence is estimated to be 0.02–0.06 per million (McGavran et al. 1966, Vinik & Moattari 1989, Yao et al. 2007). Tumors are localized in the pancreatic body or tail in 80% of patients and more than half of patients present with liver metastases (Soga & Yakuwa 1999a). In line with the other pNETs, surgery should be considered for localized glucagonoma. It is of importance to correct diabetes mellitus and mineral deficiencies in the often cachectic patients. SSAs can be administered pre-operatively to aid in this process and simultaneously low-molecular-weight heparins should be administered for prevention of thrombosis (Kaltas et al. 2004). Radical resection of the glucagonoma can result in long-lasting remission in 80–100% of patients (Soga & Yakuwa 1999a, Chu et al. 2003).

In patients with metastatic glucagonoma treatment with SSAs results in weight increase and reduction of skin lesions (Kindmark et al. 2007, Eldor et al. 2011). Small numbers of patients have been treated with PRRT with radiolabeled somatostatin. The largest series of patients has been described by Soga and coworkers. Describing 407 cases of glucagonoma, they report a 10-year survival of 100% in localized disease (not including peri-operative mortality) and 51% in case of metastatic glucagonoma (Soga & Yakuwa 1999a). Other smaller series report 5-year survival of 70% for all stages of glucagonoma combined (Chu et al. 2003, Kindmark et al. 2007, Eldor et al. 2011). No direct comparison between non-functioning pNETs and glucagonomas are available.

**VIPoma**

The syndrome caused by hypersecretion of vasoactive intestinal peptide (VIP) is known under multiple synonyms, namely VIPoma, Verner–Morrison syndrome, pancreatic cholera or Watery diarrhea hypokalemia achlorhydria (WDHA) syndrome. Currently VIPoma syndrome is mostly used in literature, but supplied with all these names one already knows a lot about VIPomas. First described by Verner and Morrison in 1958, hardly all patients present with diarrhea, sometimes so severe it causes hypokalemia and metabolic acidosis through bicarbonate depletion (Verner & Morrison 1958). The primary tumor is localized in the pancreas in 81% of patients, and these tumors behave more malignant than the approximately 20% neurogenic tumors (Soga & Yakuwa 1999b). As one of the rarest syndromes in pNETs (estimated incidence of 0.1–0.6 per million) few large series on epidemiology and survival are available. Once again, localized disease has an excellent prognosis when resection is feasible (5 year survival 94%), but 5-year survival declines to 60% in the presence of liver metastases (Soga & Yakuwa 1999b). No direct comparison with non-functioning NETs is available once more, but survival seems to be grossly similar as metastatic non-functioning pNETs. If curative surgery is no longer an option treatment with SSAs can dramatically reduce stool volumes. Reduction of tumor volume, either through debulking, embolization, PRRT or radiofrequency ablation have all successfully been used in individual cases (Peng et al. 2004, Moug et al. 2006, Kwekkeboom et al. 2008).

**ACTH**

Ectopic ACTH secretion (EAS) is a type of Cushing’s syndrome (CS), a severe endocrine disorder associated with severe morbidity and high mortality risk (Lacroix et al. 2015). In 1963, EAS was identified as a cause of CS when Liddle described a case of CS caused by a malignancy secreting ACTH (Liddle et al. 1963). It is now known to cause approximately 10–20% of CS and it is associated with pulmonary NET (small-cell lung carcinoma and carcinoid), pNET, pheochromocytoma and medullary thyroid carcinoma (Ilias et al. 2005). Typical signs and symptoms are muscle weakness, hypokalemia, body weight changes, truncal obesity, full moon face, hypertension and diabetes (Lacroix et al. 2015). EAS can often present with an aggressive form of CS, with urinary free cortisol more than 10 times elevated. EAS patients are thereby at risk of heart failure, opportunistic infection, bowel perforation and pancreatitis (Ilias et al. 2005, Isidori et al. 2006, Kamp et al. 2016). As soon as EAS is diagnosed, control of hypercortisolism should have high priority. Options include ketoconazole, metyrapone and also laparoscopic biadrenalectomy should certainly be considered in severe cases (van der Pas et al. 2012, Reincke et al. 2015). Resection of localized disease will of course cure EAS but...
should be performed preferably when hypercortisolism is controlled to prevent complications.

Due to the complications of hypercortisolism mortality is high at presentation, but thereafter, it is mainly influenced by stage and type of tumor. EAS associated with small-cell lung cancer and medullary thyroid carcinoma have the worst prognosis while occult tumors and NETs have a better prognosis (five-year survival 60–80%) (Ilias et al. 2005). Kamp and coworkers demonstrated a worse prognosis during the first 5 years of treatment of EAS patients vs other NETs, but over the entire follow-up no significant difference was found (Kamp et al. 2016). At baseline, EAS patient had stage IV disease in significantly higher percentage but number of patients was too small to correct for stage. It does however affirm that aggressive treatment of hypercortisolism is essential, because of its high mortality rate, but when this is done successfully, survival is limited by tumor burden comparable to non-functioning pNETs.

Conclusion

Every hormone hypersecretory syndrome associated with NETs presents with its own clinical challenge varying from hypoglycemia to heart failure and from opportunistic infections to diarrhea. This influences prognosis in a number a ways. On the one hand, symptoms allow for detection in earlier stages but the effects of hypersecretion can increase mortality. Survival in localized functioning NETs has always been high, but survival in metastatic disease is now also increasing, mainly due to the introduction of SSAs and PRRT with radiolabeled somatostatin which both reduce secretion and tumor growth, but also targeted therapy with everolimus and sunitinib, increases PFS.

Contemporary studies in midgut NETs show no significant difference in survival between patients with the carcinoid syndrome and those without, probably as a result of SSAs and other new therapies. The worse prognosis often reported in patients with the carcinoid syndrome is probably a reflection of tumor burden and not due to the serotonin secretion.

In pNETs multiple hormonal syndromes have been described. In studies comparing functioning pNETs as a whole, they often have a better survival than the non-functional pNETs, but correction for stage and differentiation often corrects for this fact, probably explaining the difference in survival.

For individual syndromes, excellent prognosis has been reported when a radical resection is possible and then survival is better than non-functional pNETs. Mainly insulinomas and gastrinomas seem to have a better survival than non-functioning pNETs, but this comparison can only be made by comparing different populations, which makes this conclusion limited. The overall survival in patients with the other functional pNET syndromes is shorter and conclusions are difficult to make as stage and grade differ and reported numbers are often too low to reach significance. But overall, the arsenal of drugs currently available has limited mortality associated with hypersecretion and NET mortality is now mainly caused by tumor burden and no longer by hypersecretion.

Declaration of interest

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