Abstract

Objective: The aim of the present study was to investigate the effect of exogenously administered human GH (hGH) on serum levels of interleukin (IL)-4, IL-6, IL-12 and tumour necrosis factor (TNF)-α in GH-deficient (GHD) children.

Design and methods: We evaluated 13 short prepubertal GHD children, aged between 2 and 13 years, and 13 age-matched healthy subjects as controls. Circulating cytokine values were evaluated in basal conditions in all children, and 6 and 24 h following the 1st hGH injection (0.23 mg/kg per week), and then after 3 months of hGH treatment in GHD patients. Serum levels of IL-4, IL-6, IL-12 and TNF-α were measured by commercially available ELISAs.

Results: No significant differences were found between controls and GHD children in basal values of serum IL-4, IL-6, IL-12 and TNF-α (P > 0.05 by Mann–Whitney U test). Analysis of cytokine levels during hGH treatment showed significant changes over time in TNF-α and IL-6 levels (P = 0.0014 and P = 0.00024 respectively), with the more pronounced effect observed at 6 h following the first administration of hGH (i.e. increase in IL-6 (Wilcoxon matched pairs test, P = 0.0015) and TNF-α levels (P = 0.0015)). No significant changes over time were observed in IL-4 and IL-12 serum levels.

Conclusions: In vivo release of the pro-inflammatory cytokines IL-6 and TNF-α can be affected by hGH treatment in GHD children, suggesting a direct effect of GH on the immune function.

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Introduction

Growing evidence indicates a bidirectional relationship between the neuroendocrine system and immune function. Neurohormones act on immune cells while cytokines, secreted by lymphocytes and macrophages, in turn influence the neuroendocrine system. The variability of endocrine and immune responses depends on these interactions, which can be facilitatory or inhibitory. The presence of cell surface receptors for growth hormone (GH) and insulin-like growth factor-I (IGF-I) on different lymphocyte subpopulations suggests that, in addition to the endocrine effects, there is an immune action for these hormones (1, 2). Indeed, a relationship between GH and the immune system is suggested by in vivo studies, in particular in experimental animals. In humans, no obvious immune deficit has been found in GH-deficient (GHD) patients (3, 4). However, supporting the effect of GH on immune cells, the release of interleukin (IL)-1β and tumour necrosis factor-α (TNF-α) is increased in response to an acute GH administration in GHD children (5). Furthermore, cytokine release can be affected by short-term human GH (hGH) administration in short non-GHD children indicating a direct effect of GH on the immune function (6). The aim of the present study was to evaluate the effect of short- and long-term hGH administration on in vivo production of a large body of cytokines, by monitoring serum IL-4, IL-6, IL-12 and TNF-α concentrations in GHD children, before and during hGH treatment.

Patients and methods

Patients and study design

We evaluated 13 children (nine males and four females), aged between 2 and 13 years, with isolated complete (n = 6) and partial (n = 7) GH deficiency, documented by serum GH peak levels less than 5 ng/ml and 5–10 ng/ml respectively, in response to at least two pharmacological stimuli. A group of 13 children (six males and seven females), aged between 3 and 11 years, were studied as controls; they were taking part in a screening
programme for hyperlipidaemia performed at school. In patients, the pituitary–thyroid axis function, evaluated by serum tri-iodothyronine, thyroxine, free tri-iodothyronine, free thyroxine and thyrotrophin levels, was normal; the adrenal function, estimated on the basis of basal serum cortisol values at 0800 and 2000 h, was also normal. No child suffered from diabetes insipidus, chronic diseases or acquired GH deficiency or had chromosomal abnormalities. Informed consent was obtained from the parents of all the children. Serum samples for cytokine measurement were obtained at 0900 h both in GHD children and in age-matched controls. In addition, in GHD children they were also obtained 6 and 24 h following the 1st hGH injection (0.23 mg/kg per week), and then after 3 months of GH treatment. GH was self-administered by the patients as a daily injection in the evening at bedtime. Blood samples were placed on ice immediately and centrifuged within 1 h. Sera were stored at −20 °C until tested for cytokine content.

**Measurement of cytokine levels**

Serum levels of IL-4, IL-6, IL-12 (p70) and TNF-α were measured by commercially available ELISAs (ELISA DuoSet; R&D Systems, Minneapolis MN, USA). The minimum detectable concentrations by these assays were 7 pg/ml for TNF-α, 2.34 pg/ml for IL-6, 15 pg/ml for IL-4 and 15 pg/ml for IL-12. The samples were diluted 1/5 for TNF-α, 1/10 for IL-6, 1/3 for IL-4 and 1/5 for IL-12 in assay buffer. The intra- and inter-assay coefficients of variation (C.V.) were less than 7%.

**Measurement of IGF-I levels**

Serum IGF-I concentrations were measured by double-antibody RIA using immunochemicals and tracer provided by Medgenix (Fleurus, Belgium). The sensitivity of the assay was 150 pg/ml; the intra- and inter-assay C.V. ranges were 3.9–6% and 5.6–7.5% for a quality control range of 30–450 μg/l respectively. In order to avoid interference from binding proteins, single plasma EDTA samples were treated with acid ethanol.

**Statistical analysis**

Data are presented as medians (and interquartile range) and non-parametric tests were employed in the statistical analysis of the data because of the small sample size and because the data were not normally distributed (Shapiro–Wilk’s test). The Mann–Whitney U test was used to compare unpaired data between two groups, while Friedman (in cases of more than two times), ANOVA and Wilcoxon (in cases of comparison of the same group twice) tests were used to compare paired data. Correlations were analyzed using the Spearman rank correlation test. All tests were two-sided. A P value < 0.05 was deemed statistically significant. The analyses was performed with Statistica 6.0 for Windows software (StatSoft, Inc. 2003, Tulsa, OK, USA).

**Results**

In order to evaluate the influence of hGH therapy on serum cytokine levels in GHD children, we measured IL-4, IL-6, IL-12 and TNF-α concentrations in blood samples collected before and after 6 h, 24 h and 3 months of treatment in patients. Basal values were compared with those of healthy children. No significant differences in serum levels of IL-4, IL-6, IL-12 and TNF-α before hGH treatment were observed between GHD children and controls comparable for age (Table 1). As expected, treatment with GH resulted in a significant increase over time in plasma IGF-I levels (Friedman ANOVA test \( \chi^2 \) (n = 13, degrees of freedom = 3) = 20.74; \( P = 0.0012 \)); with all individual patients showing a marked increase in circulating IGF-I levels and velocity rate of growth 1 year after the beginning of the treatment (data not shown). This showed that in all patients GH treatment was associated with a biological effect. Analysis of cytokine levels during GH treatment showed significant changes over time in TNF-α and IL-6 levels (\( P = 0.0014 \) and \( P = 0.00024 \) respectively) (Fig. 1A and B). No significant changes over time were observed in IL-4 and IL-12 levels (Fig. 1C and D). The more pronounced effect (i.e. increase in IL-6 (Wilcoxon matched pairs test, \( P = 0.0015 \)) and TNF-α levels \( P = 0.0015 \)) was observed at 6 h following the first administration of hGH (Fig. 1A and B). We could not find a statistically significant correlation between cytokine increase at 6 h after the first injection of hGH and the increase in IGF-I levels after 3 months of treatment (IL-6: \( r = 0.09, P = 0.82; \) TNF-α: \( r = 0.21, P = 0.61 \)).

**Discussion**

GH has long been postulated to stimulate immune and inflammatory reactions. It is reasonable to hypothesize that, whether GH can influence the immune system, its absence should lead to alterations in the immune response. However, the results of the studies in animals and in humans are conflicting. The dwarf Snell mouse,

<table>
<thead>
<tr>
<th>Cytokine</th>
<th>GHD children</th>
<th>Healthy children</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-4 (pg/ml)</td>
<td>23.9 (22.3–37.5)</td>
<td>23.4 (19.9–27.7)</td>
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<tr>
<td>IL-6 (pg/ml)</td>
<td>5.6 (0.5–15.8)</td>
<td>0.6 (0.2–60.1)</td>
<td>0.938</td>
</tr>
<tr>
<td>IL-12 (pg/ml)</td>
<td>5.3 (2–54.6)</td>
<td>6.2 (3–31.2)</td>
<td>0.898</td>
</tr>
<tr>
<td>TNF-α (pg/ml)</td>
<td>6.1 (1–124.6)</td>
<td>9.2 (2.8–1063.7)</td>
<td>0.228</td>
</tr>
</tbody>
</table>
having both a congenital hypopituitarism and severe cell-mediated as well as humoral immunodeficiency, normalize their immune function after GH treatment (7, 8). Moreover, experimental administration of anti-serum against GH leads to the suppression of antibody formation in mice, confirming the effect of GH on immune function (9). Hypophysectomized rats have markedly depressed synthesis of TNF-\(\alpha\) by macrophages and exogenous GH partially reverses the effect of hypophysectomy, supporting the hypothesis that the pituitary gland is needed for the synthesis of TNF-\(\alpha\) by macrophages (10, 11). In contrast, no clinical signs of immune dysfunction have been observed in humans in spite of severe deficiency due to either a mutation in the Pit-1 gene or a deletion of the GH-N gene. In fact, GH deficiency is not usually associated with immunodeficiency, except for rare X-linked combinations of isolated GH deficiency and agammaglobulinaemia (12). Although GHD patients have no increased susceptibility to infections, some immune parameters may be impaired in these subjects (13, 14).

In agreement with the absence of an overt immune defect in children with GHD, our data showed that cytokine basal levels in GHD patients do not differ from those of healthy children. On the contrary, we found a significant increase in serum IL-6 and TNF-\(\alpha\) values in GHD patients 6 h after an acute hGH administration. The levels of the cytokines started to decrease 24 h after the injection and remain unchanged for the following 3 months. Our results suggest that GH administration has a deep impact on cytokine synthesis in children with complete or partial GH deficiency. The increase in TNF-\(\alpha\) levels confirmed our previous findings that demonstrated high cytokine levels 6 h after hGH injection in GHD children (5) and after the 4th hGH injection in short non-GHD children (6).

Furthermore, in vitro studies demonstrate that the presence of GH increases the production of pro-inflammatory cytokines by monocytes in response to lipopolysaccharide (15). TNF-\(\alpha\) and IL-6 are cytokines produced particularly by monocytes/macrophages and their increase after GH administration could be due to the well-known macrophage-activating potential of GH itself (16). This effect could be direct or mediated by GH-dependent factors, such as IGF-I because immune cells express both GH and IGF-I receptors (1). However, the fact that we observed an increase in IL-6 and TNF-\(\alpha\) levels, in particular 6 h following the first administration of hGH, suggests a rather prompt effect on the macrophage. It is conceivable to hypothesize that this may reflect a direct effect of GH on macrophage, rather than an effect mediated by IGF-I.

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**Figure 1** Circulating levels of cytokines (median and 25th–75th percentile) in GHD children before and after 6 and 24 h, and then after 3 months (90 d) of GH treatment and in healthy controls (CTRL). *P = 0.0015, Wilcoxon matched pairs test.
Indeed, on the other hand, GH therapy does not seem to affect serum IL-4 and IL-12 levels during the treatment. IL-4 is known to promote the immune cell differentiation toward the Th2 phenotype and to transform naïve T cells into IL-4-producing T cells. Th2 cytokines promote Th2 activities and inhibit Th1 activities and vice versa. Takagi et al. (17) demonstrated that in burned mice, where there is a conversion of Th cell populations from Th1 cells to Th2 cells, administration of recombinant GH leads to a Th1-dominant response, supporting the role of GH in modulating the release of type 1 cytokines. These data are in accordance with our results of no effect of GH therapy on serum IL-4 levels. Furthermore, other studies have demonstrated that, in particular non-pathologic conditions, high levels of serum GH are not necessarily correlated with elevated serum IL-4 concentrations (18, 19). Unlike IL-4, IL-12 is a cytokine that stimulates a switch toward Th1 cells with production of type 1 cytokines; nevertheless, GH administration did not alter serum levels of this cytokine at any time after the beginning of the therapy. These data are in apparent contrast with our previous results that showed a stimulating effect of GH injection on IL-12 release in non-GHD children after hGH administration, suggesting that low endogenous GH levels could alter cytokine response. Furthermore, the ELISA we used detected only the p70 form of IL-12 and, it is possible, an increase in the p40 subunit, whose production greatly exceeds the p70 one, and is easily detectable with an ELISA method. In contrast to our findings in children, in GHD adults basal serum TNF-α and IL6 levels are higher than in controls and decrease after prolonged GH administration, suggesting a different regulation of cytokine production in adulthood (20).

In conclusion, we have demonstrated an effect of hGH administration on the in vivo levels of the pro-inflammatory cytokine IL-6 and TNF-α. Despite this action of GH, in GHD children a normal immune function persists.

References


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