

RESEARCH ARTICLE

CTRP3 and serum triglycerides in children aged 7-10 years

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Abstract

Introduction

The prevalence of obesity-related disorders has been steadily increasing over the past couple of decades. Diseases that were once only detected in adults are now prevalent in children, such as hyperlipidemia. The adipose tissue-derived hormonal factor C1q TNF Related Protein 3 (CTRP3) has been linked to triglyceride regulation especially in animal models. However, the relationship between circulating CTRP3 levels and obesity-related disorders in human subjects is controversial. CTRP3 can circulate in different oligomeric complexes: trimeric (<100 kDa), middle molecular weight (100–300 kDa), and high molecular weight (HMW) oligomeric complexes (>300 kDa). Previous work has identified that it is not the total amount of CTRP3 present in the serum, but the specific circulating oligomeric complexes that appear to be indicative of the relationship between CTRP3 and serum lipids levels. However, this work has not been examined in children. Therefore, the purpose of this study was to compare the levels of different oligomeric complexes of CTRP3 and circulating lipid levels among young children (aged 7–10 years).

Methods

Morphometric data and serum samples were collected and analyzed from a cross-sectional population of 62 children of self-identified Hispanic origin from a community health center, between 2015 and 2016. Serum analysis included adiponectin, insulin, leptin, ghrelin, glucagon, C-reactive peptide, triglyceride, cholesterol, IL-6, TNF, and CTRP3. Correlation analyses were conducted to explore the relationships between CTRP3 and other biomarkers.

Results

Total CTRP3 concentrations were significantly positively correlated with total cholesterol and HDL cholesterol. Whereas, HMW CTRP3 was not significantly associated with any

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variable measured. Conversely, the middle molecular weight (MMW) CTRP3 was negatively correlated with triglycerides levels, and very low-density lipoprotein (VLDL), insulin, and body mass index (BMI). The negative correlations between MMW CTRP3 and triglycerides and VLDLs were particularly strong ($r^2 = -0.826$ and -0.827 , respectively).

Conclusion

Overall, these data indicate that the circulating oligomeric state of CTRP3 and not just total CTRP3 level is important for understanding the association between CTRP3 and metabolic diseases. Further, this work indicates that MMW CTRP3 plays an important role in triglyceride and VLDL regulation which requires further study.

Introduction

Childhood obesity is a growing epidemic in the United States; its prevalence more than doubled in the past 30 years from ~7% in 1980 to 17.7% in 2012 in 6- to 11-year-olds [1, 2]. Obese children are at a significantly higher risk for developing many types of cancers, cardiovascular disease, diabetes and other metabolic disorders [3, 4]. However, there is a paucity of data regarding the development of metabolic dysfunction in children, especially among the Hispanic population. Childhood obesity is influenced by a variety of environmental, dietary, and genetic factors, many of which are actively being investigated. Our lab focuses on understanding the influence of adipose tissue health and specifically adipose tissue-derived secreted hormonal factors (hereafter referred to as adipokines) on the development of obesity and metabolic disorders. This manuscript focuses specifically on associations of C1q TNF Related Protein 3 (CTRP3) on obesity-related metabolic parameters.

Adipose tissue secretes many bioactive molecules that circulate in blood, collectively termed adipokines [5–12]. To date, over 70 adipokines have been identified [8, 13]. Leptin is the most well-known and highly studied adipokine and disruptions in proper leptin function result in severe obesity through hyperphagia (overeating) and associated metabolic disorders [14]. The second most widely studied adipokine is adiponectin. Adiponectin modulates a number of metabolic processes, including glucose regulation and fatty acid oxidation [15]. Obesity is associated with lower adiponectin levels in adults [16], and hypoadiponectinemia is a consequence of the development of obesity in childhood [17, 18]. Additionally, a novel family of secreted humoral factors, C1q TNF Related Proteins, (abbreviated CTRP1 through 15) have been identified based upon homology to adiponectin [9, 11, 19]. Reflecting profound biological potency, the initial characterization of these adipose tissue-derived CTRP factors finds wide-ranging effects upon metabolism, inflammation, and cell-growth in multiple tissue types. The associations between these factors and human health has only begun to be explored in adult populations and this manuscript is the first to explore any of these factors in children.

In animal models CTRP3 has been shown to improve insulin sensitivity as well as inhibit the development of both non-alcoholic fatty liver disease and alcoholic fatty liver disease [20–23]. However, there have been conflicting studies regarding the relationship between circulating CTRP3 levels and metabolic status. For example, CTRP3 has been reported to be elevated [24], not changed [25, 26], or reduced with obesity [24, 27–30]. These conflicting data suggest that measuring total circulating levels of CTRP3 is insufficient for determining the role of CTRP3 in human health.

Although CTRP3 is an approximately 26 kDa protein, when secreted CTRP3 forms higher order molecule structures such as a trimer (~78–90 kDa), a six-nine subunit oligomer also known as a middle molecular weight oligomer (MMW, ~180–270 kDa), or as a high molecular weight oligomer (HMW, >300 kDa) [9]. Our previous work demonstrated that CTRP3 is only found in human circulation as MMW or HMW isoforms [26]; this was also confirmed experimentally in the pediatric study population presented herein (S1 Fig). In addition, Trogen et al. [26] found that the differences in the circulating oligomeric forms of CTRP3 had strong correlations with obesity and other metabolic variables, especially circulating triglyceride levels. Therefore, we hypothesized that the MMW and HMW oligomeric CTRP3 will be correlated with metabolic variables, specifically circulating serum triglyceride levels. To test this hypothesis we re-examined a sample collected from a population of Hispanic children who we have previously studied shown to be at increased risk for obesity and metabolic diseases [31].

Methods

Study design and sample

Data for this study came from a previously performed cross-sectional study of metabolic syndrome in pre-adolescent Hispanic Children, receiving well-child care at a community health center, from June 2015 to September 2016 [31]. The study was conducted by the APPalachian Obesity and METabolic diseases (APPOMET) Working Group, an interdisciplinary group of researchers including epidemiologists, nutritionists, nurses and basic science researchers. The study was reviewed and approved by the Institutional Review Board at East Tennessee State (IRB#: 0414.16s).

Inclusion criteria for this study were: being 7–10 years of age; being of Hispanic origin by self-identification; and not having a serious physical or mental illness. Parents were provided written information about the study in either Spanish or English Language. Parents understood that participation in the study was voluntary and they received assurance of the confidentiality of the data which they provided. Parental written consent and a child written assent were obtained before data collection. A total of 62 children aged 7–10 years old were included in this study.

Measurements

As described previously a pediatric nurse practitioner measured children's height, weight, waist circumference and blood pressure using standard protocols [31]. A laboratory technician drew four milliliters (4mls) of blood from the ante-cubital fossa of each child into a serum separator tube (SST) and a ethylenediamine tetra-acetic acid (EDTA) tube. The blood samples were stored at -80°C until analysis.

Blood sample analysis: Total Cholesterol, LDL, HDL, C Reactive protein, Triglycerides, and VLDL, were performed by ETSU Clinical Laboratory: an accredited reference lab (Center for Medicare & Medicaid Services Clinical Laboratory, certification number 44D0659180). Adiponectin, IL-6, C-peptide, Ghrelin, Glucagon, and Leptin analysis were performed on Bio-Rad Bio-Plex Mag-Pix with commercially available assays according to manufactures instructions (Bio-Rad Bio-Plex, Catalog numbers: 171A7002M; 171-A7001M; & #171-AA001M).

CTRP3 Analysis: Serum samples were diluted to 1:40 with phosphate-buffered saline containing protease inhibitor cocktail (Bimake, Catalog numbers #B14001) and were separated by size using centrifugal separation (Sartorius™ Vivaspin™; VS0151) according to manufactures' directions. The flow through contains all molecules below 300 kDa in size and the concentrate contains only those molecules equal to or above 300 kDa in size. Total (unseparated samples), high molecular weight isomer (HMW), and middle molecular weight isomer (MMW) of

CTRP3 were measured using the CTRP3 ELISA (R&D systems, Catalog number #DY7925-05).

Statistical analysis

Descriptive statistics (mean and standard deviation) were calculated for all measured variables. An unpaired two-tailed t test was used to compare means between males and females for all variables tested; no sex specific differences were identified, and all samples were combined for further analysis. Normality was tested with a D'Agostino & Pearson omnibus normality test, and many of the variables were found to be not normally distributed. Therefore, all correlation coefficients were calculated via the Spearman's rank-order correlation test. All statistical analyses were performed by Graphpad Prism 6.

Results

Demographic data

The study included 62 children (29 males and 33 females) with an average BMI of 20.2 ± 4.9 kg/m^2 (calculated using the 2000 CDC growth charts) [32], and an average age of 8.7 ± 1.1 years. There were no significant sex differences in any variable measured as determined by an unpaired two-tailed t test.

Subject characteristics

The mean, standard deviation, min and max values are reported for all serum values in Table 1.

Table 1. The mean, standard deviation, min and max values are reported for all serum values (n = 62).

	Mean \pm SD	Range (min–max)
Total CTRP3 (ng/mL)	103.2 \pm 22.6	38.9–167.6
MMW CTRP3 (ng/mL)	29.7 \pm 20.0	5.7–84.6
HMW CTRP3 (ng/mL)	89.4 \pm 26.7	30.6–156.4
Adiponectin (ug/mL)	24.0 \pm 13.5	2.2–73.1
C-Peptide (pg/mL)	1243 \pm 744	277–3772
Ghrelin (pg/mL)	232.1 \pm 26.2	7.1–1338
Glucagon (pg/mL)	160.0 \pm 17.8	34.2–751.8
Leptin (pg/mL)	6360 \pm 991	174–33815
IL-6 (pg/mL)	2.7 \pm 5.2	0.05–33.6
TNF (pg/mL)	8.1 \pm 18.5	0.58–148.3
C-Reactive Protein (pg/mL)	2.7 \pm 3.8	0.21–18.8
Insulin (pg/mL)	18.2 \pm 18.4	2.0–114.0
Triglycerides (mg/dL)	111.3 \pm 48.9	35.0–263.0
Total Cholesterol (mg/dL)	148 \pm 24	75–195
HDL (mg/dL)	49.1 \pm 10.9	27.3–77.3
LDL (mg/dL)	77.0 \pm 22.3	26.6–119.6
VLDL (mg/dL)	22.5 \pm 9.7	7.0–53.0

Abbreviations: MMW, middle molecular weight; HMW, high molecule weight; IL-6, Interleukin 6; TNF, tumor necrosis factor; HDL, high-density lipoproteins; LDL, low-density lipoproteins; VLDL, very low density lipoprotein.

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CTRP3 correlations

Total CTRP3 concentrations were significantly positively correlated with total cholesterol ($p = 0.034$, $r^2 = 0.270$), and HDL cholesterol ($p = 0.033$, $r^2 = 0.271$) (S1 Table). The relationship between total CTRP3 and adiponectin approached significance ($p = 0.06$). HMW CTRP3 was not significantly associated with any other variable measured, however the positive relationship between HMW CTRP3 and HDL cholesterol levels did approach significance ($p = 0.095$) (S2 Table). On the other hand, MMW CTRP3 was significantly and negatively correlated with insulin, triglycerides, VLDL cholesterol and BMI (data and p-values shown in Fig 1 and S3 Table). MMW CTRP3 was found to be positively correlated with adiponectin ($p = 0.039$, $r^2 = 0.262$). Also, it is worth noting that the positive correlation between MMW CTRP3 and ghrelin and HDL cholesterol both approached significance ($p = 0.09$ and $p = 0.07$ respectively).

Discussion

Dyslipidemia, the abnormal amount of lipids such as triglyceride and cholesterol, is commonly induced by obesity and is a leading contributor to the development of metabolic syndrome. Metabolic syndrome is a significant public health concern and the most prevalent cause of cardiovascular disease and type 2 diabetes. There is growing evidence that children and adolescents are increasingly affected by obesity and metabolic syndrome [1–3, 33–35]. However, there is a paucity of information on the relationship of emerging hormones and their relationship with obesity related disorders, especially in young children. CTRP3 is an adipokine that has been shown to improve dyslipidemia, prevent ectopic lipid accumulation, and reduce the impact of cardiovascular disease [19–22, 24–27, 36, 37]. However, the study of the relationship between circulating CTRP3 levels and human health outcomes and characteristics has produced conflicting data. Specifically, total circulating CTRP3 levels are reported to be either reduced [27, 29, 37, 38] or elevated [39] depending on the study population. However, it has been speculated that the oligomer conformation of CTRP3 is important for its functional activity [19, 22, 40, 41], and this has been rarely studied. To date only one other study has examined the oligomeric status of CTRP3 with human disease [26]. Trogen et al. (2019) determined that all circulating CTRP3 in humans is found as either the MMW or HMW oligomer, with the trimer and monomer of CTRP3 being undetectable. Further, the authors found that the oligomeric state of CTRP3 was significantly correlated to serum triglyceride levels, but not diabetic or obesity status [21].

This is the first study to examine the circulating oligomeric state of CTRP3 in a pediatric population (7–10 years of age). The major significant finding of this study is that the oligomeric status of CTRP3 is strongly negatively correlated with circulating triglycerides and VLDL cholesterol levels. Further, we identified that the circulating oligomeric state, specifically the MMW CTRP3, and not total CTRP3 concentration is negatively associated with BMI and insulin levels. It has been hypothesized that the HMW CTRP3 isomer is the inactive form and that CTRP3 must undergo some form of cleavage to become active [19, 22, 42]. Our data supports the hypothesis, as although the HMW CTRP3 isomer was the predominate form of CTRP3 found in the blood, the concentration of MMW CTRP3 was the oligomeric state that was negatively correlated with triglyceride and VLDL cholesterol levels. Interestingly, this study did not identify a relationship between HMW CTRP3 and triglyceride levels as was identified by Trogen et al [32]. However, the discrepancy between the two studies are potentially due to the different population as Trogen et al. examined CTRP3 oligomers in an obese adult population (average BMI >30 kg/m²) with half of the population studied suffering from type 2 diabetes. Further, the negative correlation between the MMW oligomer of CTRP3 and serum triglycerides in the study described by Trogen et al. [32] approached significance ($p = 0.06$),

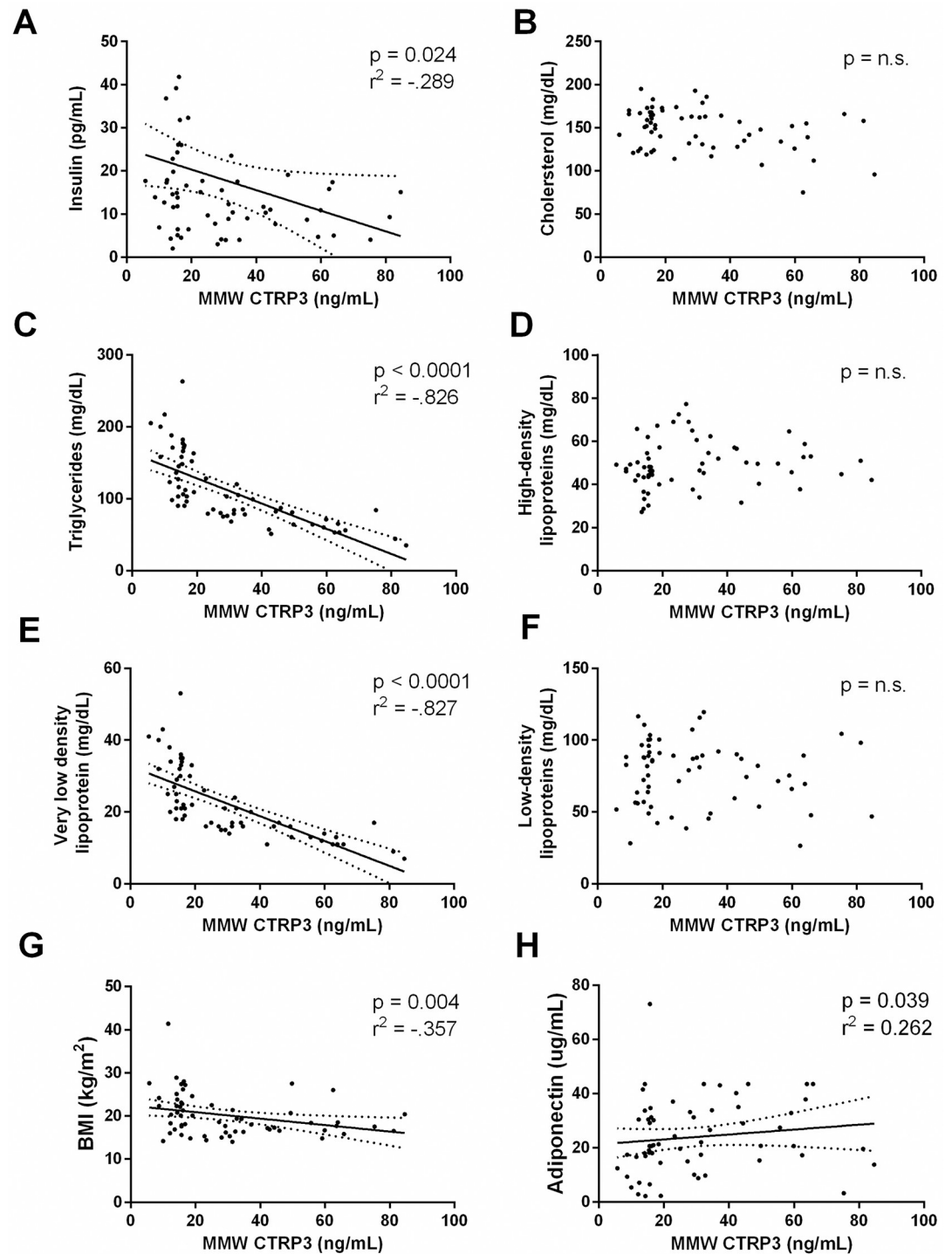


Fig 1. Correlations between MMW CTRP3 and serum analytes. The Spearman's rank-order correlation coefficient was calculated between MMW CTRP3 and serum analytes. Each dot represents a unique individual. When a significant correlation exists the linear relationship is graphed with the solid line and the 95% confidence interval with the dotted lines. Abbreviations: n.s. = not significant, MMW CTRP3 = medium molecular weight CTRP3 oligomer (<300 kDa).

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which agrees with the current findings. Together these data indicate that the oligomeric state is important to the role of CTRP3 and needs to be studied in additional healthy and diseased populations.

Conclusions

Understanding how circulating novel hormonal factors contribute to the development of disease is an essential step towards developing intervention strategies to treat/prevent childhood obesity and metabolic syndrome. Our finding that the specific oligomeric conformation of CTRP3 was strongly and negatively correlated with dyslipidemia indicates that CTRP3 plays a key role in metabolic health and its dysregulation can be an early sign of the development of metabolic disease.

Study limitations

The relatively small sample size ($n = 62$) limits some of the significance of the study findings. However, this is the second study with a unique population which has identified the correlation of the oligomeric conformation of CTRP3 and triglyceride levels. Further, the strong negative correlation identified within this population between MMW CTRP3 and triglyceride as well as VLDL cholesterol levels, combined with the previously published work in animals, strongly supports the role of CTRP3 in regulating triglycerides levels.

The cross-sectional nature of this study precludes making causal claims. However, combined with the previous findings of CTRP3 preventing hepatic triglyceride synthesis in rodents [20, 21], a potential mechanism for CTRP3-induced triglyceride regulation has been identified and requires further analysis. Lastly, we did not study the oligomeric state of other adipokines, especially adiponectin, as it was outside the scope and budget of the current study. However, the relationship between the oligomerization state of the other pertinent adipokines requires further study in the pediatric population.

Supporting information

S1 Data.

(XLSX)

S1 Fig. CTRP3 was not detectable in the LMW fraction.

(DOCX)

S1 Table. Spearman's rank-order correlation coefficient for total CTRP3 and other metabolic parameters.

(DOCX)

S2 Table. Spearman's rank-order correlation coefficient for HMW CTRP3 and other metabolic parameters.

(DOCX)

S3 Table. Spearman's rank-order correlation coefficient for MMW CTRP3 and other metabolic parameters.

(DOCX)

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References

1. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA*. 2014; 311(8):806–14. <https://doi.org/10.1001/jama.2014.732> PMID: 24570244.
2. Troiano RP, Flegal KM. Overweight children and adolescents: description, epidemiology, and demographics. *Pediatrics*. 1998; 101(3 Pt 2):497–504. PMID: 12224656.
3. Ekelund U, Anderssen S, Andersen LB, Riddoch CJ, Sardinha LB, Luan J, et al. Prevalence and correlates of the metabolic syndrome in a population-based sample of European youth. *Am J Clin Nutr*. 2009; 89(1):90–6. <https://doi.org/10.3945/ajcn.2008.26649> PMID: 19056570.
4. Maligie M, Crume T, Scherzinger A, Stamm E, Dabelea D. Adiposity, fat patterning, and the metabolic syndrome among diverse youth: the EPOCH study. *J Pediatr*. 2012; 161(5):875–80. <https://doi.org/10.1016/j.jpeds.2012.05.003> PMID: 22703953
5. Seldin MM, Tan SY, Wong GW. Metabolic function of the CTRP family of hormones. *Rev Endocr Metab Disord*. 2014; 15(2):111–23. <https://doi.org/10.1007/s11154-013-9255-7> PMID: 23963681
6. Pardo M, Roca-Rivada A, Seoane LM, Casanueva FF. Obesidomics: contribution of adipose tissue secretome analysis to obesity research. *Endocrine*. 2012; 41(3):374–83. <https://doi.org/10.1007/s12020-012-9617-z> PMID: 22434412.
7. Schaffler A, Buechler C. CTRP family: linking immunity to metabolism. *Trends Endocrinol Metab*. 2012; 23(4):194–204. <https://doi.org/10.1016/j.tem.2011.12.003> PMID: 22261190.
8. Conde J, Scotece M, Gomez R, Lopez V, Gomez-Reino JJ, Lago F, et al. Adipokines: biofactors from white adipose tissue. A complex hub among inflammation, metabolism, and immunity. *Biofactors*. 2011; 37(6):413–20. <https://doi.org/10.1002/biof.185> PMID: 22038756.
9. Wong GW, Krawczyk SA, Kitidis-Mitrokostas C, Revett T, Gimeno R, Lodish HF. Molecular, biochemical and functional characterizations of C1q/TNF family members: adipose-tissue-selective expression patterns, regulation by PPAR-gamma agonist, cysteine-mediated oligomerizations, combinatorial associations and metabolic functions. *Biochem J*. 2008; 416(2):161–77. <https://doi.org/10.1042/BJ20081240> PMID: 18783346
10. Schaffler A, Scholmerich J, Salzberger B. Adipose tissue as an immunological organ: Toll-like receptors, C1q/TNFs and CTRPs. *Trends Immunol*. 2007; 28(9):393–9. <https://doi.org/10.1016/j.it.2007.07.003> PMID: 17681884.
11. Wong GW, Wang J, Hug C, Tsao TS, Lodish HF. A family of Acrp30/adiponectin structural and functional paralogs. *Proc Natl Acad Sci U S A*. 2004; 101(28):10302–7. <https://doi.org/10.1073/pnas.0403760101> PMID: 15231994
12. Scherer PE, Williams S, Fogliano M, Baldini G, Lodish HF. A novel serum protein similar to C1q, produced exclusively in adipocytes. *J Biol Chem*. 1995; 270(45):26746–9. <https://doi.org/10.1074/jbc.270.45.26746> PMID: 7592907.
13. Alvarez-Llamas G, Szalowska E, de Vries MP, Weening D, Landman K, Hoek A, et al. Characterization of the human visceral adipose tissue secretome. *Mol Cell Proteomics*. 2007; 6(4):589–600. <https://doi.org/10.1074/mcp.M600265-MCP200> PMID: 17255083.
14. Coleman DL. A historical perspective on leptin. *Nat Med*. 2010; 16(10):1097–9. <https://doi.org/10.1038/nm1010-1097> PMID: 20930752.

15. Diez JJ, Iglesias P. The role of the novel adipocyte-derived hormone adiponectin in human disease. *Eur J Endocrinol*. 2003; 148(3):293–300. <https://doi.org/10.1530/eje.0.1480293> PMID: 12611609.
16. Ukkola O, Santaniemi M. Adiponectin: a link between excess adiposity and associated comorbidities? *J Mol Med (Berl)*. 2002; 80(11):696–702. <https://doi.org/10.1007/s00109-002-0378-7> PMID: 12436346.
17. Stefan N, Bunt JC, Salbe AD, Funahashi T, Matsuzawa Y, Tataranni PA. Plasma adiponectin concentrations in children: relationships with obesity and insulinemia. *J Clin Endocrinol Metab*. 2002; 87(10):4652–6. <https://doi.org/10.1210/jc.2002-020694> PMID: 12364452.
18. Asterholm IW, Scherer PE. Enhanced metabolic flexibility associated with elevated adiponectin levels. *The American journal of pathology*. 2010; 176(3):1364–76. <https://doi.org/10.2353/ajpath.2010.090647> PMID: 20093494
19. Peterson JM, Wei Z, Wong GW. C1q/TNF-related protein-3 (CTRP3), a novel adipokine that regulates hepatic glucose output. *J Biol Chem*. 2010; 285(51):39691–701. <https://doi.org/10.1074/jbc.M110.180695> PMID: 20952387
20. Peterson JM, Seldin MM, Wei Z, Aja S, Wong GW. CTRP3 attenuates diet-induced hepatic steatosis by regulating triglyceride metabolism. *Am J Physiol Gastrointest Liver Physiol*. 2013; 305(3):G214–24. <https://doi.org/10.1152/ajpgi.00102.2013> PMID: 23744740
21. Trogen G, Bacon J, Li Y, Wright GL, Degroat A, Hagood KL, et al. Transgenic overexpression of CTRP3 prevents alcohol-induced hepatic triglyceride accumulation. *Am J Physiol Endocrinol Metab*. 2018; 315(5):E949–E60. <https://doi.org/10.1152/ajpendo.00050.2018> PMID: 29763374
22. Li Y, Wright GL, Peterson JM. C1q/TNF-Related Protein 3 (CTRP3) Function and Regulation. *Compr Physiol*. 2017; 7(3):863–78. PMID: 28640446.
23. Wolf RM, Lei X, Yang ZC, Nyandjo M, Tan SY, Wong GW. CTRP3 deficiency reduces liver size and alters IL-6 and TGFbeta levels in obese mice. *Am J Physiol Endocrinol Metab*. 2016; 310(5):E332–45. <https://doi.org/10.1152/ajpendo.00248.2015> PMID: 26670485
24. Wagner RM, Sivagnanam K, Clark WA, Peterson JM. Divergent relationship of circulating CTRP3 levels between obesity and gender: a cross-sectional study. *PeerJ*. 2016; 4:e2573. <https://doi.org/10.7717/peerj.2573> PMID: 27781167
25. Flehmig G, Scholz M, Kloting N, Fasshauer M, Tonjes A, Stumvoll M, et al. Identification of adipokine clusters related to parameters of fat mass, insulin sensitivity and inflammation. *PLoS One*. 2014; 9(6):e99785. <https://doi.org/10.1371/journal.pone.0099785> PMID: 24968098
26. Trogen G, Alamian A, Peterson JM. High molecular weight, but not total, CTRP3 levels are associated with serum triglyceride levels. *Physiol Rep*. 2019; 7(23):e14306. <https://doi.org/10.14814/phy2.14306> PMID: 31814309
27. Deng W, Li C, Zhang Y, Zhao J, Yang M, Tian M, et al. Serum C1q/TNF-related protein-3 (CTRP3) levels are decreased in obesity and hypertension and are negatively correlated with parameters of insulin resistance. *Diabetol Metab Syndr*. 2015; 7:33. <https://doi.org/10.1186/s13098-015-0029-0> PMID: 25878729
28. Qu H, Deng M, Wang H, Wei H, Liu F, Wu J, et al. Plasma CTRP-3 concentrations in Chinese patients with obesity and type II diabetes negatively correlate with insulin resistance. *J Clin Lipidol*. 2015; 9(3):289–94. <https://doi.org/10.1016/j.jacl.2015.03.006> PMID: 26073386.
29. Wolf RM, Steele KE, Peterson LA, Magnuson TH, Schweitzer MA, Wong GW. Lower Circulating C1q/TNF-Related Protein-3 (CTRP3) Levels Are Associated with Obesity: A Cross-Sectional Study. *PLoS One*. 2015; 10(7):e0133955. <https://doi.org/10.1371/journal.pone.0133955> PMID: 26222183
30. Yoo HJ, Hwang SY, Hong HC, Choi HY, Yang SJ, Choi DS, et al. Implication of progranulin and C1q/TNF-related protein-3 (CTRP3) on inflammation and atherosclerosis in subjects with or without metabolic syndrome. *PLoS One*. 2013; 8(2):e55744. <https://doi.org/10.1371/journal.pone.0055744> PMID: 23409033
31. Alhassan BA, Liu Y, Slawson D, Peterson JM, Marrs JA, Clark WA, et al. The influence of maternal body mass index and physical activity on select cardiovascular risk factors of preadolescent Hispanic children. *PeerJ*. 2018; 6:e6100. <https://doi.org/10.7717/peerj.6100> PMID: 30581681
32. Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z, et al. 2000 CDC Growth Charts for the United States: methods and development. *Vital Health Stat 11*. 2002;(246):1–190. PMID: 12043359.
33. de Onis M, Onyango AW, Borghi E, Garza C, Yang H, Group WHOMGRS. Comparison of the World Health Organization (WHO) Child Growth Standards and the National Center for Health Statistics/WHO international growth reference: implications for child health programmes. *Public Health Nutr*. 2006; 9(7):942–7. <https://doi.org/10.1017/phn20062005> PMID: 17010261.
34. Ogden CL, Kuczmarski RJ, Flegal KM, Mei Z, Guo S, Wei R, et al. Centers for Disease Control and Prevention 2000 growth charts for the United States: improvements to the 1977 National Center for Health

- Statistics version. *Pediatrics*. 2002; 109(1):45–60. <https://doi.org/10.1542/peds.109.1.45> PMID: 11773541.
35. Schwarz NG, Grobusch MP, Decker ML, Goesch J, Poetschke M, Oyakhrome S, et al. WHO 2006 child growth standards: implications for the prevalence of stunting and underweight-for-age in a birth cohort of Gabonese children in comparison to the Centers for Disease Control and Prevention 2000 growth charts and the National Center for Health Statistics 1978 growth references. *Public Health Nutr*. 2008; 11(7):714–9. <https://doi.org/10.1017/S1368980007001449> PMID: 18167166.
 36. Petersen PS, Wolf RM, Lei X, Peterson JM, Wong GW. Immunomodulatory roles of CTRP3 in endotoxemia and metabolic stress. *Physiol Rep*. 2016; 4(5). <https://doi.org/10.14814/phy2.12735> PMID: 26997632
 37. Tan BK, Chen J, Hu J, Amar O, Mattu HS, Adya R, et al. Metformin increases the novel adipokine cartonectin/CTRP3 in women with polycystic ovary syndrome. *J Clin Endocrinol Metab*. 2013; 98(12): E1891–900. <https://doi.org/10.1210/jc.2013-2227> PMID: 24152681.
 38. Ban B, Bai B, Zhang M, Hu J, Ramanjaneya M, Tan BK, et al. Low serum cartonectin/CTRP3 concentrations in newly diagnosed type 2 diabetes mellitus: in vivo regulation of cartonectin by glucose. *PLoS One*. 2014; 9(11):e112931. <https://doi.org/10.1371/journal.pone.0112931> PMID: 25409499
 39. Choi KM, Hwang SY, Hong HC, Yang SJ, Choi HY, Yoo HJ, et al. C1q/TNF-related protein-3 (CTRP-3) and pigment epithelium-derived factor (PEDF) concentrations in patients with type 2 diabetes and metabolic syndrome. *Diabetes*. 2012; 61(11):2932–6. <https://doi.org/10.2337/db12-0217> PMID: 22837306
 40. Peterson JM. Identification of cell surface receptors for the novel adipokine CTRP3. *The FASEB Journal*. 2016; 30(1 Supplement):1249.2.
 41. Wurm S, Neumeier M, Weigert J, Schaffler A, Buechler C. Plasma levels of leptin, omentin, collagenous repeat-containing sequence of 26-kDa protein (CORS-26) and adiponectin before and after oral glucose uptake in slim adults. *Cardiovasc Diabetol*. 2007; 6:7. <https://doi.org/10.1186/1475-2840-6-7> PMID: 17311679
 42. Li Y, Ozment T, Wright GL, Peterson JM. Identification of Putative Receptors for the Novel Adipokine CTRP3 Using Ligand-Receptor Capture Technology. *Plos One*. 2016; 11(10):e0164593. <https://doi.org/10.1371/journal.pone.0164593> PMID: 27727322