Analysis of glycerol-lysophospholipids in gastric cancerous ascites

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Abstract Lysophosphatidic acid (LysoPA) has been proposed to be involved in the pathogenesis of various cancers. Moreover, glycerol-lysophospholipids (glycerol-LysoPLs) other than LysoPA are now emerging as novel lipid mediators. Therefore, we aimed to elucidate the possible involvement of glycerol-LysoPLs in the pathogenesis of gastric cancer by measuring glycerol-LysoPLs, autotaxin (ATX), and phosphatidylserine-specific phospholipase A1 (PS-PLA1) in ascites obtained from patients with gastric cancer and those with cirrhosis (as a control). We observed that after adjustments according to the albumin levels, the lysophosphatidylserine (LysoPS) and lysophosphatidylglycerol (LysoPG) levels were significantly higher, while the LysoPA and ATX levels were lower, in the ascites from patients with gastric cancer. We also found that multiple regression analyses revealed that ATX was selected as a significant explanatory factor for all the detectable LysoPA species only in the cirrhosis group and that a significant positive correlation was observed between LysoPS and PS-PLA1 only in the gastric cancer group. In conclusion, the LysoPA levels might be determined largely by LysoPC and LysoPI (possible precursors) and the PS-PLA1-mediated pathway might be involved in the production of LysoPS in gastric cancer. Glycerol-LysoPLs other than LysoPA might also be involved in the pathogenesis of cancer directly or through being converted into LysoPA.


Supplementary key words ascites • gastric cancer • cirrhosis • autotaxin

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Glycero-lysophospholipids (glycero-LysoPLs) possess a glycerol backbone with one fatty-acid chain and one hydrophilic compartment. This molecular family includes lysophosphatidic acid (LysoPA), lysophosphatidylcholine (LysoPC), lysophosphatidylethanolamine (LysoPE), lysophosphatidylglycerol (LysoPG), lysophosphatidylinositol (LysoPI), and lysophosphatidylserine (LysoPS) (1, 2). Among these glycero-LysoPLs, LysoPA has been most studied in various fields, including oncology: LysoPA works on six kinds of G protein-coupled receptors (GPCRs), LysoPA receptors 1–6, located on the cell membrane and reportedly stimulates proliferation, migration, invasion, tumor angiogenesis, and resistance to the chemotherapy of cancer cells (3–6). A series of clinical studies also reported that LysoPA receptors (7–9) and LysoPA-producing enzyme [autotaxin (ATX)] (10–13) are produced or expressed to a greater degree in cancers (5).

In addition to LysoPA, several studies have reported that other glycero-LysoPLs might also be involved in the pathogenesis of cancers. One possible role of glycero-LysoPLs other than LysoPA might be that of precursors to LysoPA, which is known to promote cancer progression. Although LysoPC is the main substrate for ATX in circulation, other glycero-LysoPLs can be hydrolyzed into LysoPA (14). Several specific GPCRs against glycero-LysoPLs other than LysoPA have recently been identified (15), and the direct
effects of these glycerol-LysoPLs, in addition to their roles as precursors of LysoPA, have been emerging, especially from basic research. For example, LysoPI is reportedly involved in cell proliferation, migration, and survival (16); LysoPE causes migration and the invasion of ovarian cancer cells (17); and LysoPS stimulates the migration of colorectal cancer cells and glioma cells (18, 19). Because specific receptors or producing enzymes could be useful targets for new medicines, glycerol-LysoPLs, including LysoPA, are attracting attention in the field of oncology.

Contrary to the possible association between glycerol-LysoPLs and cancers, which has been proposed based mainly on the results of basic research, clinical evidence of the involvement of glycerol-LysoPLs, even LysoPA, in cancers remains insufficient at present. One possible reason is that the collection of blood samples suitable for analyses of glycerol-LysoPLs is rather difficult, because the presence of large amounts of LysoPA precursors, such as LysoPC, or platelet activation can increase the levels of glycerol-LysoPLs, especially LysoPA, during blood sampling (20).

With these backgrounds in mind, the present study attempted to elucidate the possible involvement of glycerol-LysoPLs in the pathogenesis of cancer in human subjects. For this purpose, we used LC-MS/MS to measure the levels of glycerol-LysoPLs and their producing enzymes in ascites collected from subjects with gastric cancer or cirrhosis (as a control).

METHODS

Ascites from patients suffering from gastric cancer or cirrhosis

Ascites samples were collected from subjects with advanced gastric cancer (n = 48) or cirrhosis (n = 23), as a control group, for the purpose of palliative care at Kanamecho Hospital (Tokyo, Japan). Because the existence of ascites in healthy subjects is limited and the procedure for its sampling is quite invasive, we utilized the ascites from subjects with cirrhosis, in which malignant cells were not included, as a control to investigate the characteristics of malignant ascites.

The supernatant components were collected by centrifugation and stored in aliquots at −80°C, then subjected to one freeze-thaw cycle before the measurement of the glycerol-LysoPLs, ATX, and phosphatidyldlycerol-specific phospholipase A1 (PS-PLA1). The present study was conducted with the approval of the ethics review committee of the University of Tokyo, and all the participants signed informed consent forms.

Measurement of glycerol-LysoPLs, ATX, and PS-PLA1 in the ascites

The glycerol-LysoPLs were quantified using LC-MS/MS, as previously described (21, 22). Briefly, the plasma samples were mixed and sonicated with methanol and an internal standard (1 μM 17:0 LysoPA or 10 μM 17:0 LysoPC). After centrifugation at 21,500 g, the resulting supernatant was recovered and used for the LC-MS analysis. Then, 20 μl of the methanol extract was separated using a Nanospace LC (Shiseido) equipped with a C18 CAPCELL PAK ACR column (1.5 x 250 mm; Shiseido) using a gradient of solvent A (5 mM ammonium formate in water) and solvent B [5 mM ammonium formate in 95% (v/v) acetonitrile]. The eluate was sequentially ionized using an ESI probe, and the parent ion (m/z 380.2) and the fragment ion (m/z 264.2) were monitored in the positive mode using a Quantum Ultra triple quadrupole mass spectrometer (Thermo Fisher Scientific). For each LysoPL class, 12 acyl chains (14:0, 16:0, 16:1, 18:0, 18:1, 18:2, 20:3, 20:4, 20:5, 22:5, and 22:6) were monitored. We calculated the concentrations of LysoPLs from the area ratio to the internal standard: 1 μM 17:0 LysoPA (for LysoPA, LysoPE, LysoPLG, LysoPS, and LysoPS species) or 10 μM 17:0 LysoPC (for LysoPC species).

The ATX and PS-PLA1 antigen levels in the ascites were determined using a two-site immunoenzymetrix assay with the TOSOH AIA system (TOSOH, Tokyo, Japan) (23, 24). Regarding ATX, because five alternative splicing isoforms of ATX have been identified as ATXa, ATXβ, ATXγ, ATXδ, and ATXε, we also measured the classical ATX (ATXa, ATXβ, and ATXγ) and novel ATX (ATXδ and ATXε) levels using enzyme immunoassays that we recently developed (25).

Statistical analysis

All the data were statistically analyzed using SPSS (Chicago, IL). The results are expressed as the mean ± 2SD. We performed nonparametric analyses, because normality or equality of variance was rejected by the Kolmogorov-Smirnov test or the Levene test for most of the parameters or analyses; a comparison between two groups was performed using the Mann-Whitney U test and correlations were determined using the Spearman correlation test. The independent effects of the glycerol-LysoPLs and the total ATX level on LysoPA were evaluated using a stepwise multiple regression analysis. A value of P < 0.05 was regarded as denoting statistical significance in all the analyses.

RESULTS

Elevated LysoPS and LysoPG levels and lower LysoPA levels in ascites from patients with gastric cancer compared with those in ascites from patients with cirrhosis after adjustments according to the albumin level

First, we measured the concentration of glycerol-LysoPLs in ascites collected from subjects with gastric cancer and cirrhosis (Fig. 1A–F). The concentrations of total LysoPC were 4.36 ± 8.59 μM in cirrhosis versus 7.18 ± 7.90 μM in cancer (P = 0.002); those of total LysoPS were 0.00773 ± 0.0109 μM in cirrhosis versus 0.128 ± 0.484 μM in cancer (P < 0.001); those of total LysoPI were 0.817 ± 1.49 μM in cirrhosis versus 2.10 ± 5.46 μM in cancer (P < 0.001); those of total LysoPE were 0.192 ± 0.383 μM in cirrhosis versus 0.263 ± 0.467 μM in cancer (P = 0.020); and those of LysoPG were 0.0277 ± 0.038 μM in cirrhosis versus 0.0626 ± 0.271 μM in cancer (P = 0.001). Accordingly, the concentrations of total LysoPC, LysoPS, LysoPI, LysoPE, and LysoPG were significantly higher in the ascites from the subjects with gastric cancer, while the concentration of LysoPA was not different between these groups.

Because the ascites from subjects with cancer are exudates, while the ascites caused by cirrhosis are transudates, we measured the concentrations of total protein (TP) and albumin (ALB). The concentrations of TP were 1.98 ± 2.51 g/dl in cirrhosis versus 3.57 ± 2.71 g/dl in cancer (P < 0.001), while those of ALB were 0.88 ± 1.12 g/dl in cirrhosis versus 1.94 ± 1.73 g/dl in cancer (P < 0.001), confirming...
ratios of LysoPS/ALB were 0.0097 ± 0.0107. Biological factors related to each disease were involved. The ratios or transudates) or whether the differences simply reflected the concentration of ALB to investigate whether the differences simply reflected the concentration of TP and ALB were higher in the ascites caused by cirrhosis [4.17 ± 2.88 M/g/dl in cancer vs. 2.37 ± 3.97 M/g/dl in cancer ($P < 0.001$)] (Fig. 1G–I, supplemental Figure S1). Of note, only the 18:0 and 18:1 species of LysoPS were detected in the ascites, while many other species were detected in the plasma samples (22). Regarding the LysoPE species, the levels of 16:0, 18:0, and 22:6 LysoPE were higher in the ascites from the gastric cancer group before adjustment, while the levels of 18:0 and 18:2 LysoPE were lower in the gastric cancer group after adjustment according to the ALB level (supplemental Figs. S2D, S3D).

**Significantly higher concentrations of ATX in ascites from patients with cirrhosis than in ascites from patients with gastric cancer**

Because we observed different levels of LysoPA in ascites from patients with cirrhosis and in ascites from patients with gastric cancer, we measured the concentrations of ATX (a LysoPA-producing enzyme). As shown in Fig. 3A, B, the total ATX and classical ATX levels were marginally, but significantly, higher in ascites from patients with cirrhosis and, when adjusted according to the ALB level, the total ATX, classical ATX, and novel ATX levels were all considerably higher in the ascites from patients with cirrhosis compared with the levels in ascites from patients with gastric cancer.

**LysoPA levels were significantly and positively correlated with the ATX levels in ascites from patients with cirrhosis and in ascites from patients with gastric cancer**

Because the plasma LysoPA levels are strongly correlated with the ATX levels in healthy subjects (26), subjects with chronic liver diseases (27), and subjects with follicular lymphoma (11), we next investigated the correlation between the LysoPA and ATX levels. As shown in Fig. 4A–F, significant strong correlations were observed between the total LysoPA levels and the total ATX ($r = 0.728, P < 0.001$) and moderate correlations were observed between the total LysoPA and classical ATX or novel ATX levels ($r = 0.664, P < 0.001$ and $r = 0.555, P = 0.009$, respectively) in ascites from patients with cirrhosis, while only weak to moderate correlations were observed in ascites from patients with cancer. We did not find any specific correlation between the LysoPA molecular species and the total ATX levels, as shown in supplemental Table S1.
LysoPA levels were significantly correlated with the levels of possible precursor glycerol-LysoPLs in ascites from patients with cirrhosis and in ascites from patients with gastric cancer

When we previously investigated the sources of elevated plasma LysoPA levels in subjects with acute coronary syndrome, the levels of LysoPA precursors appeared to determine the plasma LysoPA levels (22). Therefore, we next investigated the correlations between LysoPA and its possible precursors, LysoPC, LysoPI, LysoPE, LysoPG, and LysoPS. As shown in Fig. 5A–C and supplemental Fig. S4A, B, the total LysoPA level was strongly correlated with the levels of LysoPI and LysoPC (r = 0.932, P < 0.001 and r = 0.710, P < 0.001, respectively), moderately correlated with those of LysoPS and LysoPE (r = 0.595, P = 0.003 and r = 0.690, P < 0.001, respectively), and uncorrelated with those of LysoPG (r = 0.396, P = 0.061) in ascites from patients with cirrhosis, while the total LysoPA level was moderately correlated with the LysoPC, LysoPI, and LysoPE levels (r = 0.445, P = 0.002; r = 0.611, P < 0.001; and r = 0.488, P < 0.001; respectively) and, interestingly, negatively correlated with the LysoPS level in ascites from patients with cirrhosis (Fig. 5D–F; supplemental Fig. S4C, D). Regarding the correlations between the LysoPA species and the corresponding glycerol-LysoPL species, we observed similar correlations (Fig. 5G–L; supplemental Tables S2, S3), suggesting that glycerol-LysoPLs, especially LysoPC, LysoPI, and LysoPE, might serve as precursors for LysoPA in the ascites.

Possible difference in determinants for LysoPA between ascites from patients with cirrhosis and ascites from patients with gastric cancer

Although the correlations between LysoPA and ATX or its possible precursor glycerol-LysoPLs showed almost the same tendency, except for LysoPS, the strength of the correlations between the LysoPA and ATX levels seemed to differ between the two groups. Therefore, we next performed multiple regression analyses using the LysoPA level as the objective variable and the levels of total ATX and glycerol-LysoPLs other than LysoPA as possible explanatory variables. As shown in Tables 1, 2, ATX was selected as a significant explanatory factor for all the LysoPA species in the cirrhosis group, but only for 18:2 LysoPA in the gastric cancer group. The glycerol-LysoPLs selected as significant explanatory factors also differed somewhat: the LysoPI species was selected for 16:0, 18:1, and 20:4 LysoPA in the cirrhosis group, while it was selected only for 20:4 LysoPA in the gastric cancer group. In contrast, the LysoPC species was selected as a significant explanatory factor for 16:0, 18:2, 20:4, and 22:6 LysoPA in the gastric cancer group, but only for 18:2 and 22:6 LysoPA in the cirrhosis group.

LysoPS levels were significantly and positively correlated with the PS-PLA levels only in ascites from patients with gastric cancer

In addition to the possible difference in the determinants for LysoPA, we have also observed that the levels of
Glycero-LysoPLs, represented by LysoPA, are reportedly involved in the pathogenesis of neoplasms: LysoPA has been suggested to accelerate tumor proliferation, migration, invasion, and metastasis (3–6). In addition to LysoPA, other glycero-LysoPLs are emerging as potent lipid mediators, based especially on the findings of basic research, and several receptors for some glycero-LysoPLs have recently been identified (15). Considering the physiological properties of these glycero-LysoPLs, they might be involved in the pathogenesis of cancer as well as LysoPA. Clinical research, however, has provided little evidence of the involvement of glycero-LysoPLs in oncology, even for LysoPA. Therefore, in the present study, we measured the levels of glycero-LysoPLs (LysoPA, LysoPC, LysoPL, LysoPE, LysoPG, and LysoPS) together with ATX and PS-PLA1 (producing enzymes for LysoPA and LysoPS, respectively) in ascites from subjects with advanced gastric cancers. We also collected ascites from subjects with cirrhosis as a control.

In this study, we found several possible differences in LysoPA determinants between ascites from patients with cirrhosis and ascites from patients with gastric cancer. Because the correlations between the LysoPA species and ATX seemed weaker (Fig. 4) and ATX was not selected as a significant explanatory factor for most of the LysoPA species using multiple regression analyses for the subjects with gastric cancer (Table 1), the LysoPA levels might not be determined by ATX in ascites from patients with gastric cancer, at least to a great degree. Instead, possible substrates for ATX, especially LysoPC and LysoPS, were selected as significant positive explanatory factors, suggesting that these substrates might determine LysoPA production in patients with gastric cancer. Although the physiological roles of this possible homeostasis of LysoPA in gastric cancer have remained unknown, several cancers reportedly exhibit increases in phosphatidylinositol, phosphatidylethanolamine, and phosphatidylcholine (30–33), as well as phospholipase A2 (34–38), which creates LysoPLs from diacylphospholipids. Considering these reports together with the results from the present study, we can hypothesize that the increased levels of diacylphospholipids might be converted to glycero-LysoPLs (other than LysoPA), which are then hydrolyzed into LysoPLs via ATX, promoting the spread of cancer. This possible producing pathway for LysoPA could be a pharmacological target for the treatment of cancer.

Besides LysoPA, we were also interested in the LysoPS levels in gastric cancer, because LysoPS is a novel lipid mediator for which receptors have recently been identified (28). As shown in Fig. 1C, H, the LysoPS level was higher in the gastric cancer group, even after adjustments to the ALB (Fig. 6A, B).

When we investigated the correlation between LysoPS and PS-PLA1, however, we found that the total LysoPS and 18:0 LysoPS levels were weakly, but significantly and positively, correlated with the PS-PLA1 level only in the ascites from the subjects with gastric cancer ($r = 0.331, P = 0.022$ and $r = 0.356, P = 0.013$, respectively) (Fig. 6C–F, supplemental Fig. S5), suggesting that the homeostasis of LysoPS might differ between patients with gastric cancer and those with cirrhosis.

**DISCUSSION**

Glycero-LysoPLs, represented by LysoPA, are reportedly involved in the pathogenesis of neoplasms: LysoPA has been suggested to accelerate tumor proliferation, migration, invasion, and metastasis (3–6). In addition to LysoPA, other glycero-LysoPLs are emerging as potent lipid mediators, based especially on the findings of basic research, and several receptors for some glycero-LysoPLs have recently been identified (15). Considering the physiological properties of these glycero-LysoPLs, they might be involved in the pathogenesis of cancer as well as LysoPA. Clinical research, however, has provided little evidence of the involvement of glycero-LysoPLs in oncology, even for LysoPA. Therefore, in the present study, we measured the levels of glycero-LysoPLs (LysoPA, LysoPC, LysoPL, LysoPE, LysoPG, and LysoPS) together with ATX and PS-PLA1 (producing enzymes for LysoPA and LysoPS, respectively) in ascites from subjects with advanced gastric cancers. We also collected ascites from subjects with cirrhosis as a control.

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might be involved in the immunological escape that is observed in cancers; when several cancer cells undergo apoptosis, PS is flipped outside the cell membrane and is converted into LysoPS by PS-PLA₂, possibly suppressing immunological attacks to other living cancer cells in tumor tissues. Further studies are needed to investigate the hypotheses suggested by the present findings.

An important issue that remains to be solved is the correlation between 18:0- and 18:1-containing LysoPS and PS-PLA₁. Basically, saturated and unsaturated fatty acids attach to the sn-1 and sn-2 positions of glycerophospholipids, respectively. Accordingly, the deacylation of the sn-1 position of PS by PS-PLA₁ theoretically results in the formation of 1-lyso, 2-acyl LysoPS, i.e., unsaturated LysoPS (rather than

Fig. 4. Correlation between the LysoPA and ATX levels in ascites from patients with cirrhosis or gastric cancer. The correlations between the total LysoPA level and the total ATX (A, D), classical ATX (B, E), and novel ATX (C, F) levels in ascites from patients with cirrhosis (A–C) or from patients with gastric cancer (D–F) are shown.

Fig. 5. Correlation between the LysoPA level and other glycerol-LysoPL levels in ascites from patients with cirrhosis or gastric cancer. The correlations between the total LysoPA level (A–F) or the 16:0 LysoPA level (G–L) and the total LysoPi (A, D), total LysoPC (B, E), total LysoPS (C, F), total ATX (G, J), 16:0 LysoPC (H, K), or 16:0 LysoPi (I, L) level in ascites from patients with cirrhosis (A–C, G–I) or from patients with gastric cancer (D–F, J–L) are shown.
the saturated form) (29), which seems to be inconsistent with our present finding that the PS-PLA1 level is also correlated with the saturated LysoPS level. The composition of fatty acids, however, varies depending on the tissue or cell type (46), and an analysis of the fatty acid composition of phosphatidylcholine in lipids extracted from the membrane fractions of mouse tissues reveals their diversity. For example, 16:0- and 22:6-containing phosphatidylcholine are predominant in the heart, while 16:0- and 16:0-containing phosphatidylcholine are predominant in the lungs and undergo further alteration under pathological conditions (47). Given that 18:0- and 18:1-containing PS may be the main fatty acids in gastric cancer cells infiltrating the peritoneum, PS-PLA1 and/or unidentified novel phospholipase A2, which deacetylates the sn-2 position of PS, might be involved in the formation of 18:0 or 18:1 LysoPS. This finding is also consistent with the fact that 16:0 LysoPA was predominant in the ascites, which is not the case with the pattern of LysoPA species in human plasma. Further studies are needed to elucidate the mechanism by which LysoPS is formed in ascites resulting from the invasion of gastric cancer.

Regarding glycero-LysoPLs other than LysoPA and LysoPS, we observed that the LysoPI and LysoPG levels were more than twice as high as those in the gastric cancer group and that the LysoPG level remained higher even after adjustment according to the ALB level. In addition to its possible role as a precursor of LysoPA, LysoPI might possess direct roles in the pathogenesis of cancers, because GPR55 has been identified as a specific GPCR for LysoPI (48, 49) and LysoPG is also reportedly involved in inflammation (50). Therefore, the results from the present study further suggest the need to investigate the pathological roles of LysoPI and LysoPG in the fields of oncology.

### Table 1

<table>
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<tr>
<th>Species</th>
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<th>95% CI</th>
<th>Standardized β</th>
<th>P</th>
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<td>Total LysoPA</td>
<td>0.039</td>
<td>0.019–0.060</td>
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<tr>
<td>16:0 LysoPC</td>
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<td>0.019</td>
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<td>18:1 LysoPA</td>
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<td>−6.187 to −1.778</td>
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<td>0.271</td>
<td>0.174–0.367</td>
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Multiple regression analyses for total LysoPA and LysoPA species in ascites from patients with gastric cancer. The glycero-LysoPLs of the corresponding molecular species and ATX were utilized as possible explanatory factors. B represents the unstandardized coefficients.

### Table 2

<table>
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<td>3.765</td>
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<td>ATX</td>
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<td>Total LysoPS</td>
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<td>ATX</td>
<td>0.440</td>
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<td>16:0 LysoPC</td>
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<td>1.925</td>
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<td>0.224</td>
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<td>20:4 LysoPA</td>
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<tr>
<td>ATX</td>
<td>0.168</td>
<td>0.087–0.248</td>
<td>0.381</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>20:4 LysoPC</td>
<td>−0.083</td>
<td>−0.161 to −0.006</td>
<td>−0.195</td>
<td>0.037</td>
</tr>
<tr>
<td>22:6 LysoPA</td>
<td>0.274</td>
<td>0.232–0.316</td>
<td>0.913</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ATX</td>
<td>0.036</td>
<td>0.006–0.067</td>
<td>0.168</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Multiple regression analyses for total LysoPA and LysoPA species in ascites from patients with cirrhosis. The glycero-LysoPLs of the corresponding molecular species and ATX were utilized as possible explanatory factors. B represents the unstandardized coefficients.
level was measured in the samples as described in Fig. 1 and the corre-
samples, of which the concentrations of glycero-LysoPLs, 
pared with patients with cirrhosis. We also admit that several 
could indicate that the LysoPA and ATX levels were very 
the pathogenesis of gastric cancer. Instead, the finding 
necessarily mean that the LysoPA might not be involved in 
thing that the LysoPA level after adjustment according to the 
should be carefully interpreted when comparing the con-
metals Figs. S4C, D, S5A; three samples for Figs. 5F, L, 6F; 
3SDs, exist in several figures and might somehow affect the 
ascites from patients with cirrhosis or gastric cancer. The PS-PLA 1 
cancer (E, F) are shown.

The main limitation of this study is that we used ascites 
collected from patients with cirrhosis as a control, because 
it is impossible to collect control ascites from healthy sub-
jects. Considering that the LysoPA and ATX levels are 
known to be elevated in cirrhosis (51), the present results 
should be carefully interpreted when comparing the con-
centrations between the two groups; for example, the find-
ing that the LysoPA level after adjustment according to the 
ALB level was lower in the gastric cancer group does not 
neccessarily mean that the LysoPA might not be involved in 
the pathogenesis of gastric cancer. Instead, the finding 
could indicate that the LysoPA and ATX levels were very 
high in ascites from patients with cirrhosis. Regardless, we 
can safely conclude that patients with gastric cancer might 
possess a distinct glycerol-LysoPL homeostasis profile, 
compared with patients with cirrhosis. We also admit that several 
samples, of which the concentrations of glycerol-LysoPLs, 
ATX, or PSPLA1 were deviated from the range of the mean ± 
3SDs, exist in several figures and might somehow affect the 
appearance of the correlations: one sample for Figs. 4E, F, 
5C, E, K, 6C; two samples for Figs. 4D, 5D, J, 6D and supple-
mental Figs. S4C, D, S5A; three samples for Figs. 5F, L, 6F; 
and four samples for Fig. 6E and supplemental Fig. S5B. To 
avoid the possible influences of these deviated points on 
the statistical analyses, we have adopted the nonparametric 
analyses, as shown in the Methods section, and confirmed 
the similar correlations when these deviated samples are 
excluded (data not shown).

In summary, in ascites from patients with gastric cancer, the 
LysoPA levels might be determined largely by its pre-
cursors, such as LysoPC and LysoPI, and LysoPS might be 
produced via a PS-PLA1-mediated pathway to a greater de-
gree than in ascites from patients with cirrhosis. These re-
results suggest the possible involvement of glycerol-LysoPLs in 
the pathogenesis of gastric cancer. AR

REFERENCES

glycerol-based lysophospholipids: new data–new insight into their 
Emerging lysophospholipid mediators, lysophosphatidylserine, ly-
sophosphatidylthreonine, lysophosphatidylethanolamine, and lys-
ophosphatidylglycerol. Prostaglandins Other Lipid Mediat. 89: 
135–139.
5. Leblanc, R., and O. Peyruchaud. 2015. New insights into the auto-
333: 183–189.
taxin-lysophosphatidate axis in cancer resistance to chemotherapy 
7. Furui, T., R. Lafushin, M. Mao, H. Khan, S. R. Watt, M. A. Watt, Y. 
edg-2/zvg-1 induces apoptosis and anoikis in ovarian cancer cells 
in a lysophosphatic acid-independent manner. Clin. Cancer Res. 5: 
4308–4318.
Watanabe, Y. Takaku, and H. Nagawa. 2003. Lysophosphatidic acid 
(LPA) enhances the metastatic potential of human colon carcino-
receptor-2 in human invasive ductal carcinoma. Breast Cancer 
Res. 6: R460–R466.
Expression and transcriptional regulation of the PD-1/Ilp3/autol-
Serum autotaxin measurement in haematological malignancies: 
a promising marker for follicular lymphoma. Br. J. Haematol. 143: 
60–70.
12. Stracke, M. L., H. C. Kruytzsch, E. J. Unsworth, A. Arestad, V. Cioce, 
E. Schiuffmann, and L. A. Liotta. 1992. Identification, purification, 
and partial sequence analysis of autotaxin, a novel myotilation-stimu-
Min, J. W. Han, H. W. Lee, and H. Y. Lee. 2002. Expression of auto-
taxin (NPP-2) is closely linked to invasiveness of breast cancer cells. 
14. Aoki, J., A. Taira, Y. Takanezawa, Y. Kishi, K. Hama, T. Kishimoto, 
K. Mizuno, K. Saku, R. Taguchi, and H. Arai. 2002. Serum lysophos-
phatidic acid is produced through diverse phospholipase pathways. 
15. Makide, K., A. Uwamizu, Y. Shinjo, J. Ishiguro, M. Okutani, A. 
Inoue, and J. Aoki. 2014. Novel lysophospholipid receptors: their 
16. Falasca, M., and R. Ferro. 2016. Role of the lysophosphatidylinosi-
Yun, D. S. Im, and Y. S. Bae. 2007. Lysophosphatidylethanolamine 
stimulates chemotactic migration and cellular invasion in SK-OV3
Glycero-lysophospholipids in gastric cancer


