A search for molecular biomarkers in gastro-intestinal cancer
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chapter 4

INCREASED PHOSPHORYLATION ON RESIDUE S795 OF THE RETINOBLASTOMA PROTEIN IN ESOPHAGEAL ADENOCARCINOMA

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Submitted
**ABSTRACT**

**Objective:** Due to its increasing incidence and relatively poor prognosis, esophageal adenocarcinoma (EAC) is becoming a significant health problem. Elucidating the mechanisms underlying EAC development is of great importance to improve upon current conventional treatment strategies. Insight into phosphorylation has proven to be useful for the development of diagnostic and molecular treatment strategies in cancer. A pathway largely dependent on phosphorylation and frequently deregulated in cancer is the cell cycle regulating p16 - Retinoblastoma (Rb) pathway. We decided to investigate kinase activity, specifically phosphorylation within the p16-Rb pathway, in EAC.

**Materials and methods:** A high-throughput peptide tyrosine kinase array containing short peptides representing 100 proteins with known phosphorylation sites, was used to assess phosphorylation activity in EAC. Also, specific phosphorylation changes of the cell cycle protein Rb and its upstream regulator P16 were validated through immunoblotting in EAC and normal esophageal cells and tissues.

**Results:** Phosphorylation activity was higher in EAC tissues as compared to normal squamous esophageal tissues. A majority of the proteins significantly higher phosphorylated in EAC were found to be involved in cell structure maintenance and immunity. Validation of Rb phosphorylation in EAC biopsy specimens and cell lines showed hyper phosphorylation of Rb associated with aberrant P16 expression in the cancer tissues. The specific Rb (S795) residue was significantly higher phosphorylated in EAC compared to normal esophageal tissue (Wilcoxon paired rank test, \( p = 0.004 \)).

**Conclusion:** Investigation of Rb(S795) phosphorylation may indicate targets for intervention and give more molecular insight in EAC.
INTRODUCTION

For a number of decades the incidence of esophageal adenocarcinoma has been steadily rising in several countries (1-4). In the US for instance the overall EAC incidence increased from 0.4 cases per 100,000 in 1975 to 2.6 cases per 100,000 in 2009 (5). The 5-year survival has improved in this same period from around 5%, but still remains rather poor at 15-20% (3,5). The exact reasons for this rise in EAC incidence is unclear. With respect to risk factors some studies have shown a relationship between increased body mass index (BMI) with an increased risk for EAC (3,6). Other important risk factors for EAC are gastro-esophageal reflux disease (GERD) and the herewith related Barrett’s esophagus (BE) (7-9). BE is a metaplastic pre-malignant transformation of the esophageal epithelium associated with GERD (7-9). Although the outcomes of EAC have improved through the bettering of conventional treatments, for instance through combining chemo-radiotherapy with surgery, outcomes of EAC are still poor (10). There is thus a need for a deeper molecular insight into EAC to develop new approaches and treatments to improve patient outcomes.

A potential route to this deeper molecular insight are kinases. This group of enzymes, through addition of a phosphate group to specific targets, activate large and far-reaching signaling cascades, which are pivotal in maintaining homeostasis in living organisms. Their pivotal role also means that the precarious biological balance they help sustain can be easily broken, through the mutation or aberrant expression of these bio-molecules. Elucidating phosphorylation activity with respect to specific processes, such as cell proliferation, has been shown to be an attractive avenue of research as molecular strategies developed around inhibitors of the involved kinases might serve as anticancer therapeutics. For instance, the targeting of the HER2 receptor tyrosine kinase has been shown to be of benefit in breast cancer treatment (11,12). Also in EAC, amplification of the HER2 gene has been noticed in up to 21% of samples (13). A recent trial has shown improvement in survival of patients with gastric and gastro-esophageal junction cancer upon combining chemotherapy with the HER2 targeting immunoglobulin Trastuzumab (14). Therefore, identifying novel aberrancies of kinases involved in cell proliferation could be useful in EAC. A potential source for these kinases is the p16-Rb pathway, which is frequently affected in cancer (15). The P16/INK4A protein inhibits the cyclinD-CDK4/6 complexes that modulate progression through the G1/S-phase checkpoint of the cell cycle, through hyper-phosphorylation of the Rb-E2F complex. Release of the E2F transcription factors consequently leads to DNA replication (15). Aberrancies of p16, such as mutations, methylations and deletions, are some of the earliest events in cancer (16). P16 is also involved in the pathogenesis of EAC with a number of P16 alterations such as gene locus loss, LOH (loss of heterozygosity), mutations and methylation being present in BE, the pre-malignant stage of EAC (17-20) and consequently increasing with increasing tissue dysplasia (17,18,20). In a number of cancers it has been shown that aberrations of p16 affect phosphorylation status of Rb (21,22). It would be of interest to investigate whether a similar bio molecular effect can be seen in EAC.

To elucidate phosphorylation mechanisms involved in the pathogenesis of EAC we have first employed a high-throughput tyrosine kinase peptide chip, to investigate broad-scale kinase activity in EAC. We additionally examined the p16-Rb pathway in EAC and normal squamous esophageal biopsy specimens to investigate whether phosphorylation of Rb might play a role in EAC pathogenesis.
MATERIALS AND METHODS

Patient material. This study received Institutional Review Board approval from the Academic Medical Center (AMC) Amsterdam and written informed consent was obtained from all participating subjects. Biopsies were obtained from EAC patients referred for endoscopy for disease staging. The study included biopsies of EAC and squamous mucosa as confirmed in matched samples taken for routine histological purposes. For the kinase chip, immunoblotting and immunohistochemistry experiments normal squamous en EAC tissue samples were isolated from a total of 51 patients. Samples were snap frozen and stored at -80 ºC until processing for experiments. Of the patients, 43 were male and 8 female. Average age was 66 ± 12 years.

Esophageal cell lines. The human hTERT immortalized esophageal cell line, EPC2-hTERT, was a kind gift from Prof. A. Rustgi (University of Pennsylvania, PA, USA) (23) and was cultured in KSFM medium (Life technologies, Bleijswijk, Netherlands) supplemented with human recombinant epidermal growth factor (EGF) and Bovine pituitary extract (Life technologies, Bleijswijk, Netherlands).

The OE19 and OE33 esophageal adenocarcinoma cell line were obtained from the ATCC and cultured in RPMI 1640 medium (Life technologies, Bleijswijk, Netherlands) supplemented with L-glutamine, penicillin/streptomycin and 10% fetal bovine serum (FBS) (Lonza, Basel, Switzerland).

Tyrosine kinase peptide array. Fifteen EAC and coupled squamous biopsies were analysed with the PAMgene tyrosine kinase peptide-microarray system (PAMgene, ’s-Hertogenbosch, the Netherlands) for two replicate experiments. This peptide-microarray contains 143 short peptides, with sequences derived from literature, with known phosphorylation sites representing 100 proteins. Biopsies were lysed in MPER lysis buffer (Thermo Fisher Scientific, Etten-Leur, Netherlands) and samples were tested in 2-3 replicates. The peptide-microarray system measures kinase kinetics by detecting phosphorylation with anti-phosphotyrosine fluorescently labelled immunoglobulins. End level average signals and initial rates of the samples were determined and corrected for signal saturation. These measurements indicated phosphorylation activity. Kinase activity heat maps were created with the CIMminer software (Genomics and Bioinformatics group, LMP, CCR, National Cancer Institute, http://discover.nci.nih.gov/cimminer/)

DNA Fluorescence in situ hybridization (FISH). To detect P16 gene locus losses in the cell lines, DNA FISH was performed as described earlier (24). For this experiment the specimens were hybridized with a directly labelled probe mix which contained the SpectrumRed- LSI p16 (9p21) locus specific probe for the 9p21 (P16) region on chromosome 9, which was obtained from Abbott Molecular (Abbott Molecular, Chicago, IL, USA).

Scoring was done with the 60x objective of the Olympus BX51 microscope (Olympus, Zoeterwoude, Netherlands). Pictures were taken with the Olympus XM10 camera and brightness and contrast adjustments were done with the Olympus Cell^F software. To define per sample P16 DNA-FISH status we used previously determined frequency cut-off values for P16 gains and losses (24). These values were obtained from counts of 20 normal squamous
epithelium cytological patient specimens (100 nuclei evaluated per case) and calculated as the mean percentage of squamous nuclei with either P16 gain or loss plus 3x standard deviation. The P16 cut-off frequency was 10% for losses and 4% for gains.

**Western Blotting.** Biopsies and cell lines were lysed in MPER lysis buffer (Thermo Fisher Scientific, Etten-Leur, Netherlands) supplemented with protease and phosphatase inhibitors (Halt protease and phosphatase inhibitor cocktail, Thermo Fisher scientific, Etten-Leur, Netherlands). For the cell lines experiments, two independent lysate samples were made from each line and a number of replicate blots were made from these samples.

Lysates combined with sample buffer (125 mM Tris/HCl, pH 6.8; 4% SDS; 2% β-mercaptoethanol; 20% glycerol; 1 mg bromphenol blue) were loaded onto SDS-protein gels and subsequently transferred onto PVDF membranes (Millipore, Amsterdam, The Netherlands). The blots were incubated overnight at 4°C with the primary antibody of interest. After incubation with the primary antibodies, blots were incubated for 1 hour at room temperature with the secondary antibody, the anti-rabbit HRP conjugated immunoglobulin (Dako, Heverlee, Belgium). Consequently blots were incubated in Lumilite plus (Boehringer-Mannheim, Mannheim, Germany) and chemiluminescence was detected using a Fuji LAS4000 illuminator (Fuji Film Medical Systems, Stamford, USA). Quantification of the blots was performed with the ImageJ software (version 1.44). Primary antibodies used were the rabbit anti-phospho-Rb(T356), anti-phospho-Rb(S795) and anti-phospho-Rb(S780) immunoglobulins (Abcam, Cambridge, United Kingdom). Also used were the rabbit monoclonal anti-P16/INK4A (Epitomics/Bio-Connect BV, Huissten, Netherlands) and rabbit polyclonal anti-Rb (ab6075, Abcam, Cambridge, United Kingdom) antibodies. The rabbit polyclonal anti-actin (Santa Cruz biotech, Heidelberg, Germany) antibody was used for quantification of the P16 and (phospho-)Rb levels.

The relative phospho-Rb levels were corrected for the total level of the Rb protein to determine the phosphorylation activity on the specific amino acid. Total Rb levels were determined for each cell line and EAC and squamous patient biopsies. From these levels an average Rb level was determined for each of the aforementioned esophageal cell lines and the BE tissue types. The average phospho-Rb levels were then corrected for these total Rb levels for the respective cell line and tissue type.

For the tissue samples total Rb expression was obtained for 24 squamous and 20 EAC samples. Phospho-Rb levels were measured for 38 normal squamous and 32 EAC samples. Phospho-Rb(S795), was investigated in protein lysates from 12 EAC and squamous samples. Phospho-Rb(S780) was investigated in 4 EAC and squamous samples. Phospho-Rb(T356) was investigated in 16 EAC and 22 squamous samples. P16 protein levels were measured for 30 normal squamous and 20 EAC samples.

**Immunohistochemistry.** 8 squamous esophageal and 19 EAC samples were used for the immunohistochemistry experiments. These samples were formalin fixated after isolation and paraffin embedded. Subsequent 5µm tissue sections of each biopsy were cut and used for the stainings. For staining, tissue slides were de-paraffinized and antigen retrieval was performed by boiling slides for twenty minutes in pre-warmed Citrate Buffer, pH 6.0. Endogenous peroxidase was blocked by incubation with 0.3% H2O2. Next, slides were blocked with 10%
normal goat serum (BioConnect, The Netherlands) and an avidin/biotin blocking kit (Vector Labs, Burlingame, USA). Slides were washed in PBS and incubated with the primary antibody for 90 minutes at room temperature. Primary antibodies used were monoclonal rabbit anti phospho-Rb(T356) and polyclonal rabbit anti phospho-Rb(S795) (both Abcam, Cambridge, United Kingdom). Slides were then incubated with the respective biotin linked secondary reagents from the LSAB™2 Kits (Dako, Heverlee, Belgium) following the manufacturer’s instructions. The peroxidase activity was visualized using DAB+. (Dako, Heverlee, Belgium). Finally, sections were counterstained with Mayer’s haematoxylin, dehydrated and mounted. Slides were photographed with a microscope equipped with a digital camera (Leica CTR500, Leica Microsystems, Germany) using the 10x objective.

A semi-quantitative approach was used to score the stained tissue samples taking into account the strength of staining and the number of nuclei stained. Only nuclei of epithelial cells were considered for scoring. For the anti-phospho-Rb (T356,S795) antibodies, staining was scored from 0 to 4. Score 0,1 = no or very light staining in few nuclei. Score 2 = staining in few nuclei. Score 3 = staining in 33-50% of nuclei. Score 4 = clear staining in almost all nuclei. Slides were scored by one researcher (DS).

Statistics. Paired t-test and Wilcoxon paired rank test to determine peptides significantly differently phosphorylated in tumor compared to normal tissues was performed in Microsoft Excel and with SPSS 20 (IBM, Amsterdam, the Netherlands). Statistical significance was set at p < 0.05. T-test, Wilcoxon paired rank and Mann-Whitney U test to look for significant differences in quantified protein expression was performed with Graph Pad Prism 5 (GraphPad software, California, USA). Statistical significance was set at p < 0.05. SEM of the quantified protein expressions was also determined with Graphpad.

RESULTS

Tyrosine kinase activity and phosphorylation of the Rb protein in esophageal adenocarcinoma. Phosphorylation activity in EAC biopsies was compared to the matching normal squamous samples for 15 patients with the PAMgene tyrosine kinase peptide-microarray system in two independent experiments. In both experiments phosphorylation activity showed an overall increase in tumor samples compared to the matching normal squamous biopsies (Figure 1). For one experiment, phosphorylation levels were too low to be analysed for all the peptides. In this case there were 100 analysable peptides. For the other experiment 142 peptides were analysable. When averaged over both experiments, of the 142 analysable peptides, 122 (86%) were more phosphorylated and 11 (8%) were less phosphorylated in EAC. Nine (6%) peptides had equal phosphorylation levels in tumor compared to normal squamous tissues. In both experiments we found a number of peptides for which the difference in phosphorylation between tumor and coupled normal squamous tissues was significant (p < 0.05; paired t-test and Wilcoxon paired rank test). We listed all peptides that were either significantly differently phosphorylated for tumor versus normal tissues in both experiments or in one experiment if it was only analysable in a single experiment. These peptides can be assigned to proteins which have a function in a variety of processes including development, immunity and also cell structure and motility (Table 1).
We found that also peptides representing proteins of the G1/S checkpoint, specifically CDK2 and Rb, were differently phosphorylated in EAC versus normal esophageal tissues. Both peptides showed higher levels of phosphorylation in tumor versus normal tissues, with ratios of respectively 1.7 and 1.5 for CDK2 and Rb. Interestingly, phosphorylation of the CDK2-peptide was on a presumed
Phosphorylation of Rb in esophageal adenocarcinoma

Inhibitory residue at the Y15 position (25), which should lead to a lower level of CDK2 activity. Nonetheless, the peptide derived from the Rb protein showed higher phosphorylation in EAC compared to the normal tissues. This is most likely due to a larger contribution of CDK4 activity, resulting in a net effect of increased Rb phosphorylation in EAC (Figure 2).

P16 gene status and protein expression in normal squamous and malignant esophageal cell lines. To investigate in cell lines if increased levels of Rb phosphorylation were associated with p16 abnormalities in EAC, we first validated gene status and the relative protein expression of P16 in cell lines representing normal squamous epithelium (EPC2-hTERT) and EAC (OE19, OE33). The P16 (9p21) gene locus status of the cells was investigated through DNA-FISH (Figure 3) and protein expression of P16 by immunoblotting. EPC2-hTERT was considered normal for P16 gene status as assessed by DNA-FISH (Table 2). Both EAC cell lines had large frequencies of P16 FISH abnormalities. OE19 showed cells with either losses or gains of the P16 allele, while OE33 exhibited exclusively gains of the gene (Table 2). When considering the protein levels, EPC2-hTERT had the highest relative P16 protein expression. In comparison, the cancer cell line OE33 which actually showed gains of P16, had a lower P16 protein expression, while OE19 had the lowest expression level (Table 2, Figure 4A). The low protein levels of P16 in OE33 is likely due to P16 gene promoter hypermethylation which is a frequent event in EAC and also has been observed in OE33 (26). Thus P16 protein levels correlated with P16 gene status as assessed by DNA-FISH in EPC2-hTERT and OE19. This correlation was not directly seen for OE33. Nevertheless, both techniques indicated aberrancies of p16 in cancer cells compared to normal

Table 1. Proteins with significantly different (p < 0.05) phosphorylation signals in tumor (T) compared to normal squamous (N) esophageal tissues as measured by the kinase array.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Protein (gene) – [p-Tyr group]</th>
<th>Fold change (T/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytoskeletal structure/ cell motility</td>
<td>Annexin A2 (ANXA2) – [Y24]</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Adapter molecule Crk (CRK) – [Y221]</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Macrophage-stimulating protein receptor (RON) – [Y1353]</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Beta catenin (CTN81) – [Y86]</td>
<td>1.9</td>
</tr>
<tr>
<td>Development/homeostasis</td>
<td>Tyrosine-protein kinase JAK2 (JAK-2) – [Y570]</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Myelin basic protein (MBP) – [Y203]</td>
<td>1.5</td>
</tr>
<tr>
<td>Immunity</td>
<td>T-cell surface glycoprotein CD3 zeta chain (CD3z) – [Y123,153]</td>
<td>4.0, 5.5</td>
</tr>
<tr>
<td></td>
<td>Signal transducer and activator of transcription 4 (STAT4) – [Y725]</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>B-cell antigen receptor complex-associated protein alpha-chain (CD79A) – [Y182/188]</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Lymphocyte cell-specific protein-tyrosine kinase (LCK) – [Y394]</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Linker for activation of T-cells family member 1 (LAT) – [Y255]</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Phosphoinositide phospholipase C-gamma-1 (PLCG1) – [Y1253]</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Proteins are collected according to the biological roles most prominently connected to the phospho-group of interest.
Phosphorylation of Rb in esophageal adenocarcinoma (EAC) has been extensively studied. However, the assessed P16 protein levels in EAC seemed to correlate better with the reported functionality of the protein.

**Phospho-Rb expression in normal and EAC cell lines.** Consequently, we compared the P16 protein expression levels to the relative Rb protein phosphorylation in the EPC2-hTERT, OE19, and OE33 cell lines. Rb has several phosphorylation sites. We investigated phosphorylation on the T356 and S795 amino acids of Rb in the cell lines. We found that on average Rb phosphorylation on these two residues inversely correlated with the P16 protein levels (Figure 4). P16 protein

**Figure 2. Schematic representation of part of the Rb phosphorylation regulatory pathway.** Both CDK2 and Rb are represented in the tyrosine kinase peptide array and had higher phosphorylation levels in adenocarcinoma compared to normal squamous esophageal tissues.

**Table 2. Frequencies for P16 locus loss and gain in esophageal cell lines by DNA FISH.**

<table>
<thead>
<tr>
<th>Cell lines</th>
<th>EPC2-hTERT</th>
<th>OE19</th>
<th>OE33</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P16 FISH frequencies (%)</strong></td>
<td>Loss</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Gain</td>
<td>1</td>
<td>24</td>
</tr>
</tbody>
</table>

100 nuclei were counted for all cell lines. OE19 and OE33 are esophageal adenocarcinoma cell lines. EPC2-hTERT is a normal squamous esophageal cell line.

squamous cells. However, the assessed P16 protein levels in EAC seemed to correlate better with the reported functionality of the protein.
levels were lower for both EAC cell lines, OE19 and OE33, compared to the normal squamous cell line, EPC2-hTERT (Figure 4A). For the T356 residue, EPC2-hTERT, showed a lower phospho-Rb(T356) level compared to the EAC cell line OE19 and comparable levels to OE33. For phospho-Rb(S795) a higher level of phosphorylation was seen for both EAC cell lines as compared to the normal squamous cell line.

**Rb phosphorylation and P16 expression in esophageal tissues.** Rb protein phosphorylation was also investigated in patient biopsies with EAC and normal squamous epithelial tissues and compared with P16 protein expression (Figure 5). For these samples phosphorylation on the S795, S780 and T356 amino acids of Rb was investigated. In all cases, the tissue phospho-Rb levels were corrected for total Rb expression. The protein expression levels within the specific tissue types were rather variable (Figure 5B,C,D). On average, expression of P16 was decreased in EAC biopsies when compared to the normal squamous esophageal tissues (Figure 5B, t-test, p = 0.049). Inversely, we found increased phosphorylation for all three investigated Rb sites in EAC as compared to normal squamous tissues (Figure 5D). On average, Rb phosphorylation at the S795 site was significantly higher in EAC compared to coupled squamous tissues (Wilcoxon paired rank test, p = 0.004).
Considering the specific phosphorylation sites, for phospho-Rb (S795), 9 of 12 (75%) of EAC cases showed increased phosphorylation as compared to matching squamous controls. For phospho-Rb(S780), 4 of 4 (100%) and for phospho-Rb(T356), 8 of 16 (50%) had increased phosphorylation in EAC. The inverse correlation between a higher Rb phosphorylation ratio compared to P16 protein expression in EAC falls in line with the functional relation of P16 and Rb phosphorylation (Figure 2).

Phospho-Rb immunohistochemistry staining in esophageal tissues. To validate and visualize the Rb phosphorylation as detected in the biopsy protein lysates we performed immunohistochemistry staining for Rb phosphorylated on the S795 and T356 groups on BE patient tissue samples. To this end 8 squamous esophageal and 19 EAC samples were stained.
Overall the stainings showed that the EAC tissues had a stronger phosphorylation on both the S795 and T356 groups than the squamous tissues (Figure 6). To better (semi-)quantify these results we designed a scoring system for the stainings performed, based on strength of staining and number of stained nuclei. The scoring confirmed that Rb phosphorylation on S795 and T356 was much more pronounced in EAC compared to squamous esophageal tissues (Table 3). If we considered the two highest scoring categories as indicative of high Rb phosphorylation, than 84.2% of the EAC tissues showed a high phosphorylation of S795 and T356 compared to
**Figure 6.** Immunohistochemistry stainings for phospho-Rb on squamous esophageal and EAC tissues. EAC tissues showed a higher nuclear expression of phospho-Rb. The scale bar indicates 200 µm.

**Table 3.** Scoring percentages for phospho-Rb immunohistochemistry staining on BE tissue samples.

<table>
<thead>
<tr>
<th></th>
<th>Score</th>
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<tbody>
<tr>
<td></td>
<td>0,1</td>
</tr>
<tr>
<td><strong>Phospho-Rb(T356)</strong></td>
<td></td>
</tr>
<tr>
<td>Sq</td>
<td>100</td>
</tr>
<tr>
<td>EAC</td>
<td>10,5</td>
</tr>
<tr>
<td><strong>Phospho-Rb(S795)</strong></td>
<td></td>
</tr>
<tr>
<td>Sq</td>
<td>100</td>
</tr>
<tr>
<td>EAC</td>
<td>0</td>
</tr>
</tbody>
</table>

For phospho-Rb groups; Score 0,1 = no or very light staining in few nuclei. Score 2 = staining in few nuclei. Score 3 = staining in 33-50% of nuclei. Score 4 = clear staining in almost all nuclei.

0% of the squamous tissues. Another interesting result of the staining was that sequential EAC tissue sections stained for the two Rb groups did not show a complete overlap with respect to stained nuclei. This indicates that certain nuclei might have increased phosphorylation on one aminoacid while lacking this increased phosphorylation on the other aminoacid.

**DISCUSSION**

Our explorative search into phosphorylation activity as a method to gain more insight into the pathogenesis of EAC confirmed that kinase activity is largely upregulated in this cancer. High phosphorylation levels have been described earlier in EAC as such our findings are in accordance with earlier studies (27,28).
A list of the proteins for which phosphorylation was significantly different in EAC compared to normal esophageal tissues shows a broad range of molecules involved in varied processes (Table 1). A large part of this list represents proteins involved in cytoskeletal structure organization and cell adhesion. But also proteins involved in immunity are represented. EAC is associated with chronic inflammation due to active reflux esophagitis (27-29). Aberrant phosphorylation related to the inflammatory process in EAC compared to normal squamous tissues falls in line with the literature (29-31). Tissue structure and inflammation related processes might be interesting candidates for molecular targets in EAC.

A pathway of interest that we investigated in this report was the phosphorylation of the Rb protein in EAC. A 1.5x higher phosphorylation of Rb was observed by the kinase chip in EAC compared to normal esophageal tissues. This aberrant phosphorylation of Rb is likely due to aberrations of its upstream regulator: p16. Aberrant p16 as detected through methylation, loss of heterozygosity and immunohistochemistry has been frequently noticed in EAC pathogenesis (17-20). P16 has thus been a molecule of interest in EAC. In this study we first investigated p16 status in EAC. There was a lower P16 protein expression in EAC tissues and cell lines compared to the normal squamous tissues (Figure 4,5). On the genetic level P16 showed an aberrant status in EAC cell lines compared to a normal squamous esophageal cell line (Table 2). The discrepancy of gains of the P16 locus seen in one EAC cell line combined with a lower P16 protein expression, is likely due to hypermethylation of the P16 gene promoter. A process frequently observed in EAC (17,18,20). We further found a negative correlation between P16 expression and phosphorylation of Rb forms in EAC cell lines and biopsies (Figure 4,5). Overall, EAC had lower P16 protein expression levels and increased phosphorylation levels of Rb.

The specific Rb phosphorylation sites of S795, S780 and T356, that we investigated all shared the same upstream cyclin dependent kinase 4 (CDK4). Phosphorylation at these amino acids leads to the detachment of Rb from its interacting proteins and stimulation of progression through the G1/S checkpoint (32-34). In the tissue lysates there was a higher rate of Rb phosphorylation on all three positions in EAC compared to the normal tissues. Overall, this effect seemed to be more pronounced for the S795 and S780, than the T356 site. And only for phosphorylation on the S795 position did this appear to be significant. However, this might be due to the relatively small number of samples investigated. Also in the immunohistochemistry stained slides the EAC tissues showed a higher expression of Rb phosphorylated on the S795 and T356 groups compared to the normal tissues. It is not clear how phosphorylation on the different sites would differ with respect to functioning. However, as Rb interacts with different proteins through different binding domains (35), it is possible that phosphorylation on the different Rb residues affect interactions with varied proteins and pathways. Interestingly, the immunohistochemistry staining patterns for phospho-Rb(S795) and phospho-Rb(T356) when comparing sequential slides differed indicating that specific nuclei might have an increased phosphorylation on a specific residue but not on the other. Future experiments should more closely examine whether specific phosphorylation on the different Rb residues might lead to differential results in EAC. Also it might be of interest to investigate if there are specific Rb sites that are more phosphorylated in the earlier stages of EAC development, i.e. in BE.
Research has shown that inhibitors of kinases involved in cell proliferation might serve as anticancer therapeutics. With respect to Rb phosphorylation some research has been done on specific molecules affecting this process in EAC. For instance, Song et al. found that in cell lines of EAC and its pre-malignant stage of Barrett’s esophagus, the green tea extract mixture of polyphenon E leads to an inhibition of proliferation and induction of apoptosis (36). This anti-proliferative function of the compound seemed to occur through the down regulation of the expression of cyclin-D1, an upstream phosphorylating regulator of Rb. Accordingly this led to a lower expression of phospho-Rb in EAC and Barrett’s cells (36). In another experiment the effects of flavopiridol, a pan-inhibitor of CDKs, on a mouse model of Barrett’s and related EAC, were investigated (37). In this model esophago-jejunostomy induced reflux combined with carcinogen exposure in a p27 null background, induced Barrett’s development. These researchers found a significantly lower prevalence of BE and EAC in flavopiridol treated animals. This was combined with a lower expression of cyclin-D1 in tumors of treated animals, with some tentative evidence for lower expression of phospho-Rb in treated mice (37). There are thus potential therapeutics that could be tested in EAC to further investigate how modulation of the specific phosphorylation of Rb could influence the disease.

In conclusion, overall phosphorylation activity is upregulated in EAC. This aberrant upregulation seems to be especially pronounced in processes related to inflammation and tissue structure organization. With respect to the p16-Rb pathway, Rb is significantly higher phosphorylated on the S795 residue. This residue might be of interest as a putative target for treatment and further molecular insight in EAC and should be further investigated.

**REFERENCE LIST**


Phosphorylation of RB in esophageal adenocarcinoma


