

University of Groningen

Lipocalin 2 and the pathophysiology of Alzheimer's disease

Dekens, Doortje W.

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2019

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Dekens, D. W. (2019). *Lipocalin 2 and the pathophysiology of Alzheimer's disease*. Rijksuniversiteit Groningen.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Chapter 5

Dynamics of neutrophil gelatinase-associated lipocalin plasma and cerebrospinal fluid concentrations in older males

Naudé PJW^{a,b,*}, Dekens DW^{a,b,*}, Eisel ULM^{b,c}, den Daas I^d, De Deyn PP^{a,e}

^aDepartment of Neurology and Alzheimer Research Center, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands.

^bDepartment of Molecular Neurobiology, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, Groningen, the Netherlands.

^cUniversity Center of Psychiatry & Interdisciplinary Center of Psychopathology of Emotion Regulation, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands.

^dQPS Netherlands BV, Groningen, the Netherlands.

^eLaboratory of Neurochemistry and Behavior, Biobank, Institute Born-Bunge, University of Antwerp, Antwerp, Belgium.

* Shared first author.

Eur J Clin Invest. 2017; 47(12).

Abstract

Background Neutrophil gelatinase-associated lipocalin (NGAL) is an inflammatory protein with gaining increasing interest for its use as marker in blood and cerebrospinal fluid (CSF) for several chronic diseases. Its biochemical properties make it an attractive marker. However, changes in blood and CSF NGAL concentrations during the diurnal rhythm in the elderly are unknown. This information is important for its optimal use as marker in studies with older people.

Methods Serial paired plasma and CSF samples were obtained from 8 healthy elderly males over a 30-hour period. NGAL and cortisol were quantified with ELISA.

Results No significant changes in plasma and CSF NGAL concentrations over time were found, whereas cortisol (included as internal control) concentrations displayed significant changes over time. Significant circadian patterns were found for plasma NGAL and for cortisol in both plasma and CSF. However, CSF NGAL concentrations did not follow a diurnal pattern in elderly males.

Conclusions This study illustrates the temporal regulation of NGAL in plasma and CSF, which potentially is a useful reference for studies measuring NGAL as biomarker in older individuals.

Introduction

Neutrophil gelatinase-associated lipocalin (NGAL), also known as lipocalin-2, siderocalin, 24p3 or uterocalin, is a 25 kDa acute phase inflammatory protein. NGAL exists as a monomer, homodimer or heterodimers with matrix metalloproteinase-9 (MMP9) [1]. It functions as a bacteriostatic agent by binding to bacterial siderophores and interferes with siderophore-mediated iron acquisition [2]. NGAL is gaining mounting interest in basic and clinical studies for its use as an inflammatory marker for various diseases. The associations of serum and plasma NGAL concentrations with disease are actively studied in various research fields, including cardiovascular disease [3], cancer [4] and neuropsychiatry, that is depression [5]. Urine NGAL concentrations are studied in kidney injury [6, 7], and CSF NGAL concentrations are measured in multiple sclerosis [8], mild cognitive disorders and Alzheimer's disease [9]. In addition to the robust changes of NGAL concentrations in certain diseases, its attractiveness for studies rests upon its physical properties that make it suitable for application as a biomarker. It is resistant to proteolytic degradation [10] and possesses great storage stability [11, 12]. However, NGAL concentrations like other inflammatory markers oscillate according to a day/night cycle. A study by Scheer et al. [13] in young healthy male participants showed that serum NGAL concentrations significantly change during a 24-hour day/night cycle. However, ageing can have a dampening effect on circadian rhythms [14]. In this respect, an altered circadian regulation of immune markers was found in elderly people [15]. However, the effect of an ageing physiological environment on the diurnal regulation of NGAL concentrations in blood and CSF is still unknown. This is of importance for studying NGAL concentrations in clinical studies because the majority of research on this topic investigates the association of blood and CSF NGAL concentrations with diseases that primarily occur in older persons.

The main aim of this study was to characterise if the dynamics of NGAL in serial measures of plasma and CSF is reduced in older male volunteers by (i) investigating changes of concentrations over time, (ii) determining circadian regulation of NGAL and (iii) studying the relationship between plasma and CSF NGAL over time, with cortisol as reference marker.

Methods

Study volunteers

After a screening process as previously described [16], serial CSF and plasma were obtained from eight healthy older volunteers of on average 63.25 years of age (Table 1). Study participants did not have any chronic or acute diseases and were not using any medication. The study protocol was approved by the local Institutional Ethics Committee (Stichting Beoordeling Ethiek Bio-Medisch Onderzoek, Assen, the Netherlands) and participants gave informed consent.

Table 1 Participant demographics.

Number of participants	8
Age, mean	63.25 (57-69)
Body Mass Index, mean	24.0 (20.5-26.3)
Gender (Male) (%)	100 %
hsCRP (mg/L) at baseline	2.17 (0.16-9.92)
hsCRP (mg/L) at last measure, mean (SD)	1.51 (0.27-5.16)

Sampling of plasma and CSF

The methodology of the serial plasma and CSF sampling used in this study was described previously [16]. In brief, after being assessed for eligibility during a 3-week screening period, the subjects came to the Clinical Pharmacology Unit on the evening of day 2. On day 1, an intravenous cannula was inserted. During day 1, each volunteer received 2 L of 0.9 % saline solution by infusion.

Intradural catheterisation was performed on day 1 by an experienced anesthesiologist in strict surgical aseptic conditions in a separate room. For antithrombotic purposes, fraxiparine (nadroparine calcium) was given 12 and 36 hours after intradural catheterisation and each subject wore elastic compression stockings.

Lights were turned off from 24:00 to 7:00 hours to allow participants to sleep. Subjects were allowed to eat before entering the study centre. Meals were not to be taken within 1 hour before start of procedure of inserting the intradural cannula. During the day in the study centre, subjects received standard meals according to QPS standard operating procedures during their stay in the clinic. Drinking of alcoholic beverages was not permitted from day 2 until follow-up. The intake of water, caffeinated coffee and tea was ad libitum during the whole study. While resident, subjects were encouraged to drink at least 1500 mL fluid per day. Smoking was not permitted on the days of CSF sampling.

Paired plasma and CSF samples were collected (2 mL per sample) by interval sampling over a 30-hour period on day 1 and day 2 under strict surgical aseptic conditions by the medical staff at the bed site. Samples were withdrawn at 1-hour intervals by aspiration with a syringe from $t = 0$ to 12 hours, at 4-hour intervals between $t = 12$ hours and $t = 24$ hours and at 2-hour intervals from $t = 24$ to 30 hours. This resulted in a total of nineteen paired serial samples. CSF and plasma serial sampling commenced at $t = 0$ (10:00 hours) in the morning, immediately after fixation of the intradural catheter.

Analyses of blood and CSF markers

Plasma and CSF NGAL concentrations were quantified using human NGAL capture antibody (R&D Systems, Minneapolis, MN, USA), recombinant human NGAL (R&D Systems) for the internal standard and biotinylated human NGAL detection antibody (R&D Systems) according to the manufacturer's protocol. Plasma was diluted 1:100 and CSF was not diluted for analyses. The intra- and interassay coefficients of variation were 3% and 5%, respectively. Cortisol in plasma and CSF and plasma C-reactive protein were measured with ELISA (Abnova,

Taipei City, Taiwan), according to the manufacturer's recommendations. The intra-assay coefficients of variation for cortisol and CRP were 3%, and interassay coefficients were 9% and 10%, respectively. Reporting of the study conforms to STROBE statement along with references to STROBE statement and the broader EQUATOR guidelines [17].

Statistical analyses

A paired samples t test on Ln-transformed CRP values was used to compare CRP concentrations between baseline measurement and the last measurement. Due to sampling at unequal intervals, a linear mixed model was used to determine changes of NGAL and cortisol over time. The Akaike information criteria (AIC) value indicated first-order autoregressive covariance structure as a better fit than compound symmetry, compound symmetry heterogeneous or toeplitz. Therefore, first-order autoregressive covariance structure was used to account for the longitudinal relationship of samples. Time was included as fixed effect and subject as random intercept. NGAL and cortisol concentrations were log transformed prior to the analysis, which reduced skewedness and satisfied assumptions for homogeneity of variance. Covariates were not included due to the homogenous study group used in this study.

Rhythmic diurnal variations were determined with cosinor analyses [18]. Analysis was performed similar to that previously described [19]. Hourly concentrations of NGAL and cortisol in plasma and CSF of each participant were normalised to their respective mean concentration over 30 hours. The linear concentration rise over time for plasma and CSF NGAL and cortisol was subtracted out of the mean concentrations, and a single cosinor fit was applied. A cosine transformation was applied to the time variable using 24 hours as the default circadian cycle. The amplitude, which is the distance between the peak and the midline of the cosine wave, was determined for NGAL and cortisol. Midline estimating statistic of rhythm (MESOR) is half of the midway between the highest and the lowest values of the fitted cosine curve. The acrophase represents the peak time of the fitted cosine. A 24-hour rhythm was accepted if the null amplitude hypothesis was rejected ($P < .05$) from an F test. GraphPad Prism version 5.01 for Windows was used for analyses of diurnal rhythms of NGAL and cortisol in plasma and CSF.

Statistical analyses were performed with SPSS version 22. P-values were considered statistically significant at a value of $<.05$.

Results

Participants

This study included healthy older men. The youngest subject was 57, and the oldest was 69 years of age. The mean BMI was 24.0 ± 2.0 kg/m², mean height was 181 ± 9.4 cm and mean weight was 78.9 ± 8.3 kg (Table 1). Plasma CRP concentrations were within normal range (<10 mg/L), indicating the absence of acute inflammation [20]. Plasma CRP concentrations were not significantly different ($P = .56$) between baseline (10:00 hours, day 1) and last measurement (16:00 hours, day 2) of the study. One participant withdrew from the study

after the fourth hour due to difficulties in obtaining CSF samples. Because only four consecutive plasma samples and two CSF samples were obtained, this participant was excluded from further analyses.

NGAL and cortisol concentrations in plasma and CSF

A mean peak value of 139 ± 45 ng/mL for plasma NGAL was observed at 02:00 hours (Figure 1A) and for CSF 1229 ± 281 pg/mL at 06:00 hours (Figure 1B). Repeated measures analysis with linear mixed model showed no significant changes in plasma NGAL concentrations ($P = .26$) or NGAL concentrations in CSF ($P = .17$) over time.

For plasma cortisol, a peak of 243 ± 115 ng/mL was observed at 06:00 hours (Figure 1C) and for CSF cortisol, 39 ± 6 ng/mL at 10:00 hours in the baseline measurement (Figure 1D). As expected, significant changes of cortisol in plasma ($P = .001$) and in CSF ($P < .001$) over time were found.

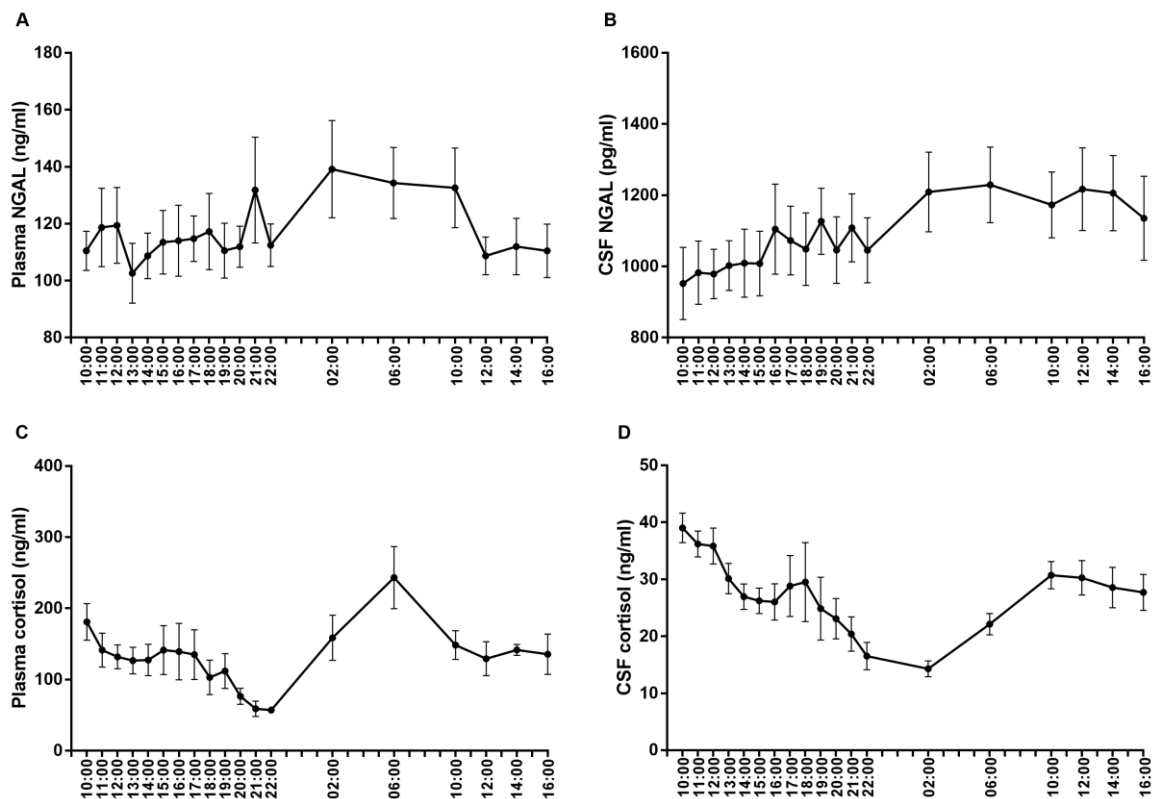


Fig. 1 Mean plasma and cerebrospinal fluid concentrations of neutrophil gelatinase-associated lipocalin and cortisol over time, presented as \pm standard error of the mean (SEM).

Diurnal characteristics of NGAL in older participants

Figure 2 shows the cosine transformation of the mean-adjusted group average (percentage of mean) data for 30-hour variations of NGAL and cortisol in plasma and CSF in older male subjects. For plasma NGAL, cosine analyses revealed a significant rhythm ($P = .001$) with a peak time at 02:12 hours (Figure 2A). NGAL concentrations in CSF, however, did not follow a

cosinor rhythm ($P = .18$; Figure 2B). A significant cosinor fit was found for cortisol in plasma ($P = .001$; Figure 2C) as well as for cortisol in CSF ($P < .001$; Figure 2D). Amplitude peaks for cortisol occurred at 07:10 hours in plasma and at 10:10 hours in CSF.

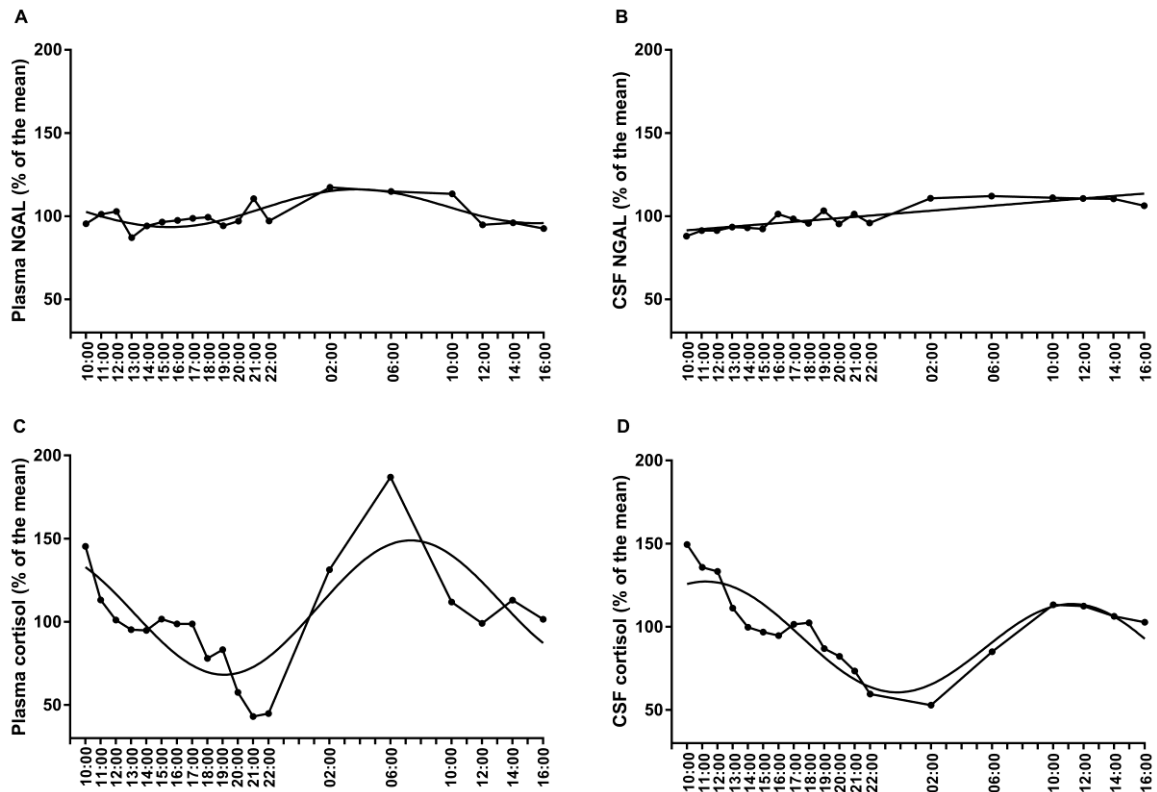


Fig. 2 Diurnal regulation of plasma and cerebrospinal fluid (CSF) of neutrophil gelatinase-associated lipocalin (NGAL) and cortisol illustrated by cosinor fits. Data presented as mean-adjusted average of NGAL and cortisol levels over 30 hours for all subjects. (A) Plasma NGAL: amplitude, -10.76 (95% CI, -15.77 to -5.75); mesor, 103.5 ; acrophase, $02:12$ hours (95% CI: 92.15 – 92.89). (B) CSF NGAL: amplitude, 3.1 (95% CI: -6.46 to 0.25); mesor, 92.43 ; acrophase, $05:20$ hours (95% CI: 104.3 – 106.0). (C) Plasma cortisol: amplitude, 38.60 (95% CI: 20.78 – 56.42); mesor, 103.8 ; acrophase, $07:10$ hours (95% CI: 100.5 – 101.5). (D) CSF cortisol: amplitude, 29.86 (95% CI: -38.91 to 20.82); mesor, 98.75 ; acrophase, $10:10$ hours (95% CI: 102.1 – 103.4).

Discussion

The main findings of this study show that the average plasma and CSF NGAL concentrations do not significantly change over time in older males. Plasma NGAL concentrations have a diminished circadian rhythm compared to plasma cortisol, and no circadian rhythmicity was found for CSF NGAL concentrations in older individuals.

NGAL in plasma and CSF

Our data show that plasma NGAL concentrations significantly fit a cosinor circadian rhythm, which is in accordance with a previous study that reported a diurnal rhythm of NGAL concentrations in blood [13]. However, no significant changes in concentrations over time were found with mixed linear regression analyses. The reduced amplitude of the circadian

rhythm for plasma NGAL shown in this study may explain less variation of plasma NGAL concentrations over time. In the study by Scheer et al., young adults demonstrated (i) a higher peak-to-trough difference (40.4%) compared to the older persons (20.5%) examined in our study and (ii) a different timing in peak and trough concentrations at 18:00 and 03:45 hours, while we found peak and trough NGAL concentrations at 02:12 and 15:45 hours, and (iii) a lower 24-hour mean NGAL level (29 ng/mL) compared to our study (116 ng/mL). Reduction in amplitude and changes in phase of circadian rhythm of blood NGAL concentrations might largely be caused by ageing [14]. Higher serum and plasma NGAL concentrations are associated with increase in age [5, 21], which can explain the higher NGAL concentrations in the older people of this study. Of note, CRP concentrations were determined in the first and last plasma measures to evaluate inflammatory status of the study volunteers.

The current study is the first to analyse diurnal variations in CSF NGAL concentrations. Interestingly, our results show nonsignificance for cosinor fit and mixed linear regression for CSF NGAL concentrations. Considering single NGAL and cortisol CSF measurements in previous studies, it seems that the average CSF NGAL concentrations over time (1086 pg/mL) found in our study are in range with previous findings in healthy control subjects (although a wide range should be noted; [8, 9, 22, 23]), while the observed mean CSF cortisol level (27 ng/mL) may be on the high end as compared to previous reports [24-26]. Yet it must be noted that the time of day at which samples in the previous studies were obtained often remains unknown, which makes it difficult to fully compare findings.

Cortisol in plasma and CSF

Cortisol concentrations significantly changed over time and had a more robust circadian rhythm than NGAL in plasma and CSF. Our results indicate that the average blood cortisol concentrations were higher (131 ng/mL vs 76 ng/mL), and the amplitude of the cortisol diurnal cycle was smaller (77.2% vs 126.3%), compared to Scheer et al. as well as other studies (summarised by [27]). The higher mean plasma concentrations and smaller amplitude for plasma cortisol cycle in our study as compared to above-mentioned studies can be explained by the older age of the study subjects. The elderly participants in the current investigation were on average 63.3 ± 5.0 years of age, whereas the participants in studies of Scheer et al. and Debono et al were much younger, with on average 20.9 ± 2.1 years of age in the study of Scheer et al. [13, 27]. As shown in multiple studies, mean blood cortisol concentrations rise with age, and the amplitude of the cortisol cycle becomes smaller, which corresponds to our findings [15, 28-30].

Serial CSF analyses for cortisol have to our knowledge only been performed in nonhuman primates [31, 32]. Contrary to NGAL, cortisol concentrations in CSF significantly changed over time and displayed a significant circadian rhythmicity with a trough at 24:00 hours and peak at 10:10 hours.

Utilization of NGAL as marker

Results from this study indicate that the average NGAL concentrations are particularly stable from 10:00 until 21:00 hours, which is a period when blood samples most likely will be collected in practice. Our data further show that CSF NGAL concentrations remain stable over time in older individuals, suggesting that it is reliable marker compared to large variations observed for other inflammatory markers in CSF in serial sampling from older humans [33].

Study limitations

Methodological issues warrant attention for proper interpretation. This study included a relatively small group size with only male participants. However, our group size compares with other studies in this line of research. Outcomes for our cosinor analyses may be skewed due to less frequent sampling between 22:00 and 10:00 hours, which can explain some differences observed in the diurnal rhythm for cortisol found in this study compared to previously discussed literature. Strengths include the investigation of an elderly study group, high-frequency sampling of paired blood and CSF samples over a period of 30 hours, and inclusion of cortisol as a reference marker. Although CSF sampling may be invasive, all participants evaluated their discomfort as no to moderate discomfort and indicated that they would participate in a similar study again [16].

Conclusion

This study confirms our hypothesis that diurnal variation in plasma and CSF NGAL levels is reduced in older males, compared to cortisol as reference marker. Findings from this study indicate that NGAL in plasma and CSF is an attractive marker due to its stability over time. The application of CSF NGAL concentrations as marker is of particular interest for neuroscience-related research due to its stability over time. Future studies are required to determine if a reduced diurnal regulation of NGAL is similarly present in older females. The effect of age-associated diseases on the diurnal regulation of NGAL should be verified for its accurate application as biomarker.

Acknowledgments

This work was supported by ZonMW Deltaplan Dementie Memorabel (733050304 and 733050501) for PJWN, PPDD and ULME. DWD is supported by a grant of the Research School of Behavioral and Cognitive Neurosciences. PJWN is funded by Alzheimer Nederland (WE. 13-2015-19) and NeuroSearch Antwerp. This work was supported by a research grant of the Interuniversity Poles of Attraction (IAP Network P7/16) of the Belgian Federal Science Policy Office, Methusalem excellence grant of the Flemish Government, agreement between Institute Born-Bunge and University of Antwerp, the Medical Research Foundation Antwerp, the Thomas Riellaerts research fund, University Research Fund of the University of Antwerp, Neurosearch Antwerp and the Alzheimer Research Center Groningen. PPDD is a member of the Targeted Network on Common mechanisms and therapeutic avenues for Down

Chapter 5

syndrome and other genetic developmental disorders of the ECNP. Furthermore, ULME and PPDD are supported by Internationale Stichting Alzheimer Onderzoek (ISAO grant #06511).

References

- [1] Strong RK, Bratt T, Cowland JB, Borregaard N, Wiberg FC, Ewald AJ. Expression, purification, crystallization and crystallographic characterization of dimeric and monomeric human neutrophil gelatinase associated lipocalin (NGAL). *Acta Crystallogr D Struct Biol.* 1998;54:93-95.
- [2] Goetz DH, Holmes MA, Borregaard N, Bluhm ME, Raymond KN, Strong RK. The neutrophil lipocalin NGAL is a bacteriostatic agent that interferes with siderophore-mediated iron acquisition. *Mol Cell.* 2002;10:1033-1043.
- [3] Cruz DN, Gaião S, Maisel A, Ronco C, Devarajan P. Neutrophil gelatinase-associated lipocalin as a biomarker of cardiovascular disease: a systematic review. *Clin Chem Lab Med.* 2012;50:1533-1545.
- [4] Lippi G, Meschi T, Nouvenne A, Mattiuzzi C, Borghi L. Neutrophil gelatinase-associated lipocalin in cancer. *Adv Clin Chem.* 2014;64:179-219.
- [5] Naudé PJ, Eisel UL, Comijs HC, et al. Neutrophil gelatinase-associated lipocalin: a novel inflammatory marker associated with late-life depression. *J Psychosom Res.* 2013;75:444-450.
- [6] Singer E, Marko L, Paragas N, et al. Neutrophil gelatinase-associated lipocalin: pathophysiology and clinical applications. *Acta Physiol (Oxf).* 2013;207:663-672.
- [7] Urbchat A, Gauer S, Paulus P, et al. Serum and urinary NGAL but not KIM-1 raises in human postrenal AKI. *Eur J Clin Invest.* 2014;44:652-659.
- [8] Marques F, Mesquita SD, Sousa JC, et al. Lipocalin 2 is present in the EAE brain and is modulated by natalizumab. *Front Cell Neurosci.* 2012;6:33.
- [9] Naudé PJW, Nyakas C, Eiden LE, et al. Lipocalin 2: novel component of proinflammatory signaling in Alzheimer's disease. *FASEB J.* 2012;26:2811-2823.
- [10] Kjeldsen L, Johnsen AH, Sengelov H, Borregaard N. Isolation and primary structure of NGAL, a novel protein associated with human neutrophil gelatinase. *J Biol Chem.* 1993;268:10425-10432.
- [11] Pedersen KR, Ravn HB, Hjortdal VE, Norregaard R, Povlsen JV. Neutrophil gelatinase-associated lipocalin (NGAL): validation of commercially available ELISA. *Scand J Clin Lab Invest.* 2010;70:374-382.
- [12] Han WK, Wagener G, Zhu Y, Wang S, Lee HT. Urinary biomarkers in the early detection of acute kidney injury after cardiac surgery. *Clin J Am Soc Nephrol.* 2009;4:873-882.
- [13] Scheer FA, Chan JL, Fagnoli J, et al. Day/night variations of high-molecular-weight adiponectin and lipocalin-2 in healthy men studied under fed and fasted conditions. *Diabetologia.* 2010;53:2401-2405.
- [14] Monk TH. Aging human circadian rhythms: conventional wisdom may not always be right. *J Biol Rhythms.* 2005;20:366-374.
- [15] Mazzoccoli G, De Cata A, Carughi S, et al. A possible mechanism for altered immune response in the elderly. *In Vivo.* 2010;24:471-487.
- [16] den Daas I, Wemer J, Abou Farha K, et al. Serial CSF sampling over a period of 30 h via an indwelling spinal catheter in healthy volunteers: headache, back pain, tolerability and measured acetylcholine profile. *Eur J Clin Pharmacol.* 2013;69:1083-1090.
- [17] Simera I, Moher D, Hoey J, Schulz KF, Altman DG. A catalogue of reporting guidelines for health research. *Eur J Clin Invest.* 2010;40:35-53.
- [18] Refinetti R, Lissen GC, Halberg F. Procedures for numerical analysis of circadian rhythms. *Biol Rhythm Res.* 2007;38:275-325.
- [19] Huang Y, Potter R, Sigurdson W, et al. Effects of age and amyloid deposition on Abeta dynamics in the human central nervous system. *Arch Neurol.* 2012;69:51-58.
- [20] Vermeire S, Van Assche G, Rutgeerts P. Laboratory markers in IBD: useful, magic, or unnecessary toys? *Gut.* 2006;55:426-431.
- [21] Lim WH, Wong G, Lim EM, et al. Circulating lipocalin 2 levels predict fracture-related hospitalizations in elderly women: a Prospective Cohort Study. *J Bone Miner Res.* 2015;30:2078-2085.
- [22] Al Nimer F, Elliott C, Bergman J, et al. Lipocalin-2 is increased in progressive multiple sclerosis and inhibits remyelination. *Neurol Neuroimmunol Neuroinflamm.* 2016;3:e191.
- [23] Khalil M, Renner A, Langkammer C, et al. Cerebrospinal fluid lipocalin 2 in patients with clinically isolated syndromes and early multiple sclerosis. *Mult Scler.* 2016;22:1560-1568.
- [24] Pearson A, de Vries A, Middleton SD, et al. Cerebrospinal fluid cortisol levels are higher in patients with delirium versus controls. *BMC Res Notes.* 2010;3:33.
- [25] Holub M, Beran O, Dzapova O, et al. Cortisol levels in cerebrospinal fluid correlate with severity and bacterial origin of meningitis. *Crit Care.* 2007;11:R41.
- [26] Mahale RR, Mehta A, Uchil S. Estimation of cerebrospinal fluid cortisol level in tuberculous meningitis. *J Neurosci Rural Pract.* 2015;6:541-544.
- [27] Debono M, Ghobadi C, Rostami-Hodjegan A, et al. Modified-release hydrocortisone to provide circadian cortisol profiles. *J Clin Endocrinol Metab.* 2009;94:1548-1554.
- [28] Van Cauter E, Leproult R, Kupfer DJ. Effects of gender and age on the levels and circadian rhythmicity of plasma cortisol. *J Clin Endocrinol Metab.* 1996;81:2468-2473.
- [29] Kern W, Dodt C, Born J, Fehm HL. Changes in cortisol and growth hormone secretion during nocturnal sleep in the course of aging. *J Gerontol A Biol Sci.* 1996;51:M3-M9.

Chapter 5

- [30] Veldhuis JD, Sharma A, Roelfsema F. Age-dependent and gender-dependent regulation of hypothalamic-adrenocorticotrophic-adrenal axis. *Endocrinol Metab Clin North Am.* 2013;42:201-225.
- [31] Garrick NA, Hill JL, Szele FG, Tomai TP, Gold PW, Murphy DL. Corticotropin-releasing factor: a marked circadian rhythm in primate cerebrospinal fluid peaks in the evening and is inversely related to the cortisol circadian rhythm. *Endocrinology.* 1987;121:1329-1334.
- [32] Umberkoman-Wiita B, Hansen S, Herbert J, Moore GF. Circadian rhythms in serum and CSF cortisol of rhesus monkeys, and their modulation by timed injections of L-5-hydroxytryptophan. *Brain Res.* 1981;222:235-252.
- [33] Llano DA, Li J, Waring JF, et al. Cerebrospinal fluid cytokine dynamics differ between Alzheimer disease patients and elderly controls. *Alzheimer Dis Assoc Disord.* 2012;26:322-328.

