*Revised manuscript DMRR-18-RES-195R1 (research article)*

**Omentin-regulated proteins combine a pro-inflammatory phenotype with an anti-inflammatory counterregulation in human adipocytes: a proteomics analysis**

**Running title:** Omentin and inflammation

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Word count (abstract): 250

Word count (main body): 3999

References: 60

Tables/figures: 4 (+ 2 Suppl.)

**Abstract**

**Aims**

Experimental and epidemiological studies reported controversial data on the role of omentin in type 2 diabetes and cardiovascular diseases. This study aimed to characterise the impact of omentin on the secretome of human adipocytes to analyse the enrichment of these proteins in metabolic and cellular signalling pathways underlying its physiological function.

**Material/methods**

Differentiated primary human adipocytes were treated without or with 500 or 2000 ng/ml omentin for 24h. The secretome was analysed by liquid chromatography coupled tandem-mass spectrometry (LC-MS/MS). Differences in protein secretion between untreated and omentin-treated adipocytes were compared using a paired t-test. Other potential upstream regulators and the overrepresentation in canonical pathways of omentin-stimulated proteins were analysed using Ingenuity Pathway Analysis.

**Results**

The supernatant of adipocytes contained 3493 proteins, of which 140 were differentially secreted by both concentrations of omentin compared to untreated adipocytes. Among the most strongly increased proteins, TNFAIP6 was increased by 140-fold in the supernatant. Omentin-regulated proteins were overrepresented in seven canonical pathways including EIF2 signalling, complement system and inhibition of matrix metalloproteases. We further identified 25 other potential upstream activators of omentin-regulated proteins, mainly pro-inflammatory cytokines and transcription regulators including NFκB.

**Conclusions**

In differentiated human adipocytes, the release of the anti-inflammatory TNFAIP6 might be part of a counterregulatory response to the pro-inflammatory action of omentin. Omentin-regulated proteins were overrepresented in pathways indicating cellular stress, a pro-inflammatory environment and a crosstalk with other organs. Other potential activators of omentin-regulated proteins point towards a central role of NFκB activation in the omentin-induced secretory process.

**Introduction**

Omentin is predominantly secreted by the stromal vascular fraction of visceral adipose tissue.1 Currently available studies controversially discuss whether omentin exerts a protective or detrimental role in type 2 diabetes (T2D) and cardiovascular diseases (CVD).

Cross-sectional studies found decreased circulating levels of omentin in obese compared to lean individuals and lower omentin levels in patients with T2D compared to glucose tolerant people.2,3 In a cross-sectional analysis of the Cooperative Health Research in the Region of Augsburg (KORA) F4 study, we observed that omentin did not differ between individuals ranging from normal glucose tolerance to T2D.4 However, higher circulating omentin was inversely associated with multiple risk factors for T2D and CVD.2-5 These findings were supported by in vitro studies showing that omentin increased Akt phosphorylation and insulin-stimulated glucose uptake in human adipocytes.1

With respect to CVD, circulating omentin was decreased in patients with coronary artery disease6,7 and appeared to have a protective role in patients with ischaemic stroke.8,9 In line, administration of omentin in mice reduced tissue damage after ischaemia/reperfusion10 and delayed the development of aortic atherosclerotic lesions with reduced vascular inflammation.11

In contrast with the findings from cross-sectional and experimental studies, the prospective analysis within the KORA F4/FF4 cohort indicated that higher circulating omentin is associated with a higher risk of T2D.12 This is in line with a prospective analysis within the European Prospective Investigation into Cancer and Nutrition (EPIC)-Potsdam study demonstrating an increased omentin-related diabetes risk among people with high adiponectin levels.13 In the same cohort, circulating omentin was associated with an increased risk of stroke14, and another prospective study reported high circulating omentin levels as predictor of cardiovascular events.15

Data on the inflammatory properties of omentin are limited to very few biomarkers. Circulating omentin associated inversely with interleukin-6 (IL-6)3,16, tumour necrosis factor (TNF)α,3 and C-reactive protein (CRP),5,13,16 and positively with adiponectin.2,4,13 On the cellular level, omentin reduced TNFα-induced inflammation in human endothelial cells and murine smooth muscle cells by inhibiting several kinases and transcription factors of inflammatory pathways.17,18

Taken together, the mechanism by which omentin affects metabolic and inflammatory processes in cardiometabolic diseases is incompletely understood. Therefore, the aims of the study were (i) to investigate the impact of omentin on the secretome of proteins in differentiated human adipocytes, (ii) to analyse the overrepresentation of the omentin-regulated proteins in well-characterised metabolic and cell signalling pathways, and (iii) to identify other potential upstream activators of omentin-regulated proteins.

**Material and methods**

*Cultivation and treatment of human adipocytes*

Primary human preadipocytes isolated from subcutaneous adipose tissue from five donors without diabetes were purchased from PromoCell (Heidelberg, Germany) and Lonza (Basel, Switzerland).19 Approval by an ethics committee was not required. Human preadipocytes were cultured in preadipocyte growth medium (PromoCell) containing 0.05 ml/ml fetal calf serum (FCS), 0.004 mg/ml endothelial cell growth supplement, 10 ng/ml epidermal growth factor, 1 µg/ml hydrocortisone and 90 µg/ml heparin until 100% confluency. Then, preadipocytes were differentiated in preadipocyte differentiation medium (PromoCell) containing 8 µg/ml D-biotin, 0.5 µg/ml insulin, 400 ng/ml dexamethasone, 44 µg/ml 3-isobutyl-1-methylxanthine (IBMX), 9 ng/ml L-thyroxine and 3 µg/ml ciglitazone. After 3 days, differentiation medium was replaced by adipocyte nutrition medium (PromoCell) containing 0.03 ml/ml FCS, 8 µg/ml D-biotin, 0.5 µg/ml insulin and 400 ng/ml dexamethasone. The adipocytes were differentiated for further 11 days. At day 14 of differentiation, adipocytes were cultivated in adipocyte nutrition medium without insulin and FCS for 4h and then treated with 500 or 2000 ng/ml omentin for 24h with untreated cells as controls. After this incubation time, adipocyte supernatant was collected and centrifuged for 10 min. at 1800 x g at 4°C. Then 800 µl were transferred in a new tube and stored at -80°C until the proteomics analysis. The aforementioned omentin concentrations were selected based on our analysis of serum samples from the KORA F4 study.12 The concentration of 500 ng/ml is close to the median level in a non-diabetic population, whereas 2000 ng/ml is close to the highest levels found in this population, but most likely closer to local levels found in adipose tissue.

*Quantitative mass spectrometry in data-independent acquisition mode*

600 µl of each supernatant were proteolysed with a modified filter aided sample preparation (FASP) procedure.20,21 Eluted peptides were supplied with indexed retention time (iRT) hyper reaction monitoring (HRM) calibration peptides (BIOGNOSYS, Schlieren, Switzerland)22 for retention time alignment and then analysed in a randomised order on a QExactive high-frequency (HF) mass spectrometer (MS) (Thermo Fisher Scientific, Waltham, MA, USA) coupled online to an UltiMate 3000 nano-RSLC (Dionex, Sunnyvale, CA, USA) equipped with a customised 20cm M-Class column (Waters, Milford, MA, USA) using a non-linear 5-40% acetonitrile gradient in a 130-min. run. Spectra were recorded in data-independent acquisition mode23-25 with the following parameters: MS spectra from 300 to 1650 m/z were recorded at 120000 resolution with an automatic gain control (AGC) target of 3e6 and a maximum injection time of 120 ms. Data-independent acquisition windows were selected based on previous data-dependent acquisition runs, with a scan resolution of 30000, an AGC target of 3e6 and a collision energy of 28. The recorded raw-files were analysed using the Spectronaut 10.0 software (BIOGNOSYS)26 with an in-house human database spectral library which was generated using Proteome Discoverer 2.1, Mascot search engine (Matrix Science, London, UK) and the Swissprot Mouse database (release 2016\_02). Quantification was based on cumulative MS2 area levels with the q-value percentile 0.25 setting.

*Statistical and pathway analysis*

Differences in protein secretion between omentin-treated and untreated differentiated human adipocytes were assessed using the paired t-test on the log2 transformed intensities. For further analyses, we used the dataset containing proteins that were differentially regulated by both 500 and 2000 ng/ml omentin treatment compared to untreated differentiated human adipocytes. Very small absolute quantification values < 100 were excluded because of the risk of measuring inaccuracy. We excluded proteins (i) whose concentrations differed by a coefficient of variation of more than 100% between donors of preadipocytes and (ii) those with different expression directions between low and high omentin concentrations. Statistical analyses were carried out with R version 3.3.3 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria) and Python version 3.6.1 (Python Software Foundation, https://www.python.org/). Statistical significance was inferred at a 2-tailed p-value <0.05.

Furthermore, we analysed the overrepresentation of proteins in canonical pathways using Ingenuity Pathway Analysis (IPA) (Qiagen, Hilden, Germany). This tool identifies pathways from the IPA library of canonical pathways that showed significant enrichment of the omentin-regulated proteins. This method enables to deduce potential physiological roles of omentin in differentiated human adipocytes from the secretome. Fisher´s exact test was used to calculate the probability that the association between the proteins in the dataset and the canonical pathways were explained by chance alone. The Benjamini-Hochberg method was used to correct for multiple testing (B-H p-value). In addition, we analysed other potential upstream activators of the omentin-regulated proteins. Based on the characteristics of other potential upstream activators, the potential secretory mechanism for omentin-regulated proteins can be inferred from the proteins in the adipocyte supernatant. Again, Fisher´s exact test was used to assess the probability that potential activators assigned to the dataset was due to chance alone. The activation z-score aims to infer the activation states of predicted upstream regulators. A z-score above 2 points towards the activation of potential upstream regulators; a z-score below -2 indicates the inhibition of potential upstream regulators. For all analyses in IPA, we used fold changes of omentin-regulated proteins that referred to 2000 ng/ml omentin. Data on the localisation of omentin-regulated proteins are based on the IPA library. The algorithms developed for use in IPA are described elsewhere.27

**Results**

The supernatant of omentin-treated and untreated differentiated human adipocytes contained 3493 proteins. Of these proteins, 275 proteins were regulated by 500 ng/ml omentin and 317 proteins by 2000 ng/ml omentin. There was an overlap of 140 proteins between both omentin concentrations, which are listed in Suppl. Table 1. These proteins are localised either in the cytoplasm, extracellular space, plasma membrane or nucleus (Suppl. Table 1). Suppl. Figure 1 depicts the dose-dependent effect of omentin on the secretion of these 140 proteins.

**Impact of omentin on protein secretion**

Table 1 shows the top 20 of the most upregulated and the top 20 of the most downregulated proteins by omentin (see Suppl. Table 1 for the full list of up- and downregulated proteins). Tumor necrosis factor-inducible gene 6 protein (TNFAIP6) was the by far most regulated protein in this dataset. TNFAIP6 was upregulated 57-fold by 500 ng/ml omentin (p=4.76x103) (data not shown) and 140-fold by 2000 ng/ml omentin (p=4.43x10-3) compared to untreated differentiated human adipocytes. Six other proteins were upregulated by more than 4-fold (4- to 24-fold, p-values between 2.89x10-4 and 4.6x10-2)by 500 ng/ml omentin and more than 10-fold (12- to 89-fold, p-values between 1.49x10-3 and 3.03x10-2) by 2000 ng/ml omentin: C-X-C motif chemokine 5 (CXCL5), complement factor B (CFB), cathepsin S (CTSS), secreted frizzled-related protein 4 (SFRP4), LIM and senescent cell antigen-like-containing domain protein 1 (LIMS1) and Lys-63-specific deubiquitinase BRCC36 (BRCC3). The remaining 13 proteins were upregulated by less than 10-fold by both omentin concentrations compared to control. In total, 18 out of the 20 proteins upregulated by 2000 ng/ml omentin (Table 1) were also among the top 20 upregulated proteins when treating adipocytes with 500 ng/ml omentin (exceptions: NEDD8 ultimate buster 1 (NUB1) and intercellular adhesion molecule 1 (ICAM1)).

The degree of downregulation of proteins was less pronounced for both omentin concentrations than the degree of upregulation described above. Overall, the expression of the top 20 downregulated proteins was reduced by 1.3- to 2.6-fold (p-values between 5.54x10-4 and4.91x10-2). Thirteen of these proteins were also in the top 20 of downregulated proteins in adipocytes treated with 500 ng/ml omentin (data not shown).

**Canonical pathways**

Omentin-regulated proteins were overrepresented in seven canonical pathways (B-H p<0.05). By far the strongest association was observed for Eukaryotic Initiation Factor (EIF)2 Signaling (p=2.77x10-15). Other pathways included Complement System, Inhibition of Matrix Metalloproteases, Acute Phase Response Signaling, Regulation of eIF4 and the 70 kDa ribosomal S6 kinase (p70S6K) Signaling, Hepatic Fibrosis/Hepatic Stellate Cell Activation, and Protein Ubiquitination Pathway (p-values between 3.92x10-4 and 4.87x10-2) (Table 2).

**Potential upstream regulators**

Using the IPA analysis software, we identified 25 potential upstream activators of the omentin-regulated proteins. Most of these activators were pro-inflammatory cytokines (IL1B, TNF, IFNG, IL1A, MIF, CXCL8, IL6, OSM, IL17A and SPP1). The second biggest group consisted of transcription regulators (STAT1 and 3, SMARCA4, SP1 and ETS1). Other groups were growth factors (TGFB1), transmembrane immune receptors (TLR3 and 4) and enzymes (PTGS2 and NOS2), protein complexes (NFκB and Cg) and kinases (IKBKB and MAPK8) (Table 3).

**Discussion**

The main findings of this study were (i) that the most strongly regulated secreted protein upon omentin treatment of differentiated human adipocytes supernatant was the anti-inflammatory protein TNFAIP6, (ii) that omentin-regulated proteins were overrepresented in pathways which might promote cellular stress, a pro-inflammatory environment and a crosstalk with other organs, and (iii) that the pro-inflammatory phenotype of other potential upstream activators might point to the induction of inflammatory pathways, predominantly of NFκB, for the omentin-induced secretory process.

*Anti-inflammatory TNFAIP-6 as most regulated protein upon omentin treatment*

TNFAIP6 is only produced upon exposure to inflammatory factors and has been described as protein with anti-inflammatory and tissue-protective properties.28 It acts as an endogenous inhibitor of inflammatory processes and represents a component of a negative feedback loop.28 Interestingly, one anti-inflammatory action of TNFAIP6 is the regulation of chemokine function.28 TNFAIP6 binds to multiple chemokines and interacts with them through their glycosaminoglycan (GAG)-binding site, which leads to the inhibition of their binding to GAGs and endothelial cell surfaces.28 In this comprehensive proteomics study, the chemokine CXCL5 was the second most upregulated protein in the supernatant of omentin-treated adipocytes. We hypothesise that TNFAIP6 might counterregulate the pro-inflammatory action of omentin in the acute setting by neutralising the potentially detrimental effects of chemokines such as CXCL5 secreted in response to omentin exposure on other cells such as adipocytes and endothelial cells. Such counterregulation would be in line with findings from cross-sectional studies showing an inverse association between omentin and cardiometabolic risk factors. The contrasting data from prospective studies linking omentin to higher cardiometabolic risk during follow-up would be consistent with persistently elevated omentin and loss or attenuation of this endogenous negative feedback loop.

In addition, our study revealed pentraxin-related protein (PTX3) as further binding partner of TNFAIP6, which was upregulated by omentin. PTX3, TNFAIP6 and hyaluronic acid (HA) are able to build multimolecular PTX3/TNFAIP6/HA complexes.29 PTX3 belongs to the pentraxin family of acute-phase proteins and is expressed after exposure to inflammatory signals such as interleukin (IL)-1 and TNFα.30 Moreover, PTX3 is associated with endothelial function and cardiovascular events.31

Taken together, our study identified TNFAIP6 and two potential binding partners (CXCL5 and PTX3) as upregulated proteins upon acute omentin treatment. These proteins represent novel candidates for further studies that might reinforce or attenuate omentin activity as separate proteins or bound to TNFAIP6 and thereby affect cardiometabolic risk.

*Omentin-regulated proteins associated with inflammation, T2D and comorbidities*

It is noteworthy that further proteins that are among the most omentin-regulated proteins in adipocyte supernatant have been implicated in the pathogenesis of T2D. One protein is the adipokine SFRP4 which belongs to the Sfrp family; the largest family of wingless (Wnt) inhibitors.32 Higher levels of SFRP4 were associated with a higher risk of T2D and associated with higher fasting glucose, and lower insulin sensitivity index and disposition index.33

CTSS is another protein which has been upregulated by omentin. This protein has been reported to be higher in diabetic rats compared to healthy ones and correlated with blood glucose levels.34 In addition, CTSS is upregulated in adipose tissue from obese patients and its inhibition led to a decrease of lipid content and adipocyte marker expression34 indicating that it might affect both glucose metabolism and adipocyte function.

Two other proteins are known to be involved in endothelial dysfunction: intercellular adhesion molecule 1 (ICAM-1) and vascular cell adhesion protein 1 (VCAM-1) belong to the Ig superfamily of cell membrane proteins.35 The release of the soluble form of ICAM-1 (sICAM-1) and VCAM-1 (sVCAM-1) is related to inflammatory and infectious diseases.35 Higher levels of both proteins are associated with increased risk for cardiovascular events.36 Interestingly, we found that sICAM-1 and sVCAM-1 are also released by adipocytes in response to omentin. Although it is not known why adipocytes produce the soluble forms of these proteins and if they represent mere risk markers of CVD or rather contribute to its development, it should be noted that this finding agrees with the aforementioned positive association between omentin and cardiovascular risk in prospective studies.

LIMS1 has been described to be upregulated by the pro-inflammatory TNFα.37 We found that also omentin is able to upregulate LIMS1 in adipocytes. One important role of LIMS1 is the regulation of the function of renal tubules37 suggesting a potential omentin-mediated crosstalk with kidneys and diabetes-associated nephropathy.

With respect to potential omentin-induced signalling pathways, we identified an omentin-stimulated upregulation of the NFκB activating protein (NKAP), which activates NFκB. It has been proposed that NKAP mediates TNF- and IL-1-induced NFκB activation.38 Our data show that NKAP is also released into the supernatant of omentin-treated adipocytes. Again, we can exclude that NKAP is released because of cell death as we performed cell viability tests that did not indicate any differences between untreated and omentin-treated adipocytes (data not shown).

Activated NFκB signalling is associated with the action of the inflammasome. Interestingly, BRCC3, which also belongs to the strongest upregulated proteins, has been identified as deubiquitinating enzyme of NLR Family Pyrin Domain Containing 3 (NLRP3) and thereby regulates the activity of the inflammasome.39 This in turn supports the pro-inflammatory action of omentin.

*Omentin-regulated proteins associated with general cellular functions*

Most of the top 20 of the most-downregulated proteins by omentin also play a role in the regulation of cellular processes. Several proteins are involved in protein synthesis such as the eukaryotic translation initiation factor 3 subunit D (EIF3D) and the eIF2 alpha kinase activator homolog GCN1.40,41 In obesity, stress kinases are able to inhibit the general protein synthesis and thereby affect endoplasmatic reticulum (ER) function, which in turn has a harmful impact on inflammation and metabolism.42 This finding indicates that omentin might cause cellular stress in differentiated human adipocytes.

The most interesting protein in this group was selenoprotein P (SEPP1) which has anti-oxidant activity. Secreted selenoprotein P is suggested to bind to proteoglycans on the vascular endothelial surface and thereby protects against oxidative damage.43 However, several studies reported a detrimental effect of selenoprotein P on insulin sensitivity.43,44 Nevertheless, this finding might be explained by a dysregulated carbohydrate metabolism in T2D because selenoprotein P is regulated by insulin and glucose levels.44 Further studies are necessary to evaluate the role of adipocyte-derived selenoprotein on adipocytes and/or other cell types relevant for cardiometabolic diseases.

*Omentin-regulated secretory proteins were overrepresented in pathways relevant for cellular stress, a pro-inflammatory environment, and crosstalk between organs*

Figure 1 shows a hypothetic model for the potential physiological role of omentin in differentiated human adipocytes which will be explained in detail in the following:

The *EIF2 Signalling* pathway was the most significant pathway across the omentin-regulated proteins. Nineteen out of 20 affected proteins are ribosomal proteins (RPs). Interestingly, apart from one protein all proteins were downregulated in our dataset indicating that the EIF2 signalling pathway is inhibited. In the pathway named *Regulation of eIF4 and p70S6K Signalling*, five out of six regulated proteins were also RPs mostly overlapping with those from the *EIF2 Signalling* pathway. The protein machinery can be downregulated by phosphorylation of EIF2 by various stress kinases which are activated by metabolic overload leading to inhibition of general protein synthesis and ER stress.42 This again indicates that omentin-treated adipocytes might suffer from cellular stress associated with reduced protein synthesis.

The pathways named *Complement System* and *Acute Phase Response Signalling* are additional canonical pathways in which omentin-regulated proteins are significantly overrepresented. The acute-phase response leads to a higher release of pro-inflammatory factors which are able to activate the complement system.45 Apart from immune defense, the complement system is also involved in metabolic and inflammatory processes in adipose tissue.46 The omentin-regulated complement components C3, CFB and CFH have pro-inflammatory properties and are associated with insulin resistance and T2D.46,47 Based on our data, we conclude that omentin directly induced the acute-phase response and components of the complement system which in turn might contribute to the observed pro-inflammatory condition in adipocytes and thus promote the development of insulin resistance and T2D.

The pathway designated *Inhibition of the Matrix Metalloproteases* contains matrix metalloproteases (MMPs), as the omentin-regulated MMP2, which are able to regulate the bioavailability and activity of chemokines.48 The tissue inhibitors of metalloproteases (TIMP) tightly control the synthesis and degradation of MMPs.49 The omentin-regulated TIMP1 is known as an adipocyte-secreted protein upregulated by pro-inflammatory cytokines such as IL-1β, IL-6 and TNFα mediated by NFκB.50,51 Our data suggest that omentin-regulated MMP2 might contribute to the pro-inflammatory environment and its regulator TIMP1 might be regulated by omentin through activation of NFκB in adipocytes.

Another inflammation-related canonical pathway is the *Protein Ubiquitination Pathway*. The ubiquitin-proteasome system is known as activator of NFκB because its activitiy depends on the ubiquination of IκB followed by proteasomal degradation.52 Therefore, these data again support the potential importance of NFκB in omentin action in adipocytes.

Our study also revealed *Hepatic Fibrosis/Hepatic Stellate Cell Activation* as pathway in which omentin-affected proteins are overrepresented. It is known that proteins that are released from adipocytes are also able to control hepatic inflammation and fibrosis.53 In our dataset, predominantly VCAM-1 and ICAM-1 as well as MMP2 and TIMP1 were upregulated by omentin and involved in this pathway. Serum levels of VCAM-1 and ICAM-1 are predictors of hepatic fibrosis and hepatocellular carcinoma risk, respectively.54,55 Interestingly, the transcriptional activation of TIMP-1 and MMP-2 is important for the pathogenesis of liver fibrosis.53 The potential link between these proteins and pathways should be investigated by omentin treatment of hepatocytes or co-culture experiments of adipose tissue and hepatocytes to characterise the potential role of omentin in the cross-talk between both tissues.

*Potential upstream regulators of omentin-regulated proteins are predominantly NFκB activators*

The in silico characterisation of potential upstream regulators of the omentin-regulated secretion pattern identified several molecular mechanisms by which omentin might regulate protein secretion and thereby affect the development of T2D and CVD in human studies. Most of the potential upstream activators of the proteins that are differentially regulated by omentin are pro-inflammatory cytokines. Interestingly, the most activated upstream cytokines IL-1β and TNFα regulate the activity of NFκB and all three classes of MAPK (JNK, ERK1/2 and p38 MAPK).56,57 The cytokine IFN-γ is known to activate the transcription factor signal transducer and activator of transcription (STAT) 1 via the receptor-associated Janus kinases JAK 1 and 2 leading to the regulation of alternative cytokine signaling pathways. In addition, IFN-γ is also described to activate ERK1/2 and has been implicated in the vascular proliferative responses in atherosclerosis.58 The cytokine IL-6 activates STAT3 through JAKs and thereby induces the transcription of target genes and regulates lipid and glucose metabolism as well as immune responses.59 The transmembrane receptors toll-like receptors (TLR)3 and 4 also regulate NFκB activity56, and Sp1 transcription factor (SP1) regulates transcription factor p65 (RelA) which is involved in NFκB heterodimer formation.60 In addition, NFκB and its inhibitor of nuclear factor kappa-B kinase subunit beta (IKBKB) were themselves identified as potential upstream regulators. Therefore, this study argues for a central role of NFκB in the pro-inflammatory action of omentin.

*Strengths and limitations*

One important strength of our study is the use of primary human differentiated adipocytes. In addition, we used physiological concentrations of omentin and performed a comprehensive analysis of the almost 3,500 secreted proteins induced by omentin using proteomics analysis.

Regarding limitations, it should be noted that we used commercially available preadipocytes which we differentiated into mature adipocytes. Although the preadipocytes had been purified by magnetic beads or cultivation in medium which impeded the adherence of other cell types, a low level of contamination with e.g. immune or endothelial cells cannot be excluded as in all in vitro assays using primary cells isolated from adipose tissue. Additionally, differentiation into mature adipocytes never reaches 100%, so that our cultures may also have contained a low percentage of preadipocytes, which however was the same for each treatment group for any given cell donor. We found that omentin-regulated proteins are localised either in the cytoplasm, extracellular space, plasma membrane or nucleus. According to a colorimetric cell viability test (WST-8) no differences following omentin treatment were observed compared to control (data are not shown), so that it is unlikely that cell death due to omentin treatment contributed to the effects described here. However, we cannot exclude that a low level of cell death in all treatment groups led to the release of proteins that are usually localised within the cell.

*Conclusion*

Omentin increased the secretion of a series of proteins, most importantly TNFAIP6, from differentiated human adipocytes. This protein is only expressed in response to inflammatory stimuli and has anti-inflammatory activities which may suggest an inhibitory feedback loop to omentin release. However, the majority of omentin-regulated proteins and their potential upstream regulators pointed towards pro-inflammatory effects of omentin that may be mediated primarily by NFκB. Pathway analysis supported a role of omentin in inflammation, cellular stress and inter-organ cross-talk, which may explain the positive associations between omentin and cardiometabolic risk in prospective studies in humans.

**Acknowledgement**

We thank Miriam Cnop (Brussels) for critical reading of this manuscript.

**Funding**

This study was supported by research grants from the German Diabetes Association (Deutsche Diabetes-Gesellschaft, DDG) to Dr. Maren Carstensen-Kirberg. This work was also supported by the Ministry of Culture and Science of the State of North Rhine-Westphalia and the German Federal Ministry of Health (BMG) as well as by a grant from the German Federal Ministry of Education and Research (BMBF) to the German Center for Diabetes Research (DZD).

**Conflicts of interest**

The authors declare that they have no competing interests.

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**References**

1. Yang RZ, Lee MJ, Hu H, Pray J, Wu HB, Hansen BC, Shuldiner AR, Fried SK, McLenithan JC, Gong DW. Identification of omentin as a novel depot-specific adipokine in human adipose tissue: possible role in modulating insulin action. Am J Physiol Endocrinol Metab 2006;290:E1253–E1261.
2. de Souza Batista CM, Yang RZ, Lee MJ, Glynn NM, Yu DZ, Pray J, Ndubuizu K, Patil S, Schwartz A, Kligman M, Fried SK, Gong DW, Shuldiner AR, Pollin TI, McLenithan JC. Omentin plasma levels and gene expression are decreased in obesity. Diabetes 2007;56:1655–1661.
3. Pan HY, Guo L, Li Q. Changes of serum omentin-1 levels in normal subjects and in patients with impaired glucose regulation and with newly diagnosed and untreated type 2 diabetes. Diabetes Res Clin Pract 2010;88:29–33.
4. Herder C, Ouwens DM, Carstensen M, Kowall B, Huth C, Meisinger C, Rathmann W, Roden M, Thorand B. Adiponectin may mediate the association between omentin, circulating lipids and insulin sensitivity: results from the KORA F4 study. Eur J Endocrinol 2015;172:423–432.
5. Wang Q, Feng X, Zhou C, Li P, Kang J. Decreased levels of serum omentin-1 in patients with obstructive sleep apnoea syndrome. Ann Clin Biochem 2013;50:230–235.
6. Shibata R, Ouchi N, Kikuchi R, Takahashi R, Takeshita K, Kataoka Y, Ohashi K, Ikeda N, Kihara S, Murohara T. Circulating omentin is associated with coronary artery disease in men. Atherosclerosis 2011;219:811-814.
7. Du Y, Ji Q, Cai L, Huang F, Lai Y, Liu Y, Yu J, Han B, Zhu E, Zhang J, Zhou Y, Wang Z, Zhao Y. Association between omentin-1 expression in human epicardial adipose tissue and coronary atherosclerosis. Cardiovasc Diabetol 2016;15:90.
8. Xu T, Zuo P, Cao L, Gao Z, Ke K. Omentin-1 is Associated with Carotid Plaque Instability among Ischemic Stroke Patients. J Atheroscler Thromb 2018;25:505-511.
9. Xu T, Zuo P, Wang Y, Gao Z, Ke K. Serum omentin-1 is a novel biomarker for predicting the functional outcome of acute ischemic stroke patients. Clin Chem Lab Med 2018;56:350-355.
10. Kataoka Y, Shibata R, Ohashi K, Kambara T, Enomoto T, Uemura Y, Ogura Y, Yuasa D, Matsuo K, Nagata T, Oba T, Yasukawa H, Numaguchi Y, Sone T, Murohara T, Ouchi N. Omentin prevents myocardial ischemic injury through AMP-activated protein kinase- and Akt-dependent mechanisms. J Am Coll Cardio 2014;63:2722-2733.
11. Watanabe K, Watanabe R, Konii H, Shirai R, Sato K, Matsuyama TA, Ishibashi-Ueda H, Koba S, Kobayashi Y, Hirano T, Watanabe T. Counteractive effects of omentin-1 against atherogenesis. Cardiovasc Res 2016;110:118-128.
12. Herder C, Kannenberg JM, Niersmann C, Huth C, Carstensen-Kirberg M, Wittenbecher C, Schulze M, Blüher M, Rathmann W, Peters A, Roden M, Meisinger C, Thorand B. Independent and opposite associations of serum levels of omentin-1 and adiponectin with increases of glycaemia and incident type 2 diabetes in an older population: KORA F4/FF4 study. Eur J Endocrinol 2017;177:277-286.
13. Wittenbecher C, Menzel J, Carstensen-Kirberg M, Biemann R, di Giuseppe R, Fritsche A, Isermann B, Herder C, Aleksandrova K, Boeing H, Weikert C, Schulze MB. Omentin-1, adiponectin, and the risk of developing type 2 diabetes. Diabetes Care 2016;39:e79–e80.
14. Menzel J, di Giuseppe R, Biemann R, Wittenbecher C, Aleksandrova K, Pischon T, Fritsche A, Schulze MB, Boeing H, Isermann B, Weikert C. Omentin-1 and risk of myocardial infarction and stroke: Results from the EPIC-Potsdam cohort study. Atherosclerosis 2016;251:415-421.
15. Saely CH, Leiherer A, Muendlein A, Vonbank A, Rein P, Geiger K, Malin C, Drexel H. High plasma omentin predicts cardiovascular events independently from the presence and extent of angiographically determined atherosclerosis. Atherosclerosis 2016;244:38-43.
16. Moreno-Navarrete JM, Ortega F, Castro A, Sabater M, Ricart W, Fernández-Real JM. Circulating omentin as a novel biomarker of endothelial dysfunction. Obesity (Silver Spring) 2011;19:1552-1559.
17. Zhong X, Li X, Liu F, Tan H, Shang D. Omentin inhibits TNF-α-induced expression of adhesion molecules in endothelial cells via ERK/NF-κB pathway. Biochem Biophys Res Commun 2012;425:401-406.
18. Kazama K, Usui T, Okada M, Hara Y, Yamawaki H. Omentin plays an anti-inflammatory role through inhibition of TNF-α-induced superoxide production in vascular smooth muscle cells. Eur J Pharmacol 2012;686:116-123.
19. Carstensen M, Wiza C, Röhrig K, Fahlbusch P, Roden M, Herder C, Ouwens DM. Effect of Sfrp5 on cytokine release and insulin action in primary human adipocytes and skeletal muscle cells. PLoS One 2014;9:e85906.
20. Grosche A, Hauser A, Lepper MF, Mayo R, von Toerne C, Merl-Pham J, Hauck SM. The proteome of native adult Muller glial cells from murine retina. Mol Cell Proteomics 2016;15:462-480.
21. Wiśniewski JR, Zougman A, Mann M. Combination of FASP and StageTip-based fractionation allows in-depth analysis of the hippocampal membrane proteome. J Proteome Res 2009;8:5674-5678.
22. Bruderer R, Bernhardt OM, Gandhi T, Reiter L. High-precision iRT prediction in the targeted analysis of data-independent acquisition and its impact on identification and quantitation. Proteomics 2016;16:2246-2256.
23. Lepper MF, Ohmayer U, von Toerne C, Maison N, Ziegler A-G, Hauck SM. The proteomic landscape of patient-derived CD4+ T cells in recent-onset type 1 diabetes. J Proteome Res 2018;17:618-634.
24. Gillet LC, Navarro P, Tate S, Röst H, Selevsek N, Reiter L, Bonner R, Aebersold R. Targeted data extraction of the MS/MS spectra generated by data-independent acquisition: a new concept for consistent and accurate proteome analysis. Mol Cell Proteomics 2012;11:O111.016717.
25. Geiger T, Cox J, Mann M. Proteomics on an Orbitrap benchtop mass spectrometer using all-ion fragmentation. Mol Cell Proteomics 2010;9:2252-2261.
26. Bruderer R, Bernhardt OM, Gandhi T, Miladinović SM, Cheng LY, Messner S, Ehrenberger T, Zanotelli V, Butscheid Y, Escher C, Vitek O, Rinner O, Reiter L. Extending the limits of quantitative proteome profiling with data-independent acquisition and application to acetaminophen-treated three-dimensional liver microtissues. Mol Cell Proteomics 2015;14:1400-1410.
27. Ingenuity Pathway Analysis. Bioinformatics 2014;30:523-530.
28. Day AJ, Milner CM. TSG-6: A multifunctional protein with anti-inflammatory and tissue-protective properties. Matrix Biol 2018 e-pub ahead of print 31 January 2018; doi: 10.1016/j.matbio.2018.01.011.
29. Salustri A, Garlanda C, Hirsch E, De Acetis M, Maccagno A, Bottazzi B, Doni A, Bastone A, Mantovani G, Beck Peccoz P, Salvatori G, Mahoney DJ, Day AJ, Siracusa G, Romani L, Mantovani A. PTX3 plays a key role in the organization of the cumulus oophorus extracellular matrix and in in vivo fertilization. Development 2004;131:1577-1586.
30. Lee GW, Lee TH, Vilcek J. TSG-14, a tumor necrosis factor- and IL-1-inducible protein, is a novel member of the pentaxin family of acute phase proteins. J Immunol 1993;150:1804-1812.
31. Fornai F, Carrizzo A, Forte M, Ambrosio M, Damato A, Ferrucci M, Biagioni F, Busceti C, Puca AA, Vecchione C. The inflammatory protein Pentraxin 3 in cardiovascular disease. Immun Ageing 2016;13:25.
32. Bovolenta P, Esteve P, Ruiz JM, Cisneros E, Lopez-Rios J. Beyond Wnt inhibition: new functions of secreted Frizzled-related proteins in development and disease. J Cell Sci 2008;121(Pt 6):737-746.
33. Mahdi T, Hänzelmann S, Salehi A, Muhammed SJ, Reinbothe TM, Tang Y, Axelsson AS, Zhou Y, Jing X, Almgren P, Krus U, Taneera J, Blom AM, Lyssenko V, Esguerra JL, Hansson O, Eliasson L, Derry J, Zhang E, Wollheim CB, Groop L, Renström E, Rosengren AH. Secreted frizzled-related protein 4 reduces insulin secretion and is overexpressed in type 2 diabetes. Cell Metab 2012;16:625-633.
34. Wilkinson RD, Williams R, Scott CJ, Burden RE. Cathepsin S: therapeutic, diagnostic, and prognostic potential. Biol Chem 2015;396:867-882.
35. Peter K, Weirich U, Nordt TK, Ruef J, Bode C. Soluble vascular cell adhesion molecule-1 (VCAM-1) as potential marker of atherosclerosis. Thromb Haemost 1999;82 Suppl 1:38-43.
36. Shai I, Pischon T, Hu FB, Ascherio A, Rifai N, Rimm EB. Soluble intercellular adhesion molecules, soluble vascular cell adhesion molecules, and risk of coronary heart disease. Obesity (Silver Spring) 2006;14:2099-2106.
37. Xu H, Cao H, Xiao G. Signaling via PINCH: Functions, binding partners and implications in human diseases. Gene 2016;594:10-15.
38. Chen D, Li Z, Yang Q, Zhang J, Zhai Z, Shu HB. Identification of a nuclear protein that promotes NF-kappaB activation. Biochem Biophys Res Commun 2003;310:720-724.
39. Py BF, Kim MS, Vakifahmetoglu-Norberg H, Yuan J. Deubiquitination of NLRP3 by BRCC3 critically regulates inflammasome activity. Mol Cell 2013;49:331-338.
40. Lee AS, Kranzusch PJ, Doudna JA, Cate JH. eIF3d is an mRNA cap-binding protein that is required for specialized translation initiation. Nature 2016;536:96-99.
41. Marton MJ, Vazquez de Aldana CR, Qiu H, Chakraburtty K, Hinnebusch AG. Evidence that GCN1 and GCN20, translational regulators of GCN4, function on elongating ribosomes in activation of eIF2alpha kinase GCN2. Mol Cell Biol 1997;17:4474-4489.
42. Gregor MF, Hotamisligil GS. Inflammatory mechanisms in obesity. Annu Rev Immunol 2011;29:415-445.
43. Steinbrenner H, Speckmann B, Klotz LO. Selenoproteins: Antioxidant selenoenzymes and beyond. Arch Biochem Biophys 2016;595:113-119.
44. Steinbrenner H. Interference of selenium and selenoproteins with the insulin-regulated carbohydrate and lipid metabolism. Free Radic Biol Med 2013;65:1538-1547.
45. Gruys E, Toussaint MJ, Niewold TA, Koopmans SJ. Acute phase reaction and acute phase proteins. J Zhejiang Univ Sci B 2005;6:1045-1056.
46. Moreno-Navarrete JM, Fernández-Real JM. The complement system is dysfunctional in metabolic disease: Evidences in plasma and adipose tissue from obese and insulin resistant subjects. Semin Cell Dev Biol 2017;S1084-9521:30132-30135.
47. Vlaicu SI, Tatomir A, Boodhoo D, Vesa S, Mircea PA, Rus H. The role of complement system in adipose tissue-related inflammation. Immunol Res 2016;64:653-664.
48. Nissinen L, Kähäri VM. Matrix metalloproteinases in inflammation. Biochim Biophys Acta 2014;1840:2571-2580.
49. Derosa G, D'Angelo A, Tinelli C, Devangelio E, Consoli A, Miccoli R, Penno G, Del Prato S, Paniga S, Cicero AF. Evaluation of metalloproteinase 2 and 9 levels and their inhibitors in diabetic and healthy subjects. Diabetes Metab 2007;33:129-134.
50. Kralisch S, Klein J, Lossner U, Bluher M, Paschke R, Stumvoll M, Fasshauer M. Proinflammatory adipocytokines induce TIMP-1 expression in 3T3-L1 adipocytes. FEBS Lett 2005;579:6417-6422.
51. Weise S, Kralisch S, Sommer G, Lossner U, Bluher M, Stumvoll M, Fasshauer M. Tissue inhibitor of metalloproteinase-1 mRNA production and protein secretion are induced by interleukin-1 beta in 3T3-L1 adipocytes. J Endocrinol 2008;198:169-174.
52. Wang J, Maldonado MA. The ubiquitin-proteasome system and its role in inflammatory and autoimmune diseases. Cell Mol Immunol 2006;3:255-261.
53. Saxena NK, Anania FA. Adipocytokines and hepatic fibrosis. Trends Endocrinol Metab 2015;26:153-161.
54. Lefere S, Van de Velde F, Devisscher L, Bekaert M, Raevens S, Verhelst X, Van Nieuwenhove Y, Praet M, Hoorens A, Van Steenkiste C, Van Vlierberghe H, Lapauw B, Geerts A. Serum vascular cell adhesion molecule-1 predicts significant liver fibrosis in non-alcoholic fatty liver disease. Int J Obes (Lond) 2017;41:1207-1213.
55. Chen VL, Le AK, Podlaha O, Estevez J, Li B, Vutien P, Chang ET, Rosenberg-Hasson Y, Pflanz S, Jiang Z, Ge D, Gaggar A, Nguyen MH. Soluble intercellular adhesion molecule-1 is associated with hepatocellular carcinoma risk: multiplex analysis of serum markers. Sci Rep 2017;7:11169.
56. Hoesel B, Schmid JA. The complexity of NF-κB signaling in inflammation and cancer. Mol Cancer 2013;12:86.
57. Thalhamer T, McGrath MA, Harnett MM. MAPKs and their relevance to arthritis and inflammation. Rheumatology (Oxford) 2008;47:409-414.
58. Ramana CV, Gil MP, Schreiber RD, Stark GR. Stat1-dependent and –independent pathways in IFN-gamma-dependent signaling. Trends Immunol 2002;23:96-101.
59. Hu W, Lv J, Han M, Yang Z, Li T, Jiang S, Yang Y. STAT3: The art of multi-tasking of metabolic and immune functions in obesity. Prog Lipid Res 2018;70:17-28.
60. Kim JY, Jung HH, Ahn S, Bae S, Lee SK, Kim SW, Lee JE, Nam SJ, Ahn JS, Im YH, Park YH. The relationship between nuclear factor (NF)-κB family gene expression and prognosis in triple-negative breast cancer (TNBC) patients receiving adjuvant doxorubicin treatment. Sci Rep 2016;6:31804.

**TABLE 1** Top 20 of the most upregulated and top 20 of the most downregulated proteins by 2000 ng/ml omentin in the supernatant of differentiated human adipocytes.

|  |  |  |  |
| --- | --- | --- | --- |
| **Protein** | **Entrez gene name** | **Expression fold** | **Expression p-value** |
| **UPREGULATION** | | | |
| TNFAIP6 | Tumor necrosis factor-inducible gene 6 protein | +140.39 | 4.43 x 10-3 |
| CXCL5 | C-X-C motif chemokine 5 | +89.21 | 1.49 x 10-3 |
| CFB | Complement factor B | +35.23 | 7.98 x 10-3 |
| CTSS | Cathepsin S | +12.92 | 1.89 x 10-2 |
| SFRP4 | Secreted frizzled-related protein 4 | +12.03 | 3.03 x 10-2 |
| LIMS1 | LIM and senescent cell antigen-like-containing domain protein 1 | +11.95 | 8.98 x 10-3 |
| BRCC3 | Lys-63-specific deubiquitinase BRCC36 | +11.90 | 8.62 x 10-3 |
| PTX3 | Pentraxin-related protein PTX3 | +8.04 | 6.13 x 10-3 |
| PROCR | Endothelial protein C receptor | +5.11 | 4.03 x 10-3 |
| PLA2G2A | Phospholipase A2, membrane associated | +5.05 | 3.35 x 10-2 |
| RPL22L1 | 60S ribosomal protein L22-like 1 | +4.50 | 3.74 x 10-2 |
| VCAM1 | Vascular cell adhesion molecule 1 | +4.13 | 1.15 x 10-2 |
| ALDH1L2 | Mitochondrial 10-formyltetrahydrofolate dehydrogenase | +3.91 | 3.48 x 10-3 |
| CORO2B | Coronin-2B | +3.91 | 4.59 x 10-2 |
| TFPI2 | Tissue factor pathway inhibitor 2 | +3.67 | 2.58 x 10-2 |
| RPN2 | Dolichyl-diphosphooligosaccharide--protein glycosyltransferase subunit 2 | +3.64 | 2.09 x 10-2 |
| NUB1 | NEDD8 ultimate buster 1 | +3.56 | 1.05 x 10-2 |
| NVL | Nuclear valosin-containing protein-like | +3.27 | 2.66 x 10-2 |
| ICAM1 | Intercellular adhesion molecule 1 | +3.22 | 9.13 x 10-4 |
| NKAP | NF-kappa-B-activating protein | +3.22 | 8.02 x 10-3 |
| **DOWNREGULATION** | | | |
| NUCKS1 | Nuclear ubiquitous casein and cyclin-dependent kinase substrate 1 | -2.62 | 1.73 x 10-3 |
| TTK | Dual specificity protein kinase TTK | -2.60 | 5.34 x 10-3 |
| PLCG2 | 1-phosphatidylinositol 4,5-bisphosphate phosphodiesterase gamma-2 | -2.29 | 2.65 x 10-2 |
| MAP1S | Microtubule-associated protein 1S | -2.09 | 8.47 x 10-3 |
| NCL | Nucleolin | -2.00 | 2.04 x 10-3 |
| CASQ1 | Calsequestrin 1 | -1.89 | 1.31 x 10-2 |
| EIF3D | Eukaryotic translation initiation factor 3 subunit D | -1.76 | 3.53 x 10-2 |
| RALGAPA1 | Ral GTPase-activating protein subunit alpha-1 | -1.75 | 1.39 x 10-3 |
| EXOC2 | Exocyst complex component 2 | -1.65 | 4.91 x 10-2 |
| TPD52L2 | Tumor protein D54 | -1.64 | 3.27 x 10-2 |
| GCN1 | eIF-2-alpha kinase activator GCN1 | -1.63 | 2.14 x 10-2 |
| FAM120A | Constitutive coactivator of PPAR-gamma-like protein 1 | -1.63 | 3.26 x 10-2 |
| DNMBP | Dynamin-binding protein | -1.61 | 2.93 x 10-2 |
| SEPP1 | Selenoprotein P | -1.56 | 7.24 x 10-3 |
| RPL24 | 60S ribosomal protein L24 | -1.55 | 4.00 x 10-2 |
| FAHD1 | Acylpyruvase FAHD1, mitochondrial | -1.53 | 3.85 x 10-3 |
| ROR2 | Tyrosine-protein kinase transmembrane receptor ROR2 | -1.52 | 1.24 x 10-2 |
| PTMA | Prothymosin alpha | -1.51 | 4.88 x 10-2 |
| PLXDC2 | Plexin domain-containing protein 2 | -1.50 | 3.21 x 10-2 |
| TSPAN3 | Tetraspanin-3 | -1.48 | 3.05 x 10-2 |

The fold-change in expression for the listed proteins refers to adipocytes treated with 2000 ng/ml omentin for 24h compared to untreated adipocytes. The expression p-value was calculated by a paired t-test.

**TABLE 2** Enrichment of the omentin-regulated proteins in differentiated human adipocyte supernatant in canonical pathways.

|  |  |  |
| --- | --- | --- |
| **Canonical pathway** | **B-H p-value** | **Omentin-regulated proteins** |
| EIF2 Signaling | 2.77 x 10-15 | RPL11, RPL24, RPL4, RPL22, RPL22L1, RPL35A, RPL12, RPL10A, RPL27, RPL27A, RPL18A, RPS13, EIF3D, RPL23A, RPS27L, RPL5, RPS15A, RPL36, RPS3, RPS24 |
| Complement System | 3.92 x 10-4 | C1R, C3, C1S, CFB, CFH |
| Inhibition of Matrix Metalloproteases | 5.99 x 10-3 | HSPG2, TIMP1, MMP2, TFPI2 |
| Acute Phase Response Signaling | 5.99 x 10-3 | C1R, C3, C1S, CFB, SERPINA3, CP, HNRNPK |
| Regulation of eIF4 and p70S6K Signaling | 2.23 x 10-2 | EIF3D, RPS13, RPS27L, RPS15A, RPS3, RPS24 |
| Hepatic Fibrosis / Hepatic Stellate Cell Activation | 4.63 x 10-2 | VCAM1, LY96, ICAM1, TIMP1, HGF, MMP2 |
| Protein Ubiquitination Pathway | 4.87 x 10-2 | PSMB3, USP32, PSMA7, UBE3B, HSPA13, PSMA1, UBE2I |

The analysis was based on proteins which were differentially secreted upon treatment with 2000 ng/ml omentin. P-values for the canonical pathways were calculated by Fisher´s exact test and corrected for multiple testing using the Benjamini-Hochberg method (B-H p-value).

EIF, Eukaryotic Initiation Factor; p70S6K, 70 kDa ribosomal S6 kinase.

Abbreviations of omentin-regulated proteins are explained in Suppl. Table 1.

**TABLE 3** Top 25 of other potential upstream activators of omentin-regulated proteins.

|  |  |  |  |
| --- | --- | --- | --- |
| **Upstream**  **Regulator** | **Activation**  **z-score** | **p-value** | **Omentin-regulated proteins** |
| **CYTOKINES** | | | |
| IL1B | 4.38 | 4.20 x 10-10 | C1R, C3, CD44, CFB, CP, CTSS, CXCL5, HGF, HPRT1, HSPG2, ICAM1, LY96, MMP2, MYLK, PAPPA, PLA2G2A, PLXDC2, PTX3, SELENOP, SERPINA3, TFPI2, TIMP1, TNFAIP6, TPD52L2, VCAM1 |
| TNF | 4.65 | 5.47 x 10-9 | ALAD, B4GALT1, C3, CA12, CALR, CD44, CFB, CP, CTSS, CXCL5, EXT1, HGF, HPRT1, HSPG2, ICAM1, LY96, MMP2, MYLK, OGN, PAPPA, PDIA4, PLA2G2A, PLXDC2, PTX3, RPS13, RPS3, SELENOP, SERPINA3, SMPD1, TFPI2, TIMP1, TNFAIP6, TPD52L2, VCAM1 |
| IFNG | 2.10 | 5.08 x 10-5 | AHCY, C1R, C3, CD44, CFB, CP, CTSS, CXCL5, HSPG2, HTRA1, ICAM1, KCTD7, LY96, MMP2, PAPPA, PLA2G2A, PTX3, RPL23A, SELENOP, TIMP1, TNFAIP6, VCAM1 |
| IL1A | 2.81 | 1.13 x 10-4 | CD44, CXCL5, HSPG2, ICAM1, MMP2, PTX3, SERPINA3, VCAM1 |
| MIF | 2.07 | 1.13 x 10-4 | CD44, HGF, ICAM1, MMP2, TIMP1, VCAM1 |
| CXCL8 | 2.18 | 1.39 x 10-4 | CD44, HSPG2, ICAM1, MMP2, VCAM1 |
| IL6 | 2.89 | 9.49 x 10-4 | AHNAK, C3, CD44, CP, CXCL5, HGF, ICAM1, MMP2, PLA2G2A, SERPINA3, TIMP1, TTK, VCAM1 |
| OSM | 2.55 | 2.65 x 10-3 | C1R ,C1S, CXCL5, HGF, ICAM1, MMP2, SERPINA3, SMPD1, TIMP1, VCAM1 |
| IL17A | 2.39 | 3.69 x 10-3 | C3, CXCL5, ICAM1, MMP2, TIMP1, VCAM1 |
| SPP1 | 2.18 | 6.39 x 10-3 | CD44, CXCL5, ICAM1, MMP2, TIMP1 |
| CSF2 | 2.41 | 7.75 x 10-2 | C3, CFH, HGF, ICAM1, LY96, MMP2 |
| **GROWTH FACTORS** | | | |
| TGFB1 | 2.06 | 8.50 x 10-7 | AHNAK, C1R, C1S, C3, CD44, CFB, CFH, CRMP1, CTSS, DAAM1, EXT1, EXT2, FBLN2, HGF, HSPG2, HTRA1, ICAM1, LASP1, LIMS1, LOXL2, MMP2, MYLK, MYO1C, PAPPA, PTX3, RPN2, SERPINA3, TIMP1, TNFAIP6, VCAM1 |
| **TRANSMEMBRANE RECEPTORS** | | | |
| TLR4 | 2.19 | 3.03 x 10-3 | C3, CD44, CFB, HTRA1, ICAM1, PTX3, SMPD1, VCAM1 |
| TLR3 | 2.43 | 6.34 x 10-3 | C3, CFB, ICAM1, PROCR, PTX3, TIMP1 |
| **ENZYMES** | | | |
| PTGS2 | 2.22 | 1.02 x 10-4 | CD44, CXCL5, ICAM1, MMP2, NOP2, PTMA, TNFAIP6 |
| NOS2 | 2.00 | 3.41 x 10-2 | CD44, CP, SERPINA3, TIMP1 |
| **TRANSCRIPTION REGULATORS** | | | |
| STAT1 | 2.37 | 4.51 x 10-4 | C1R, C1S, C3, CFB, CTSS, HTRA1, ICAM1, LY96, SERPINA3 |
| SMARCA4 | 2.56 | 6.30 x 10-4 | AHNAK, CD44, CP, CTSS, ICAM1, LMNA, LOXL2, LUM, MMP2, MYLK, PTX3, SELENOP |
| SP1 | 2.58 | 1.01 x 10-3 | B4GALT5, CXCL5, HGF, ICAM1, MAT2B, MMP2, MYLK, PROCR, SMPD1, TFPI2, TIMP1 |
| STAT3 | 2.24 | 1.04 x 10-2 | CFB, HGF, ICAM1, MMP2, PDIA4, PLA2G2A, SERPINA3, TFPI2, TIMP1 |
| ETS1 | 2.18 | 1.39 x 10-2 | B4GALT5, CD44, HGF, ICAM1, MMP2 |
| **COMPLEXES** | | | |
| NFkB (complex) | 3.63 | 6.73 x 10-7 | B4GALT1, C1R, C3, CD44, CFB, CGREF1, CXCL5, ICAM1, MMP2, MYLK, PLA2G2A, PTX3, SERPINA3, TFPI2, TIMP1, TNFAIP6, VCAM1 |
| Cg | 2.79 | 2.48 x 10-3 | ICAM1, MMP2, PAPPA, PTX3, SFRP4, TFPI2, TIMP1, TNFAIP6 |
| **KINASES** | | | |
| IKBKB | 2.01 | 1.46 x 10-5 | C3, CD44, CP, CXCL5, HGF, ICAM1, MMP2, OGN, PTX3, VCAM1 |
| MAPK8 | 2.19 | 4.21 x 10-3 | B4GALT1, B4GALT5, BDP1, MMP2, PTX3 |

The identification of potential upstream activators was based on differentially regulated proteins by omentin treatment with 2000 ng/ml in differentiated human adipocytes supernatant. The p-values were calculated by Fisher’s exact test. The molecule type was filtered according to the following categories: complex, cytokine, enzyme, growth factor, kinase, phosphatase, transcription regulator, translation regulator, transmembrane receptor and transporter.

Cg, choriogonadotropin; CXCL8, C-X-C motif chemokine ligand 8; ETS1, ETS proto-oncogene 1; IFNG, interferon gamma; IKBKB, inhibitor of kappaB kinase beta; IL1A, interleukin-1 alpha; IL1B, interleukin-1 beta; IL6, interleukin-6; IL17A, interleukin 17 alpha; MAPK8, mitogen-activated protein kinase 8; MIF, macrophage migration inhibitory factor; NFkB(complex), nuclear factor kappa B; NOS2, nitric oxide synthase 2; OSM, oncostatin M; PTGS2, prostaglandin-endoperoxide synthase 2; SMARCA4, SMI/SNF related, matrix associated, actin dependent regulator of chromatin, subfamily 5, member 4; SP1, Sp1 transcription factor; SPP1, secreted phosphoprotein 1; STAT1, signal transducer and activator of transcription 1; STAT3, signal transducer and activator of transcription 3; TGFB1, transforming growth factor beta 1; TNF, tumor necrosis factor; TLR3, toll-like receptor 3; TLR4, toll-like receptor 4.

Abbreviations of omentin-regulated proteins are explained by Suppl. Table 1.

**Figure 1** Proposed physiological role of omentin in differentiated human adipocytes.