Differential Expression of Axl and Gas6 in Renal Cell Carcinoma Reflecting Tumor Advancement and Survival

Anna Gustafsson,¹ Danuta Martuszewska,¹ Martin Johansson,² Carl Ekman,¹ Sassan Hafizi,¹ Börje Ljungberg,³ and Björn Dahlbäck¹

Abstract Purpose: Overexpression of the receptor tyrosine kinase Axl is implicated in several cancers. Therefore, we conducted this study to determine the expression of Axl and its ligand Gas6 in various renal cell carcinoma (RCC) types and in oncocytoma.

Experimental Design: Real-time quantitative reverse transcription-PCR was used to quantify tumor mRNA levels for Axl and Gas6 in a cohort (n = 221) of RCC patients. Serum levels of soluble sAxl and Gas6 proteins were measured using specific ELISA assays (n = 282). The presence of Axl protein in tumor tissue was evaluated by immunohistochemistry (n = 294). Results were correlated to tumor-associated variables, clinical biochemical tests, and patient survival.

Results: Tumor Axl mRNA levels correlated independently to survival when assessed against tumor stage and grade. In the study group, the median cancer-specific survival of all RCC patients during 307 months of follow-up was 55 months (confidence interval, ±40.4). The 25% of patients with lowest tumor Axl mRNA levels had significantly better survival than the rest (P = 0.0005), with 70% of the patients still alive at the end of follow-up. In contrast, in patients with medium-high Axl mRNA, only 25% were alive at the end of follow-up. Tumor Gas6 mRNA levels correlated to survival, tumor-associated variables, and disease severity as did serum levels of soluble sAxl and Gas6 protein. However, no correlation between Axl protein in tumor tissue and survival was found.

Conclusions: Axl and Gas6 expression in RCC are associated with tumor advancement and patient survival. In particular, low tumor Axl mRNA levels independently correlated with improved survival.

Renal cell carcinoma (RCC) represents ~2% to 3% of all human cancers (1), being the most common cancer of the adult kidney (2). The prevalence is skewed between men and women (1.5:1), and RCC incidence peaks at 60 to 70 years of age (3). The only curative treatment of RCC is surgery (4). Today, smaller and less advanced RCC tumors are detected by imaging techniques, such as ultrasound and computed tomography, and nephron-sparing surgery of tumors <4 cm in diameter is an alternative that provides recurrence-free and long-term survival.

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Tyro3 and Mer, constitutes the TAM family of receptor tyrosine kinases that share the ligand Gas6 (product of the growth arrest specific gene 6; refs. 11–13). Together these receptors regulate many processes, such as cell proliferation, survival, cell adhesion, migration, blood clot stabilization, inflammation, cytokine release, and phagocytosis of apoptotic cells (10). Gas6 was originally found as a gene induced in cells during growth arrest (14). Axl was originally identified as a transforming gene in chronic myeloid leukemia patients (15, 16) and in a chronic myeloproliferative disorder (17) wherein Axl was suggested to be capable of transforming cells without intrinsic activating mutations. Axl has been shown to be overexpressed and to have mitogenic and prosurvival roles in a broad spectrum of human malignancies, e.g., breast, lung, colon, thyroid, and ovarian cancers (18–22). Recently, Axl was shown to mediate glioma cell proliferation, migration, and invasion (23), and in human gliomas, both Axl and its ligand Gas6 are frequently overexpressed and predict poor prognosis (24). Moreover, Axl affects multiple cellular behaviors required for neovascularization, such as endothelial proliferation, migration, survival, and tube formation in vitro, and regulates angiogenesis in vivo (25). Axl is a transmembrane protein, but soluble Axl (sAxl), consisting of the proteolytically released extracellular domain (26), is present in human serum as well (27). Gas6 is also present at low concentrations in circulation (27), and in both mouse and human serum Gas6 circulates in complex with sAxl (26).4 The concentration profiles and biological implications of sAxl and Gas6 protein in serum in RCC patients are, thus far, not investigated.

Axl and Gas6 expression in the human kidney is increased in inflammatory renal disease (28), and based on a study of Axl mRNA in 20 cases of cRCC, it has been proposed that Axl mRNA levels are increased in cRCC tissue (29). We have now conducted a large study to determine the expression of Axl and its ligand Gas6 at the mRNA level in RCC. Moreover, we have investigated the levels of sAxl and Gas6 protein in serum of RCC patients, as well as the presence of Axl in tumor tissue by immunohistochemistry.

Table 1. Patient information and clinicopathologic variables in relation to RCC subtype and oncocytoma

<table>
<thead>
<tr>
<th>Variable</th>
<th>pRCC</th>
<th>cRCC</th>
<th>chRCC</th>
<th>Oncocytoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (%)</td>
<td>35 (11.4)</td>
<td>250 (81.2)</td>
<td>14 (4.5)</td>
<td>9 (2.9)</td>
</tr>
<tr>
<td>Patient sex %, male/female</td>
<td>65.7/34.3</td>
<td>59.2/40.8</td>
<td>50/50</td>
<td>55.6/44.4</td>
</tr>
<tr>
<td>Patient age range (median)</td>
<td>25-82 (65)</td>
<td>34-85 (67)</td>
<td>36-80 (66.5)</td>
<td>50-80 (66)</td>
</tr>
<tr>
<td>TMM stage I + II/III/IV</td>
<td>18/10/7</td>
<td>102/61/86</td>
<td>8/4/2</td>
<td></td>
</tr>
<tr>
<td>Nuclear grade 1/2/3/4</td>
<td>5/11/15/3</td>
<td>9/148/124/67</td>
<td>-3/10/1</td>
<td></td>
</tr>
<tr>
<td>Tumor size mm range (median)</td>
<td>25-250 (70)</td>
<td>20-170 (80)</td>
<td>30-150 (88)</td>
<td>30-100 (40)</td>
</tr>
<tr>
<td>Vein invasion, no/yes</td>
<td>26/9</td>
<td>147/101</td>
<td>9/5</td>
<td>7/7-</td>
</tr>
<tr>
<td>Capsule invasion, no/yes</td>
<td>24/9</td>
<td>161/85</td>
<td>11/2</td>
<td>4/-</td>
</tr>
<tr>
<td>Survival (1)/(2)</td>
<td>51(-)/47</td>
<td>41 (±12.846)/42</td>
<td>-/86</td>
<td>-/100</td>
</tr>
</tbody>
</table>

NOTE: (1) indicates median survival months (CI), and (2) indicates the percentage of 5-y survival rate.

Immunohistochemical analysis of Axl staining in a tissue microarray of RCC. A tissue microarray was constructed by taking two valid tissue cores (0.6 mm) from each tumor block (n = 294) and inserting them into a recipient paraffin block (tissue microarray block). Each tissue microarray block included 98 tissue cores (49 cases in duplicates). Paraffin sections (4 μm) were deparaffinized and subjected to antigen retrieval by boiling in 10 mmol/L citrate buffer (pH 6). The expression of Axl was detected using the Axl-#042 antisera (4.4 mg/mL total IgG) at a dilution of 1:400. Immunohistochemical staining was done using the DAKO Techmate 500 staining equipment including Envision as secondary reagent, according to the instructions of the manufacturer (DAKO). For nuclear counterstaining, hematoxylin was used. An experienced pathologist evaluated the resulting staining pattern and the staining intensity. Defective cores, i.e., cores with absent tissue, large areas of necrosis, fat, and haemorrhages, and unstained cores, were omitted from the analysis, rendering 173 tumors that were used for analysis. Depending on staining intensity, Axl expression was divided into three groups: no, low, and high (0–2). The specificity of the Axl-#042 antisera was evaluated by blocking specific Axl staining by preadsorption of antisera with an excess of sAxl antigen (Supplementary Fig. S2A and B).

Statistical analysis. For statistical analysis of nonparametric data, the Mann-Whitney U test and Spearman rank correlation test were used. Survival curves were evaluated with the Kaplan-Meier method, and cumulative survival data were compared using the log-rank test. Multivariate prognostic analysis according to the Cox proportional hazard regression model was done to evaluate intervariate independence in relation to prognostic relevance. Survival time was measured from the date of nephrectomy to the date of death or the latest follow-up. All statistical tests were two sided, and the significance level was set at 0.05. Statistical analyses were done using the SPSS software package (version 16.0.2 for Macintosh; SPSS Institute). All assays were done blinded to the study end point.

Results

Axl and Gas6 tumor mRNA levels in RCC. Axl and Gas6 tumor mRNA levels were determined with qRT-PCR in a large cohort of RCC patients (n = 221), displaying a representative distribution of RCC types (ref. 8; Table 1). Axl and Gas6 tumor mRNA levels differed between RCC types and the levels found in unaffected kidney cortex tissue (Fig. 1A and B). Thus, median tumor Axl mRNA levels were increased in pRCC, whereas median Gas6 mRNA was decreased in both pRCC and cRCC.
In contrast, in chRCC and oncocytoma, Axl mRNA expression was very low, whereas Gas6 expression was slightly higher than that of unaffected kidney cortex tissue (Fig. 1A). No significant change of median expression of cRCC tumor Axl mRNA could be detected (Fig. 1A). In cRCC, there was a correlation between Axl and Gas6 mRNA levels ($r_s = 0.297, P < 0.001$; Supplementary Fig. S3A). Another noteworthy observation in cRCC was that the tumor Axl and Gas6 mRNA levels correlated positively with the Axl and Gas6 mRNA in their respective matched kidney cortex samples ($r_s (Gas6) = 0.353, P = 0.044$ and $r_s (Axl) = 0.347, P = 0.048$; data not shown).

**Axl and Gas6 protein levels in RCC.** The concentrations of sAxl and Gas6 protein in serum did not correlate to tumor Axl and Gas6 mRNA levels (Supplementary Fig. S4A and B), and there were no differences in serum levels of sAxl and Gas6 between the different RCC types (data not shown). However, compared with healthy controls, the serum concentrations of sAxl protein were lower (Fig. 1C) whereas those of Gas6 were higher in RCC (Fig. 1C), and the Gas6/sAxl ratios were higher in RCC patients than in controls (Fig. 1D). Although Gas6 and sAxl protein were changed in different directions compared with controls, there was a positive correlation between the two in RCC patients ($r_s = 0.360, P < 0.001$; Supplementary Fig. S3B).

In immunohistochemical analysis, Axl staining was strong in human normal kidney, in particular in tubular epithelial cells (Supplementary Fig. S5D, right). In RCC tissue, Axl staining varied considerably between individual cases where no or both low and high intensities were found (Supplementary Fig. S5A-C and D, left). Of particular note, neither Axl tumor mRNA nor sAxl serum protein concentrations correlated to the intensity of the Axl immunohistochemical staining (Supplementary Fig. S6A and B).

**Axl and Gas6 mRNA and protein levels in RCC patients correlated with tumor associated clinical variables and biochemical analyses.** Correlation analyses were done to investigate whether Axl and Gas6 tumor mRNA and/or protein levels were related to clinicopathologic variables in patients with RCC (Table 2). Increased sAxl and Gas6 protein levels in serum correlated with more advanced tumor stage ($P (Axl) = 0.037; P (Gas6) = 0.010$), with nuclear grade ($P (Axl) = 0.018; P (Gas6) < 0.001$), and with tumor-thrombus extension factors related with worse outcome (vein invasion; $P (Axl) = 0.001; P (Gas6) = 0.001$), and furthermore, Gas6 also correlated with renal capsule invasion in all tumors ($P = 0.013$). Decreased tumor Gas6 mRNA levels correlated with more advanced tumor stage ($P = 0.03$) and more aggressive nuclear grade ($P = 0.014$), whereas no correlation between tumor Axl mRNA levels and
tumor stage was found. No correlation between Axl immuno-histochemical levels and any of the mentioned variables could be detected (data not shown).

To estimate the systemic effects of the kidney tumors, because paraneoplastic syndromes, including an abnormal liver function, anemia, low platelet count, and elevated erythrocyte sedimentation rate, are found in ~30% of patients with symptomatic RCC (5), the levels of hemoglobin, albumin, erythrocyte sedimentation rate, and C-reactive protein were correlated to the levels of sAxl and Gas6 protein in serum. Hemoglobin and albumin concentrations correlated negatively to both the sAxl and Gas6 serum protein levels (P < 0.001; Supplementary Fig. S7A and B). In contrast, erythrocyte sedimentation rate and C-reactive protein correlated positively to both sAxl and Gas6 serum protein concentrations (P < 0.001; Supplementary Fig. S7C and D).

### Axl and Gas6 tumor mRNA and patient survival

Median cancer-specific survival of all RCC patients during 307 months of follow-up was 55 months [95% confidence interval (CI), 40.39]. Although there was no simple linear relationship between RCC Axl mRNA levels and survival (Supplementary Fig. S8A and B), patients with the 25% lowest Axl mRNA stood out as a group with longer survival than the rest of the patients (Fig. 2A; Supplementary Fig. S8B). However, there was no difference in survival between patients with medium and high tumor Axl mRNA levels (Supplementary Fig. S8B). In the patient group with medium and high tumor Axl mRNA levels, the median survival during the follow-up was 40 months (CI, 10.91). In

### Table 2. Tumor variables significantly associated with Axl and Gas6 tumor mRNA and serum levels of sAxl and Gas6 proteins

<table>
<thead>
<tr>
<th></th>
<th>Axl Tumor mRNA (cRCC)</th>
<th>Serum protein</th>
<th>Gas6 Tumor mRNA (cRCC)</th>
<th>Serum protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNM stage</td>
<td>—</td>
<td>0.126* 0.037 (273)</td>
<td>-0.166* 0.030 (172)</td>
<td>0.155* 0.010 (274)</td>
</tr>
<tr>
<td>Nuclear grade</td>
<td>0.111 0.146 (173)</td>
<td>0.141* 0.018 (280)</td>
<td>-0.187* 0.014 (172)</td>
<td>0.229 † 0.001 (281)</td>
</tr>
<tr>
<td>Venous involvement</td>
<td>—</td>
<td>0.197 † 0.001 (278)</td>
<td>-0.115 0.135 (171)</td>
<td>0.199 † 0.001 (279)</td>
</tr>
<tr>
<td>Capsule involvement</td>
<td>0.085 0.268 (170)</td>
<td>0.096 0.113 (272)</td>
<td>-0.105 0.176 (169)</td>
<td>0.151* 0.013 (273)</td>
</tr>
</tbody>
</table>

**NOTE:** Data given are as follows: Spearman correlation coefficient/P value (in italics)/number of cases (in brackets). Significant correlations are in bold font.

*Correlation is significant at the 0.05 level (two tailed).

†Correlation is significant at the 0.01 level (two tailed).
contrast, in the “low Axl” group, 70% were alive at the end of follow-up (Fig. 2A). The improved survival time in the low Axl group was not a consequence of selection bias of less aggressive chRCC or of oncocytoma, because the same results were obtained in the specific cRCC group (P = 0.02; Fig. 2B).

In contrast to what we found for tumor Axl mRNA, increased tumor Gas6 mRNA levels was associated with improved survival (P = 0.037; Fig. 2C). In the “high Gas6” group the median survival was 170 months (CI, undefined), whereas the “low Gas6” group had median survival of 38 months (CI, ±9.756). The combined Axl and Gas6 mRNA results yielded additional information. Thus, when analyzing the influence of Gas6 mRNA on survival in patients with either low or high tumor Axl mRNA expression (median division), we found that high tumor Gas6 mRNA further improved the survival of patients with median low levels of tumor Axl mRNA, with 86.5% surviving at the end of the follow up (P = 0.018; Fig. 2D). However, tumor Gas6 mRNA levels did not influence the poor prognosis in patients with high tumor Axl mRNA levels (data not shown). In agreement with the survival analysis, patients that died of the disease had higher tumor Axl mRNA levels (P = 0.032) and lower Gas6 mRNA levels (P = 0.021) than those who stayed disease free (data not shown).

In multivariate prognostic analysis according to the Cox proportional hazard regression model of tumor Axl and Gas6 mRNA, tumor Axl mRNA remained as an independent prognostic factor in relation to cancer-specific survival (P = 0.004; CI, 1.278-3.712) whereas tumor Gas6 mRNA lost its prognostic information (Table 3).

Axl and Gas6 protein levels and patient survival. The levels of sAxl and Gas6 protein in serum from RCC patients correlated negatively to survival, i.e., having lower serum levels was negatively to survival, i.e., having lower serum levels was associated with improved survival (P = 0.037; Fig. 2C). In the “high Gas6” group the median survival was 170 months (CI, undefined), whereas the “low Gas6” group had median survival of 38 months (CI, ±9.756). The combined Axl and Gas6 mRNA results yielded additional information. Thus, when analyzing the influence of Gas6 mRNA on survival in patients with either low or high tumor Axl mRNA expression (median division), we found that high tumor Gas6 mRNA further improved the survival of patients with median low levels of tumor Axl mRNA, with 86.5% surviving at the end of the follow up (P = 0.018; Fig. 2D). However, tumor Gas6 mRNA levels did not influence the poor prognosis in patients with high tumor Axl mRNA levels (data not shown). In agreement with the survival analysis, patients that died of the disease had higher tumor Axl mRNA levels (P = 0.032) and lower Gas6 mRNA levels (P = 0.021) than those who stayed disease free (data not shown).

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Axl and Gas6 in Renal Cell Carcinoma

Table 3. Multivariate prognostic analysis according to the Cox proportional hazard regression model

<table>
<thead>
<tr>
<th>Prognostic factor</th>
<th>Exp(β)</th>
<th>P</th>
<th>95% CI for Exp(β)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumor Axl mRNA</td>
<td>2.107</td>
<td>0.007</td>
<td>1.231-3.605</td>
</tr>
<tr>
<td>Tumor Gas6 mRNA</td>
<td>1.258</td>
<td>0.248</td>
<td>0.852-1.856</td>
</tr>
<tr>
<td>Age (&lt;65 y, &gt;65 y)</td>
<td>0.754</td>
<td>0.148</td>
<td>0.515-1.105</td>
</tr>
<tr>
<td>Sex (male versus female)</td>
<td>1.280</td>
<td>0.216</td>
<td>0.866-1.893</td>
</tr>
<tr>
<td>Tumor diameter (&lt;80 mm, &gt;80 mm)</td>
<td>1.082</td>
<td>0.683</td>
<td>0.742-1.577</td>
</tr>
<tr>
<td>Grade (I + II versus III + IV)</td>
<td>1.414</td>
<td>0.196</td>
<td>0.836-2.394</td>
</tr>
<tr>
<td>Stage (I + II versus III + IV)</td>
<td>12.143</td>
<td>&lt;0.001</td>
<td>6.666-22.121</td>
</tr>
<tr>
<td>After final stepwise analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tumor Axl mRNA</td>
<td>2.178</td>
<td>&lt;0.001</td>
<td>1.278-3.712</td>
</tr>
<tr>
<td>Stage (I + II versus III + IV)</td>
<td>12.095</td>
<td>&lt;0.001</td>
<td>6.858-21.332</td>
</tr>
</tbody>
</table>

Discussion

RCC is characterized by a variable clinical course and known for its unpredictable behavior (5, 9). Therefore, it is of great value to identify the fundamental molecular basis for the biological events underlying individual tumors. The 2002 TNM staging classification system (30), the Fuhrman grading system (36), and the histologic subtyping into different kidney tumors are generally accepted as the most important prognostic factors (5). However, it is currently unclear whether this system is optimal for prediction of survival in RCC. There have been considerable efforts to find other markers conclusively associated with risk of progressive disease. Markers currently under investigation are carbonic anhydrase IX, vascular endothelial growth factor (VEGF), hypoxia inducible factor, Ki67, p53, PTEN, E-cadherin, and CD44 (5). However, none of them is presently recommended for use in clinical routine, and thus, there is a great need for reliable prognostic and predictive markers.

In this report, low tumor Axl mRNA was shown to be an independent prognostic factor for RCC. Moreover, high tumor Gas6 mRNA was associated with improved survival. Combining Axl and Gas6 mRNA levels further defined a population of patients having low Axl and high Gas6 mRNA levels and good prognosis. The positive effects of high tumor Gas6 mRNA, together with the contrary expression patterns of tumor Axl and Gas6 mRNA in RCC, are intriguing because it has been shown in human glioma that high tumor Axl and Gas6 mRNA levels indicated worse prognosis (24) and because of observations that Gas6 binding to Axl stimulates proliferation and survival (37–39). Thus far, increased Gas6 mRNA correlating with favorable prognosis has only been reported in human breast cancer (40). Furthermore, in cRCC, tumor Axl mRNA levels were broadly distributed and the results are consequently more informative than those of a previous study of 20 patients that suggested Axl mRNA levels to be significantly up-regulated in cRCC (29). A methodologic difference that possibly can explain the divergent results is that tumor Axl mRNA was semiquantitatively estimated after RT-PCR by gel electrophoresis in the previous study, whereas we have used quantification by qRT-PCR.

Axl/Gas6 signaling is involved in directed cell migration of smooth muscle cells in the context of remodeling of the vessel wall after vascular injury and for endothelial cells during tumor angiogenesis (25, 41). Thus, Axl has recently been shown to affect multiple cellular behaviors required for neovascularization in vitro, and loss of Axl expression in tumor cells blocked the growth of solid human neoplasms in an in vivo breast carcinoma model (25). As such, this angiogenic potency of Axl/Gas6 signaling might contribute to tumor progression in RCC, wherein vascularization plays an important role (9) and could be one explanation for a worse outcome of patients with higher
Axl mRNA levels. Still intriguing is the observation that high tumor Gas6 mRNA levels correlated with longer survival. Recently, Gas6 via Axl was shown to have inhibitory effects on the VEGF receptor–driven angiogenic program (42), the importance of which, especially in cRCC angiogenesis wherein the majority of cases are von Hippel-Lindau–defective with increased levels of hypoxia-inducible factor-α target genes such as VEGF (9), is well known (43, 44). Therefore, high RCC Gas6 mRNA levels could be beneficial by possibly inhibiting this VEGF-driven angiogenesis. Furthermore, prolonged Gas6 stimulation results in Axl internalization and lysosomal degradation (45), and this Gas6-dependent Axl down-regulation over time could possibly contribute to the better prognosis of RCC patients with high tumor Gas6 levels.

Unfortunately, we cannot report any information about the phosphorylation status of Axl in tumor tissues, which would be informative with respect to receptor activation. However, it should be emphasized that it was Axl at the mRNA level that correlated to survival time of RCC patients and that Axl protein in tumor tissue did not.

The Gas6 system has been implicated in primary haemostasis, and Gas6−/− mice are rescued from induced thrombosis (46). Possibly, the skewed balance between sAxl and Gas6 protein in serum and, thus, the assumed risk of increased thrombus formation, likewise the various correlations of sAxl and Gas6 serum protein to several tumor risk factors, could contribute to the poor outcome of patients with RCC. Indeed, lower levels of sAxl and Gas6 protein in serum correlated to longer survival in RCC patients. Furthermore, we have verified that Gas6 protein in serum is correctly γ-carboxylated (data not shown), as Gas6 that is not would not be functional. The mechanisms regulating the shedding of sAxl protein from cells and the Gas6 protein levels in serum under healthy conditions and in malignancies are unknown. We find it unlikely that the sAxl and Gas6 protein in the serum of RCC patients were derived from the tumor tissue because there were no correlations between Axl and Gas6 mRNA levels in RCC and corresponding sAxl and Gas6 protein levels in serum. Possibly, sAxl and Gas6 are derived from endothelial cells, fibroblasts, and/or vascular smooth muscle cells (13) and aberrantly released into the circulation in response to the disease.

In conclusion, we report that tumor Axl and Gas6 mRNA levels and sAxl and Gas6 serum protein levels correlated to survival of patients with RCC. Particularly noteworthy was the observation that low tumor Axl mRNA in RCCs at time of nephrectomy remained as an independent survival factor after multivariate prognostic analysis. Altogether, our study contributes to a greater understanding of the complicated pathobiology of RCC, wherein the discovery of new molecular markers for use in prognosis and/or medical intervention is highly desired.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Acknowledgments

We thank Prof. Håkan Axelson, Lund University, for the valuable discussions and critical feedback on the results presented and Elise Nilsson for her technical assistance in the preparation of the immunohistochemistry slides.
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