

A new link between steroid resistance, glucocorticoid receptor and nuclear factor kappa B p65 in idiopathic nephrotic syndrome

Katarina SZILAGYI¹, Ludmila PODRACKA², Niels E. FRANKE³,
Jan MOJZIS¹, Ladislav MIROSSAY¹

¹ Safarik University School of Medicine, Department of Pharmacology, Kosice, Slovakia

² Safarik University School of Medicine, Department of Pediatrics, Kosice, Slovakia

³ VU University Medical Center, Department of Pediatric Hematology/Oncology, Amsterdam, The Netherlands

Correspondence to: Katarina Szilagyi, PhD.,
Department of Pharmacology, Safarik University School of Medicine
Trieda SNP 1, 040 01 Kosice, Slovakia.
TEL: +421908115938; FAX: +421556428524; E-MAIL: katarina.szilagyi@gmail.com

Submitted: 2009-08-25 *Accepted:* 2009-09-30 *Published online:* 2009-11-11

Key words: **glucocorticoids; sensitivity; relapse; peripheral blood cells; idiopathic nephrotic syndrome**

Neuroendocrinol Lett 2009; **30**(5):629–636 PMID: 20035271 NEL300509A12 © 2009 Neuroendocrinology Letters • www.nel.edu

Abstract

OBJECTIVES: The aim of our study was to investigate levels of glucocorticoid receptor (GR α), nuclear factor kappa B (NF κ B) p65/p50 and inhibitor of NF κ B alpha (I κ B α) in the peripheral mononuclear blood cells (PMBC) of children with idiopathic nephrotic syndrome (INS).

METHODS: The expression of GR α , NF κ Bp65/p50 and I κ B α was determined in 59 patients (age 10.2 \pm 5.1) and 25 healthy controls (CO) (age 13.1 \pm 3.4) using Western blot analysis. Patients were labeled according to their clinical sensitivity to glucocorticoids (GCs) as responders (RE), partial responders (PR), and non-responders (NR).

RESULTS: Significantly higher expressions of GR α were observed in RE than in PR, NR ($p < 0.01$) and even CO ($p < 0.05$). Similarly, expression of NF κ Bp65 was higher in RE in comparison to PR, NR and CO ($p < 0.05$). These differences were more emphasized in the relapse: levels of GR α were significantly lower in PR than in RE and CO ($p < 0.01$). Significant differences were also observed in expression of NF κ B: RE showed significantly higher expression of NF κ Bp65 in comparison to PR, NR and even CO ($p < 0.01$).

CONCLUSIONS: Lower levels of both GR α and NF κ Bp65 are associated with poor or no response to GCs and the difference is more pronounced in patients experiencing relapse of INS.

Abbreviations :

GCs	- glucocorticoids	RE	- responders
ALL	- acute lymphoblastic leukemia	PR	- partial responders
INS	- idiopathic nephrotic syndrome	NR	- non-responders
GR α	- glucocorticoid receptor alpha	CO	- healthy controls
NF κ B	- nuclear factor kappa B	CI	- calcineurin inhibitors
I κ B	- inhibitor of NF κ B	PBS	- phosphate-buffered saline
PMBC	- peripheral mononuclear blood cells	SDS	- sodium dodecyl sulfate

INTRODUCTION

Glucocorticoids (GCs) are employed in a therapy of various diseases such as asthma, bowel diseases, glomerulopathies and rheumatoid arthritis due to their anti-inflammatory and immunosuppressive effects. In addition, induction of apoptosis underlies their role in a therapy of hematological malignancies, e.g. acute lymphoblastic leukemia (ALL) or lymphomas. However, insufficient response or even resistance to GCs may occur in any of these diseases at the very beginning of therapy (primary resistance) or develop during steroid treatment (secondary resistance) (Kofler *et al.*, 2000).

Steroid-resistant patients represent major therapeutic dilemma especially in disorders where clinical response is closely related to prognosis, as it has been observed in idiopathic nephrotic syndrome (INS). INS is the most frequent glomerular disease in childhood and is characterized by massive proteinuria, edema and hypoalbuminemia. Clinical experience has demonstrated that patients with poor response to steroids have unfavorable prognosis and often develop an end-stage renal failure (Gbadegesin & Smoyer, 2008).

Nevertheless, in general, there is very little known about possible molecular mechanisms that might underlie resistance to GCs. The issue of steroid resistance is being widely studied in the field of hematological malignancies, particularly in ALL. The primary focus of those investigations was to correlate sensitivity to GCs with levels of glucocorticoid receptor alpha (GR α). Indeed, the majority of studies performed on that subject confirmed a link between the level of GR α in target cells and the response to GCs in ALL (Gruber *et al.*, 2009; Pui *et al.*, 1984; Schwartz *et al.*, 2001). In contrast, other studies carried out in various inflammatory diseases found no differences in GR α density between steroid sensitive and resistant subjects (Honda *et al.*, 2000; Lane *et al.*, 1996; Onda *et al.*, 2004; Schlaeghecke *et al.*, 1994).

Besides GR α expression, extensive interest is devoted to other transcriptional factors, e.g. nuclear factor kappa B (NF κ B) (Bantel *et al.*, 2002), which mainly consists of p65/p50 complex and inhibits the function of GR α and vice versa (Scheinman *et al.*, 2002). Experimental data imply that the mechanism of reciprocal transcriptional repression of NF κ B by GR α is mediated through the physical interaction with the p65 subunit alone (McKay & Cidlowski, 1998). Beyond this, the transcriptional activity of the NF κ B p65/p50 heterodimer is regulated by GCs via up-regulation of the NF κ B inhibitor alpha (I κ Ba) (Baeuerle & Baltimore, 1996). These observations are supported by a recent *in vitro* study, which suggests that targeting the NF κ B pathway by enhanced expression of GR α , NF κ Bp65 and I κ B may sensitize cells to GCs (Oerlemans *et al.*, 2007).

In the context of the results obtained from steroid resistance studies in ALL, the aim of our investigation was to elucidate the association between clinical sensi-

tivity to GCs and levels of GR α , NF κ B subunits and I κ Ba in the peripheral mononuclear blood cells (PMBC) of children with INS. Furthermore, levels of GR α , NF κ B p65/p50 and I κ Ba were studied with regard to the activity of disease in order to characterize the pattern of proteins studied expression. In addition, all the results were compared to a control group to identify any differences between patients with INS and healthy subjects.

MATERIALS AND METHODS

Subjects and design of the study

Fifty nine patients with INS, 20 females and 39 males, aged 1–19 years (average age 10.2 years) were enrolled into the study. Patients were divided into three groups according to their response to standard therapy of INS (4-week course of daily oral prednisone at 60 mg/m²/day followed by 40 mg/m²/day on alternate days for an additional four weeks): i) patients with complete remission of proteinuria after only GCs were labeled as “responders” (RE), ii) as “partial responders” (PR) were labeled patients with only partial remission achieved after only GCs (proteinuria fluctuated between 166 mg/1.73m² and < 2 g/1.73 m²) (Ehrich *et al.*, 2008), these patients required additional medications to achieve disease control, iii) “non-responders” (NR) failed to achieve even partial remission after 8 weeks of only steroid therapy.

Moreover, patients were subdivided according to the onset/relapse and remission of the disease. An onset or a relapse of the disease was diagnosed when proteinuria had exceeded 50 mg/m²/kg. Blood samples had been drawn from relapsing patients before therapy of the actual relapse was initiated. More detailed clinical and immunosuppressive treatment characteristics of subjects are listed in Table 1 and Table 2.

As a control group, blood samples were collected from 25 healthy controls (CO), 12 females and 13 males, aged 8–18 years (average age 13.1 years) without any acute disease or a drug history in last two months.

Informed consent was obtained from parents or guardians of all children before enrollment in this study. The study was approved by the Ethic committee of the Safarik University School of Medicine in Kosice, Slovakia.

Blood cells preparation

Peripheral blood was collected in EDTA tubes and processed within 1 hour. The PMBC were isolated from all patients and CO by density centrifugation using the Ficoll PM 400 (Sigma-Aldrich, USA). Each sample of venous blood was diluted 1:1 with phosphate-buffered saline (PBS) and density gradient centrifugation performed at 1 600 rpm for 30 min. at 20 °C. Viability and number of cells were determined using trypan blue.

Western blot analysis

Cell lysates for GR α , NF κ Bp65, NF κ Bp50 and I κ Ba detection were prepared as described before (Haarman

et al., 2004) Briefly, the suspension of cells was promptly frozen in liquid nitrogen, frozen pellet was resuspended in lysis buffer (1.2% Igepal, Sigma-Aldrich, USA in PBS; Protease inhibitor cocktail, Sigma-Aldrich, USA; phenylmethylsulfonyl fluoride, Serva, Germany; aprotinin, Serva, Germany) and lysates were clarified by microcentrifugation. Protein concentration was measured using Bio-Rad D_c Protein Assay (Bio-Rad, USA). Following protein measurement, sample buffer (0.5 mol.l⁻¹ Tris-HCl, pH=6.8; 1% glycerol, 4% sodium dodecyl sulfate (SDS), 0.005% bromphenol blue) supplemented with 5% β-mercaptoethanol was added and lysates were boiled. Immunoblotting was performed as described before (Haarman *et al.*, 2004): twenty micrograms of the total cell lysates were separated on a 7.5% (GRα) and 12.5% (NFκBp65/p50, IκBα and β actin) polyacrylamide gel containing SDS and electroblotted onto a nitrocellulose membrane (Pall Gelman Laboratory, USA). Afterwards membranes were washed and incubated in non-fat dry milk (Laktino, Promil, Czech Republic) to block any non-specific antibody binding. The following primary antibodies were used: anti-GRα (Santa-Cruz, USA, sc-1003, 1:500), anti-NFκBp65 (Santa-Cruz, USA, sc 8008, 1:500), anti-NFκBp50 (Santa-Cruz, USA, sc-8414, 1:1 000), anti-IκBα/MAD3 (BD Transduction Laboratories, USA, 1:1000) and as a control for protein loading anti-β actin (Santa-Cruz, USA, sc-47778, 1:3 000). As secondary antibodies goat-anti-rabbit-HRP (Santa-Cruz, USA, sc-2004, 1:2 000) and goat-anti-mouse-HRP (Dako, USA, p0447, 1:2 000) antibodies were added. Membranes were washed and proteins were visualized by enhanced chemiluminescence (Pierce, USA) according to the manufacturer's instructions on X-ray film (Pierce, USA). The signal intensity of GRα, NFκBp65/p50 and IκBα was determined densitometrically (software Quantity One, Bio-Rad, USA) and normalized to β actin. Levels of GRα, NFκBp65, NFκBp50 and IκBα were expressed relative to an internal standard the value of which was set at 1.

Statistics

Statistical analysis was performed using SPSS for Windows 15.0 (SPSS, Inc., USA) and GraphPad Prism 5 (GraphPad Software, Inc., USA). Based on normality tests, the results were analysed using ANOVA or Kruskal Wallis for multiple comparisons. Significant differences were further confirmed by t-test or Mann-Whitney U test to compare the medians of the two groups. A *p*-value of 0.05 or less was considered statistically significant.

RESULTS

Decreased levels of GRα and NFκBp65 are associated with steroid insensitivity

To determine the correlation between levels of the proteins investigated and any response to treatment with GCs, we analyzed the quantity of GRα, NFκBp65/50 and

Tab. 1. Subjects characteristics.

Parameter	Subjects with INS			Healthy controls
	RE	PR	NR	
Number of individuals (M/F)	12/7	21/5	6/8	13/12
Age at study (mean±SD)	7.8±4.8	10.6±4.7	12.4±5.2	13.1±3.4
Renal biopsy (MCNS/FSGS/none)	8/1/10	21/3/2	1/11/2	-
Status of disease (relapse/remission)	10/9	13/13	13/1	-

M: male; F: female; MCNS: minimal change nephrotic syndrome; FSGS: focal segmental glomerulosclerosis;

Tab. 2. Patients treatment characteristics.

	Subjects with INS		
	RE	PR	NR
Treatment (number of patients):			
- no IS	19	26	14
- GCs	18	16	7
- GCs and/or CI	1	2	3
Time without GCs (months) (mean±SD)	12.8±13.1	9.5±9.6	16.5±13.3
Time with GCs (months) (mean±SD)	4	2±1.4	15±14.78
Dose of GCs (mg/kg/day) (mean±SD)	0.25	0.72±0.76	0.8±0.58

GCs: glucocorticoids; CI: calcineurin inhibitors; IS: immunosuppressant

IκBα in the whole cell lysates of the PMBC of patients and healthy controls using Western blot (Figure 1). Significantly higher expressions of GRα were observed in a group of RE than PR, NR and even CO (*p*=0.0039; 0.0024 and 0.0221; respectively) (Figure 2A).

Similar differences were detected in expression of NFκBp65 subunit between RE and PR, NR and CO (*p*=0.048; 0.002 and 0.022; respectively) (Figure 3A). In contrast, no significant differences were found in the expression of either NFκBp50 or IκBα across all the groups studied (data not shown).

Decline in GRα and NFκBp65 expression is pronounced in the relapse of INS

To gain further insight into whether the level of the proteins studied may vary in association with the activity of disease, the expression of GRα, NFκBp65/p50 and IκBα were compared within clinical subgroups with the remission and relapse of INS. No differences

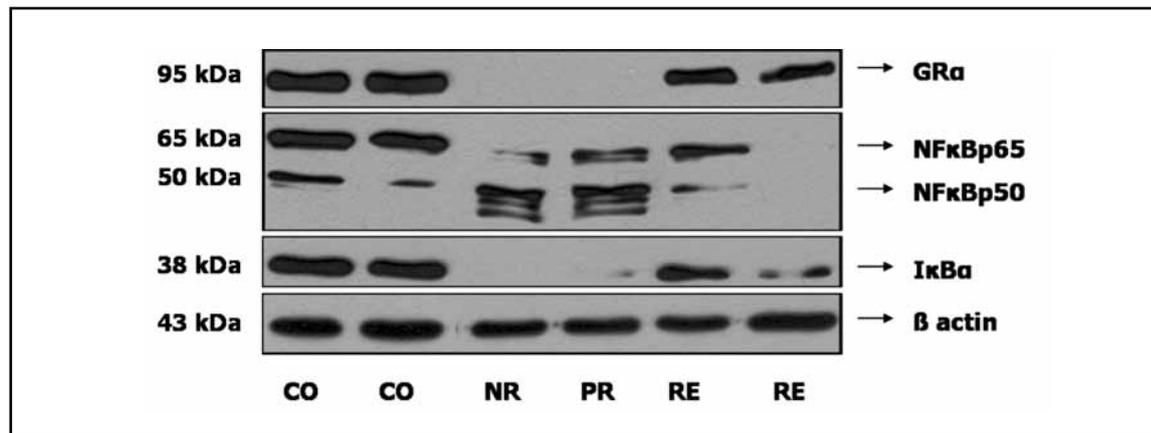


Fig. 1. Western blot analysis of the levels of glucocorticoid receptor alpha (GR α), nuclear factor kappa B (NF κ B) p65/p50 subunits, inhibitor of NF κ B alpha (I κ B α) and β actin (as a control for protein loading) revealing the different amount of proteins studied. The whole cell lysates were prepared from the peripheral mononuclear blood cells (PMBC) of healthy controls (CO) and children with idiopathic nephrotic syndrome (INS) with various responses to glucocorticoids (GCs). Patients without even partial remission after GCs were labeled as non-responders (NR). Those with partial remission after GCs or with other immunosuppressants in an attempt to achieve remission were labeled as partial responders (PR). Responders (RE) represent patients with complete remission after standard treatment with solely GCs.

were observed across any of the groups studied and levels of proteins in the remission of disease, except for the expression of GR α in the RE and CO ($p=0.0094$) (Figure 2B and 3B).

Surprisingly, the expression of GR α and the NF κ Bp65 subunit were significantly different across groups studied in relapse of INS. In particular, the expression of GR α was significantly lower in the PR group than it was in the RE, NR and CO groups ($p=0.0031$; 0.0311 and 0.0004 ; respectively) (Figure 2C). Significant differences were also observed in expression of NF κ B: patients labeled as RE showed significantly higher expression of the p65 subunit in comparison to the PR, NR and CO groups ($p=0.002$; 0.0019 and 0.0088 ; respectively) (Figure 3C).

Interestingly, expression of GR α and NF κ Bp65 did not differ across RE in remission and relapse. However, in a group of PR expression of both GR α and NF κ Bp65 was significantly higher in patients in remission than in those in relapse ($p=0.001$ and 0.0024 ; respectively) (Figure 4A and 4B). Since only one NR was in remission at the time of blood collection, no statistical analysis was performed in this case.

Similar to results observed across clinical groups, no differences in the expression of the p50 subunit of NF κ B were found in relation to the activity of disease (data not shown). However, levels of I κ B α differed significantly within the RE group, where patients in the relapse exhibited significantly higher levels of the protein than those in remission ($p=0.0175$) (Figure 4C).

Tab. 3. Relative expression of GR α , NF κ Bp65, NF κ Bp50 and I κ B α in the PMBC of INS patients and healthy controls.

Subjects	Relative expression of the proteins studied (mean \pm SEM)*			
	GR α	NF κ Bp65	NF κ Bp50	I κ B α
RE total	0.59 \pm 0.09	0.81 \pm 0.11	0.63 \pm 0.063	0.33 \pm 0.08
RE in remission	0.67 \pm 0.11	0.65 \pm 0.17	0.56 \pm 0.09	0.15 \pm 0.07
RE in relapse	0.5 \pm 0.14	0.95 \pm 0.14	0.7 \pm 0.08	0.5 \pm 0.09
PR total	0.28 \pm 0.07	0.51 \pm 0.09	0.67 \pm 0.21	0.27 \pm 0.06
PR in remission	0.49 \pm 0.11	0.76 \pm 0.11	0.55 \pm 0.08	0.32 \pm 0.09
PR in relapse	0.07 \pm 0.04	0.24 \pm 0.1	0.82 \pm 0.43	0.22 \pm 0.08
NR total	0.21 \pm 0.07	0.21 \pm 0.07	0.58 \pm 0.14	0.32 \pm 0.15
NR in remission	-	-	-	-
NR in relapse	0.15 \pm 0.07	0.14 \pm 0.08	0.64 \pm 0.16	0.32 \pm 0.17
CO	0.35 \pm 0.06	0.47 \pm 0.08	0.88 \pm 0.17	0.37 \pm 0.06

* correlated to internal standard included in each experiment value of which was set at 1

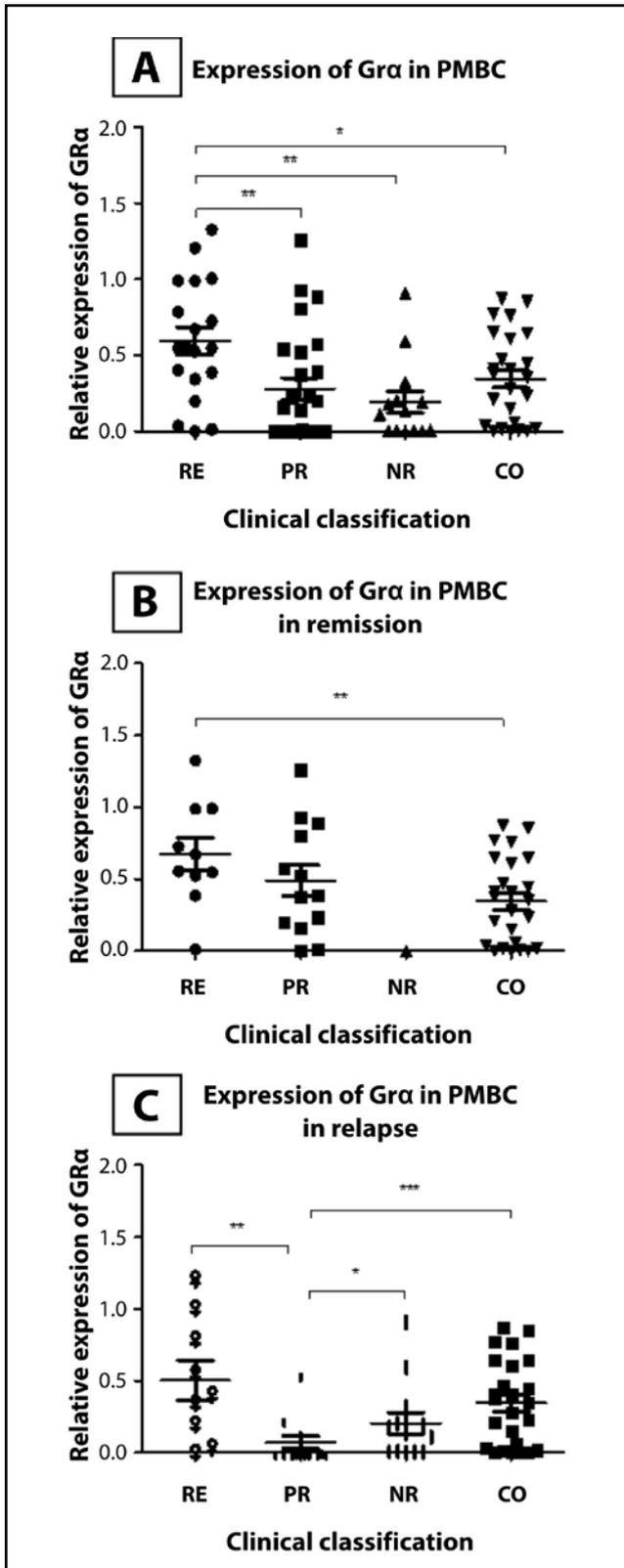


Fig. 2. Relative expression of the glucocorticoid receptor (GRA) in the peripheral mononuclear blood cells (PMBC) of patients with idiopathic nephrotic syndrome (INS) labeled as responders (RE), partial responders (PR) and non-responders (NR) to glucocorticoids (GC). **A** – comparison of clinical subgroups and healthy controls (CO). **B** – comparison of clinical subgroups in remission and CO. **C** – comparison of clinical subgroups in relapse of INS and CO. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; (Mann-Whitney test)

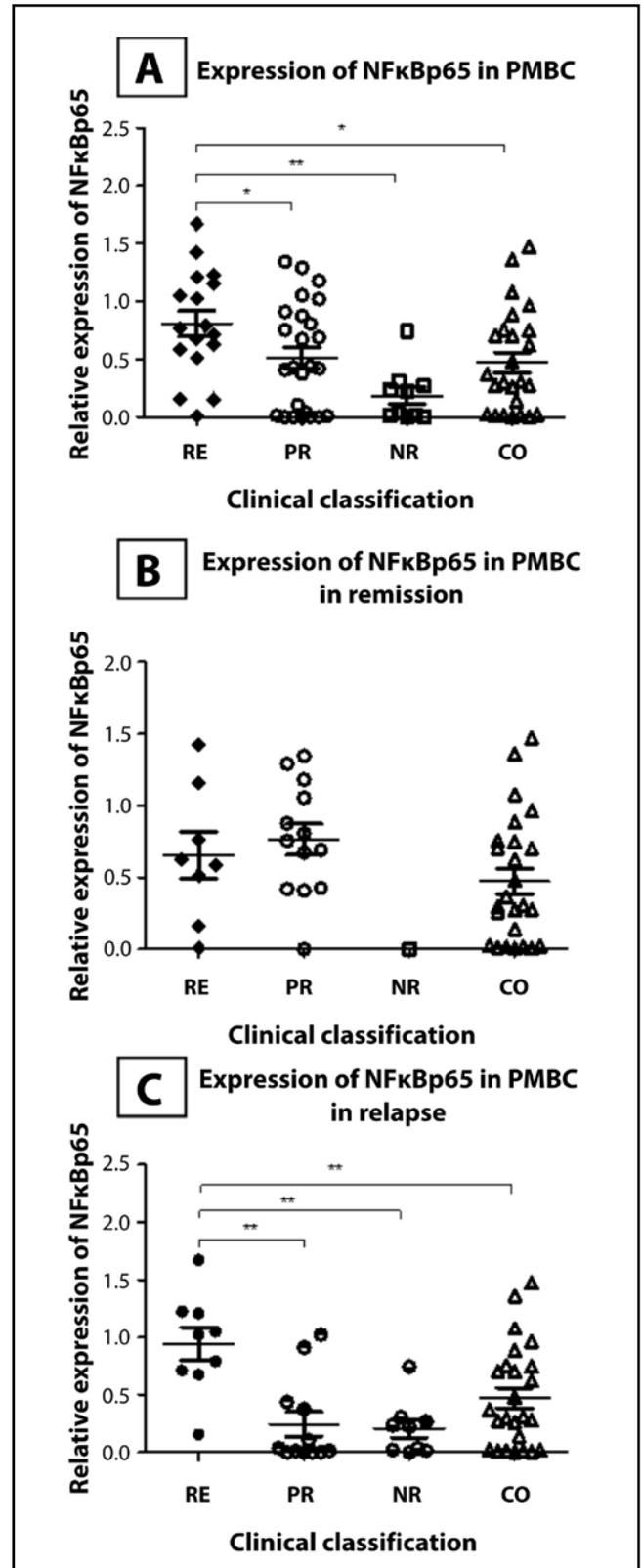


Fig. 3. Relative expression of the nuclear factor kappa B p65 subunit (NFkBp65) in the peripheral mononuclear blood cells (PMBC) of patients with idiopathic nephrotic syndrome (INS) labeled as responders (RE), partial responders (PR) and non-responders (NR) to glucocorticoids (GC). **A** – comparison of clinical subgroups and healthy controls (CO). **B** – comparison of clinical subgroups in remission and CO. **C** – comparison of clinical subgroups in relapse of INS and CO. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; (Mann-Whitney test)

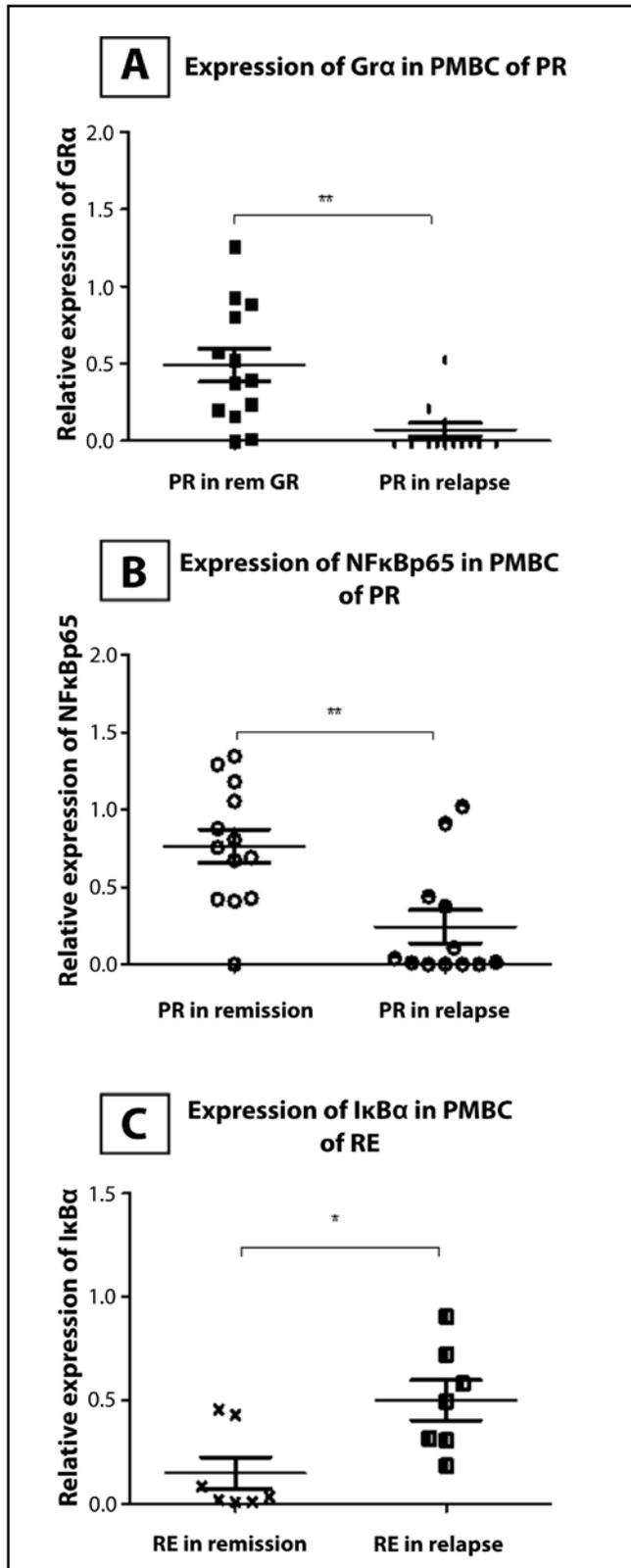


Fig. 4. Relative expression of the glucocorticoid receptor (GRα) and the nuclear factor kappa B (NFκB) p65 in the peripheral mononuclear blood cells (PMBC) of patients with idiopathic nephrotic syndrome (INS) labeled as partial responders (PR) to glucocorticoids (GC). **A** – comparison of levels of GRα in PR in the remission and relapse. **B** – comparison of levels of NFκBp65 in PR in the remission and relapse. **C** – comparison of levels of IκBα in RE in the remission and relapse. ** $p < 0.01$; (Mann-Whitney test).

DISCUSSION

For the first time this study links low levels of both GRα and NFκBp65 subunit with resistance to GCs in INS. Importantly, we have illustrated that the difference is more pronounced when patients with partial and no response to steroids experience relapse.

Miscellaneous effects of GCs are mediated through the GRα localized in the cytoplasm, which is transferred to the nucleus after ligand binding (Davies *et al.*, 2002; Wochnik *et al.*, 2005) and subsequently initiates the transcription of genes regulating cell death and inflammation (Herr *et al.*, 2007). Therefore, it is not surprising that several studies have shown that sensitivity to GCs is partially dependent on the level of receptors found within a cell (Gross *et al.*, 2009). Concurrent with GC responsiveness in cancer (Sanchez-Vega & Gandhi, 2009), GRα expression is positively correlated with sensitivity to steroids in INS in our study ($p < 0.01$) and might provide a further evidence for supporting the earlier observations in proteinuric adults (Han *et al.*, 2008; Tanaka *et al.*, 1992). However, our findings could not confirm previously published data obtained from nephrotic children (Haack *et al.*, 1999; Wasilewska *et al.*, 2003). Several factors that might contribute to those different conclusions should be considered. First, in comparison to the study of Wasilewska *et al.*, (2003), which involved only steroid sensitive patients and healthy controls, children with partial and/or no response were also enrolled in our cohort. Second, our study divided patients in clinical subgroups (RE, PR and NR), that differed from those used by Haack and colleagues (1999).

Interestingly, we also observed that NFκBp65 levels significantly correlated with the steroid response of nephrotic children ($p < 0.05$), which is consistent with experimental data published by Aviles *et al.*, (2004). The mode of mutual inhibition exhibited by GRα and the NFκBp65/p50 complex is conveyed via physical interaction of the receptor and the p65 subunit (Ray & Prefontaine, 1994). Moreover, stoichiometric interaction is required for transcriptional activity of NFκB, thereby its function might be impaired by the imbalanced expression of the p65 and p50 subunits (Perkins, 2000). These findings were supported by *in vitro* experiment using Cos-1 cells transfected with only p50 homodimers, in which no response to GCs was determined (McKay & Cidlowski, 1998). Therefore, insufficient expression of NFκBp65 might be involved in a poor response or resistance to GCs, as it has been observed in our study.

It has been noted that steroid treatment can increase expression of GRα (autoinduction) and that phenomenon might modulate sensitivity to GCs (Eisen *et al.*, 1988); whereas failure of autoinduction in T-cell lines detected after exposure to steroids observed was closely related to resistance (Schmidt *et al.*, 2006). Regarding our clinical observations, the influence of GCs on the measured levels of GRα might be ruled out mainly on

the basis that all but one responsive patients were not being treated with steroids at the time of blood collection. Furthermore, certain individual children using a long-term treatment with partial and no response to GCs expressed slightly higher levels of GR α than those not undergoing treatment. Similar explanation might be applied in the case of NF κ Bp65 expression, which is also influenced by GCs (De Bosscher *et al.*, 2003).

It has been demonstrated that down-regulation in GR α expression in malignant cells between diagnosis and relapse is associated with resistance to steroid therapy (Pui *et al.*, 1984; Bloomfield *et al.*, 1981), hence we also focused on levels of GR α , NF κ Bp65/p50 and I κ Ba in the PMBC at the state of relapse and remission.

Based on this knowledge we theorized whether nephrotic children with various clinical responses to GCs show significant differences in levels of GR α and NF κ B related proteins while experiencing relapse.

Whereas expressions of GR α , NF κ Bp65/p50 and I κ Ba were comparable for patients in remission, to our surprise, levels of both GR α and NF κ Bp65 significantly differed when patients were in the relapse. In particular, a very significant decline in GR α and NF κ Bp65 expression was observed in relapsing PR compared to relapsing RE ($p < 0.01$, both proteins). The same significant difference was found in levels of NF κ Bp65 between NR and RE in the relapse ($p < 0.01$). In addition, both GR α and NF κ Bp65 were dramatically down-regulated in PR with relapse when compared to the same clinical subgroup in remission ($p < 0.01$, both proteins). Due to the fact that achieving remission in corticoreistant patients is very rare, assessment of this specific subgroup could not be performed.

Conceivably, one may think whether the lower levels of GR α and NF κ Bp65 expression seen in our cohort of nephrotic patients might underlie onset and/or relapse of INS. The finding was dominantly pronounced in a group of PR and partially also in NR, therefore, it is more likely that the lower expression of these proteins is related to the response of these patients to steroid treatment in a further course of disease as it has been suggested in pediatric patients with ALL (Pui & Costlow, 1986).

Levels of p50 subunit and I κ Ba were determined in the PMBC of our patients and compared with sensitivity to GCs in general, as well as in respect to the activity of disease. Yet, no differences in protein levels were found between patients with various steroid response and/or healthy controls. Concurrently, the same results were observed for the p50 subunit in the study of Aviles *et al.*, (2004). In regard to I κ Ba expression, experimental investigations have shown increased levels of this protein in tumor and airway cells with *in vitro* sensitivity to GCs (Oerlemans *et al.*, 2007; Kang *et al.*, 2006). However, to our best knowledge no study focusing on I κ Ba levels and steroid sensitivity in INS patients has yet been published. For illustration, Sahali *et al.*, (2001)

suggested a link between a lower expression of the cytosolic I κ Ba levels in the PMBC of patients with steroid sensitivity experiencing relapse of INS, possibly caused by increased proteasome degradation. In contrast, we observe up-regulation of I κ Ba in relapsing RE in comparison to the same clinical subgroup in a remission. That finding corresponds with the role of I κ Ba in the NF κ B-GR α loop (Oerlemans *et al.*, 2007).

In conclusion, our study supports the importance of both GR α and NF κ Bp65 levels in the PMBC in the clinical response to GCs in children with INS. This pivotal observation was even more pronounced in patients with partial and/or no response to GCs experiencing relapse. Our current results encourage further clinical studies in order to find a reliable and effective tool that would indicate the response of nephrotic children to steroids. Such a diagnostic tool may help clinicians to tailor and optimize immunosuppressive treatment of INS or other steroid-treated diseases and thereby avoid the unwanted effects, which are frequently associated with steroid therapy.

ACKNOWLEDGMENTS

We are grateful to prof. Andrej Böör, M.D., CSc. from Institute of Pathology, Safarik University School of Medicine, Kosice, Slovakia for performing histological evaluation of biopsy material. We thank Dr. Jacqueline Cloos from Department of Pediatric Hematology/Oncology, VU University Medical Center, Amsterdam, The Netherlands for her useful advice. We are also grateful to Marta Vysocka and Magdalena Tarrova for their excellent help during collection and processing of samples. We are thankful to Dr. Kieran Green for reviewing and correcting the English language of the manuscript.

This study was supported by a grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Norwegian Financial Mechanism.

REFERENCES

- 1 Aviles DH, Matti VV, Manning J, Ochoa AC, Zea AH (2004). Decreased expression of T-cell NF-kappaB p65 subunit in steroid-resistant nephrotic syndrome. *Kidney Int.* **66**: 60–67.
- 2 Baeuerle PA, Baltimore D (1996). NF-kappa B: ten years after. *Cell.* **87**: 13–20.
- 3 Bantel H, Schmitz ML, Raible A, Gregor M, Schulze-Osthoff K (2002). Critical role of NF-kappaB and stress-activated protein kinases in steroid unresponsiveness. *FASEB J.* **16**: 1832–1834.
- 4 Bloomfield CD, Smith KA, Peterson BA, Munck A (1981). Glucocorticoid receptors in adult acute lymphoblastic leukemia. *Cancer Res.* **41**: 4857–4860.
- 5 Davies TH, Ning YM., Sanchez ER (2002). A new first step in activation of steroid receptors: hormone-induced switching of FKBP51 and FKBP52 immunophilins. *J Biol Chem.* **277**: 4597–4600.

- 6 De Bosscher K., Van den Berghe W., Haegeman G (2003). The interplay between the glucocorticoid receptor and nuclear factor-kappaB or activator protein-1: molecular mechanisms for gene repression. *Endocr Rev.* **24**: 488–522.
- 7 Ehrlich JH, Pape L, Schiffer M (2008). Corticosteroid-resistant nephrotic syndrome with focal and segmental glomerulosclerosis: an update of treatment options for children. *Paediatr Drugs.* **10**: 9–22.
- 8 Eisen LP, Elsasser MS, Harmon JM (1988). Positive regulation of the glucocorticoid receptor in human T-cells sensitive to the cytolytic effects of glucocorticoids. *J Biol Chem.* **263**: 12044–12048.
- 9 Gbadegesin R, Smoyer W (2008). Nephrotic syndrome. In: Geary DF, Shaefer F, editors. *Comprehensive Pediatric Nephrology*, 1st edition. London: Mosby. p. 205–228.
- 10 Gross KL, Lu NZ, Cidlowski JA (2009). Molecular mechanisms regulating glucocorticoid sensitivity and resistance. *Mol Cell Endocrinol.* **300**: 7–16.
- 11 Gruber G, Carlet M, Turtcher E, Meister B, Irving JA, Ploner C, *et al.*, (2009). Levels of glucocorticoid receptor and its ligand determine sensitivity and kinetics of glucocorticoid-induced leukemia apoptosis. *Leukemia.* **23**: 820–823.
- 12 Haack D, Scharer K, Asam-Tauscher A, Vecsei P (1999). Glucocorticoid receptors in idiopathic nephrotic syndrome. *Pediatr Nephrol.* **13**: 653–656.
- 13 Haarman EG, Kaspers GJ, Pieters R, Rottier MM, Veerman AJ (2004). Glucocorticoid receptor alpha, beta and gamma expression vs in vitro glucocorticoid resistance in childhood leukemia. *Leukemia.* **18**: 530–537.
- 14 Han SH, Park SY, Li JJ, Kwak SJ, Jung DS, Choi HY, *et al.*, (2008). Glomerular glucocorticoid receptor expression is reduced in late responders to steroids in adult-onset minimal change disease. *Nephrol Dial Transplant.* **23**: 169–175.
- 15 Herr I, Gassler N, Friess H, Buchler MW (2007). Regulation of differential pro- and antiapoptotic signaling by glucocorticoids. *Apoptosis.* **12**: 271–291.
- 16 Honda M, Orii F, Ayabe T, Imai S, Ashida T, Obara T, *et al.*, (2000). Expression of glucocorticoid receptor beta in lymphocytes of patients with glucocorticoid-resistant ulcerative colitis. *Gastroenterology.* **118**: 859–866.
- 17 Kang BN, Tirumurugan KG, Deshpande DA, Amrani Y, Panettieri RA, Walseth TF, *et al.*, (2006). Transcriptional regulation of CD38 expression by tumor necrosis factor-alpha in human airway smooth muscle cells: role of NF-kappaB and sensitivity to glucocorticoids. *FASEB J.* **20**: 1000–1002.
- 18 Kofler R, Schmidt S, Kofler A, Ausserlechner MJ (2003). Resistance to glucocorticoid-induced apoptosis in lymphoblastic leukemia. *J Endocrinol.* **178**: 19–27.
- 19 Lane SJ, Atkinson BA, Swaminathan R, Lee TH (1996). Hypothalamic-pituitary-adrenal axis in corticosteroid-resistant bronchial asthma. *Am J Respir Crit Care Med.* **153**: 557–560.
- 20 McKay LI, Cidlowski JA (1998). Cross-talk between nuclear factor-kappa B and the steroid hormone receptors: mechanisms of mutual antagonism. *Mol Endocrinol.* **12**: 45–56.
- 21 Oerlemans R, Vink J, Dijkmans BA, Assaraf YG, van Miltenburg M, van der Heijden J, *et al.*, (2007). Sulfasalazine sensitises human monocytic/macrophage cells for glucocorticoids by upregulation of glucocorticoid receptor alpha and glucocorticoid induced apoptosis. *Ann Rheum Dis.* **66**: 1289–1295.
- 22 Onda K, Rimbara E, Hirano T, Oka K, Abe H, Tahara K, *et al.*, (2004). Role of mRNA expression of transcription factors in glucocorticoid sensitivity of peripheral blood mononuclear cells and disease state in rheumatoid arthritis. *J Rheumatol.* **31**: 464–469.
- 23 Perkins ND (2000). The Rel/NF-kappa B family: friend and foe. *Trends Biochem Sci.* **25**: 434–440.
- 24 Pui CH, Dahl GV, Rivera G, Murphy SB, Costlow ME (1984). The relationship of blast cell glucocorticoid receptor levels to response to single-agent steroid trial and remission response in children with acute lymphoblastic leukemia. *Leuk Res.* **8**: 579–585.
- 25 Pui CH, Costlow ME (1986). Sequential studies of lymphoblast glucocorticoid receptor levels at diagnosis and relapse in childhood leukemia: an update. *Leuk Res.* **10**: 227–229.
- 26 Ray A, Prefontaine KE (1994). Physical association and functional antagonism between the p65 subunit of transcription factor NF-kappa B and the glucocorticoid receptor. *Proc Natl Acad Sci USA.* **91**: 752–756.
- 27 Sahali D, Pawlak A, le Gouvello S, Lang P, Valanciute A, Remy P, *et al.*, (2001). Transcriptional and post-transcriptional alterations of IkappaBalpha in active minimal-change nephrotic syndrome. *J Am Soc Nephrol.* **12**: 1648–1658.
- 28 Sanchez-Vega B, Gandhi V (2009). Glucocorticoid resistance in a multiple myeloma cell line is regulated by a transcription elongation block in the glucocorticoid receptor gene (NR3C1). *Br J Haematol.* **144**: 856–864.
- 29 Scheinman RI, Gualberto A, Jewell CM, Cidlowski JA, Baldwin AS, Jr. (1995). Characterization of mechanisms involved in transrepression of NF-kappa B by activated glucocorticoid receptors. *Mol Cell Biol.* **15**: 943–953.
- 30 Schlaghecke R, Beuscher D, Kornely E, Specker C (1994). Effects of glucocorticoids in rheumatoid arthritis. Diminished glucocorticoid receptors do not result in glucocorticoid resistance. *Arthritis Rheum.* **37**: 1127–1131.
- 31 Schmidt S, Irving JA, Minto L, Matheson E, Nicholson L, Ploner A, *et al.*, (2006). Glucocorticoid resistance in two key models of acute lymphoblastic leukemia occurs at the level of the glucocorticoid receptor. *FASEB J.* **20**: 2600–2602.
- 32 Schwartz CL, Thompson EB, Gelber RD, Young ML, Chilton D, Cohen HJ, *et al.*, (2001). Improved response with higher corticosteroid dose in children with acute lymphoblastic leukemia. *J Clin Oncol.* **19**: 1040–1046.
- 33 Tanaka H, Akama H, Ichikawa Y, Makino I, Homma M (1992) Glucocorticoid receptor in patients with lupus nephritis: relationship between receptor levels in mononuclear leukocytes and effect of glucocorticoid therapy. *J Rheumatol.* **19**: 878–883.
- 34 Wasilewska A, Zoch-Zwierz W, Tomaszewska B, Wiercinski R, Stasiak-Barmuta A (2003). Expression of glucocorticoid receptors in mononuclear cells in nephrotic syndrome. *Pediatr Nephrol.* **18**: 778–782.
- 35 Wochnik GM, Ruegg J, Abel GA, Schmidt U, Holsboer F, Rein T (2005). FK506-binding proteins 51 and 52 differentially regulate dynein interaction and nuclear translocation of the glucocorticoid receptor in mammalian cells. *J Biol Chem.* **280**: 4609–4616.