Anthropometric factors have significant influence on the outcome of the GHRH–arginine test: establishment of normative data for an automated immunoassay specifically measuring 22 kDa human growth hormone

Timo Deutschbein, Martin Bidlingmaier, Jochen Schopohl, Christian J Strasburger and Stephan Petersenn

Abstract

Context: Adult growth hormone (GH) deficiency (GHD) is diagnosed by provocative testing of GH secretion.

Objective: To improve the diagnostic accuracy of GH-releasing hormone (GHRH) plus arginine (GARG) testing, we evaluated the influence of age, BMI and sex and established normative data for an automatic immunoassay specifically measuring 22 kDa human GH.

Design/setting: Prospective multicenter study.

Participants: Eighty-seven patients with hypothalamic–pituitary disease and 200 healthy controls. Patients were classified according to the number of pituitary hormone deficiencies (PHD). GHD was assumed when ≥2 PHD (in addition to GH) were present (n=51); 36 patients with <2 PHD were considered GH sufficient (GHS). ROC analysis identified cutoffs with ≥95% specificity for GHD. Controls were prospectively stratified for sex, age and BMI.

Interventions: All participants received GHRH and l-arginine.

Main outcome measures: GH was measured by immunoassay (iSYS, IDS).

Results: In controls, multiple stepwise regression analysis showed that BMI (21%, P < 0.0001), sex (20%, P < 0.0001) and age (5%, P < 0.001), accounted for 46% of GH peak level variability during GARG. Comparison of peak GH during GARG (GHD vs GHS + controls) revealed an overall cutoff of 3.9 ng/mL (sensitivity 86%, specificity 95%). After adjustment for BMI and sex, optimal cutoffs (male vs female) were 6.5 vs 9.7 ng/mL in lean, 3.5 vs 8.5 ng/mL in overweight and 2.2 vs 4.4 ng/mL in obese subjects respectively.

Conclusion: BMI and sex account for most of the variability of peak GH levels during GARG. Consequently, diagnostic accuracy of the GARG test is significantly improved by use of adjusted cutoffs.

Introduction

Human growth hormone (GH) deficiency (GHD) is associated with significant morbidity and mortality (1, 2). For instance, large series have repeatedly shown that hypopituitarism is generally associated with an increase in overall mortality, cardiovascular events and malignancies compared with the normal population (3, 4).
Apart from that, GH-deficient individuals (especially those without replacement therapy) experience a decrease in quality of life, bone mineral density and lean body mass. Accordingly, careful diagnostic workup of suspected patients is imperatively required.

In patients with proven panhypopituitarism (i.e., at least 3 pituitary hormone deficiencies (PHD)), low levels of circulating insulin-like growth factor 1 (IGF-I), the primary mediator of the effects of GH, are highly suspicious of somatotroph insufficiency (1, 2, 5, 6, 7). However, as illustrated in current guidelines, most patients should undergo provocative testing to establish the diagnosis of GHD (1, 2, 7). Although the insulin tolerance test (ITT) is still regarded as gold standard (1, 2, 7), it is usually not widely applied (6). This is mainly explained by its need for serious hypoglycemia, resulting in undoubted limitations due to potential risks and several contraindications (e.g. ischemic heart disease, seizures).

As a consequence, several other dynamic endocrine tests have been evaluated to explore somatotroph function, for instance, single or combined stimulation with GH secretagogues like arginine, clonidine, GH-releasing hormone (GHRH), GH-releasing peptide 6 (GHRP6), glucagon and levodopa (L-DOPA) (5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16). Some of these tests have severe limitations (e.g. impaired sensitivity, high costs); however, the GHRH plus arginine (GARG) test has repeatedly been described as a good alternative to the ITT (1, 2, 5, 7, 17, 18, 19). Of note, as GH responses during the GARG test decline by increasing body mass index (BMI) and age, adjusted cutoffs have been proposed (13, 14). Unfortunately, however, the weighted influence of these two variables (either alone or in combination) as well as the influence of sex have not been adequately evaluated so far.

Recently, desirable characteristics for GH measurement have been stated by a consensus recommendation (20). These aspects are fulfilled by a modern automated immunoassay specifically measuring 22 kDa human GH (21).

Our study was therefore designed to empirically define reference data for stimulated GH responses in adults, improving the diagnostic accuracy of the GARG test using the formerly mentioned immunoassay. We investigated a well-defined cohort of healthy subjects who were prospectively recruited in such a way that anthropometric factors (e.g. age, BMI, and sex) were reflected on a sufficiently weighted basis. Multiple stepwise regression analysis was performed to identify their potential influence on GH levels. To identify cutoffs with at least 95% specificity for GHD, patients suffering from hypothalamic–pituitary diseases were included, using the degree of pituitary impairment as gold standard and applying receiver-operating characteristics (ROC) analysis.

**Subjects and methods**

**Subjects**

The study protocol was approved by the local ethics committee (approval number: 04-2390), and all study participants provided written informed consent.

**Controls**

Two hundred healthy subjects were recruited from the general population. None of these subjects had a history of severe and/or chronic illness (especially of endocrine origin). Females on hormonal contraceptives or hormone replacement therapy as well as all subjects who were currently or in the prior months taking drugs known to interfere with the synthesis or metabolism of endocrine parameters were excluded. To evaluate the influence of anthropometric variables, subjects were prospectively stratified for sex (male vs female), age (18–30 years, 31–50 years and >50 years) and BMI (<25 kg/m², 25–30 kg/m² and >30 kg/m²). Study participants were selected in such a way that each group comprised at least 10 subjects (i.e. 10 males aged 18–30 years with a BMI <25 kg/m²; 10 males aged 31–50 years with a BMI <25 kg/m²; 10 males older than 50 years with a BMI <25 kg/m²; and so on). Unfortunately, one control subject was misclassified at screening. Therefore, the group ‘females, 31–50 years, BMI >30 kg/m²’ contains only 9 subjects.

**Patients**

Eighty-seven patients with hypothalamic–pituitary diseases were enrolled (details are given in Table 1). Subjects who had already been surgically treated had their first regular endocrine workup at least three months after surgery. Two of the 87 patients (2.3%) had been treated by irradiation 1 and 9 years prior to GARG testing respectively. Both of them had insufficiencies of all pituitary axes at the time of GARG testing. Patients with suspected or proven pituitary insufficiency received hormonal replacement therapy (i.e. glucocorticoids, gonadal steroids, thyroxine and desmopressin) with the exception of growth hormone. In detail, 45 patients with corticotropin insufficiency received hydrocortisone orally
(median dose per day 15 mg, range 10–40 mg), with dose adjustment depending on signs and symptoms of under- or over-replacement. Of note, only 2 patients received doses >25 mg (i.e. 30 and 40 mg respectively). Fifty-four patients with thyrotropic insufficiency were substituted with l-thyroxin, with doses adjusted according to both peripheral hormone levels and clinical symptoms. At the time of GARG testing, fT4 levels were all in the normal range (median fT4 1.37 ng/L, range 0.8–2.1 ng/L). Thirty-four male subjects received testosterone replacement, with individual doses depending on hormone levels, clinical symptoms and age. In these subjects treated with testosterone, a median testosterone of 3.3 ng/mL (range 1.1–10.7 ng/mL) was measured at the time of GARG testing. Of note, one subject had levels below the normal range of our assay. Premenopausal females with gonadotropic insufficiency were substituted with oral contraceptives or hormone replacement doses, depending on individual preferences.

**Methods**

*Collection of samples*

Blood sampling was generally performed between 08:00h and 10:00h after an overnight fast. Samples were taken by venipuncture of a forearm vein. If measurement was not performed directly afterward, blood samples were centrifuged and stored at −20°C.

*Dynamic testing procedures for the assessment of somatotroph function*

During GARG, patients received GHRH (1 µg/kg) by an i.v. bolus, followed by a 30-min i.v. infusion of l-arginine (30 g). Blood samples were taken at 0, 30, 45, 60, 90 and 120 min. In the initial phase of the study, we also evaluated the diagnostic performance of the ITT. In 44 patients, administration of insulin (0.10–0.15 U/kg) was followed by blood sampling at 0, 15, 30, 45, 60, 90 and 120 min. Both target serum glucose of ≤40 mg/dL and symptoms of neuroglucopenia were required as indicators of sufficient stress response.

*Additional hormonal workup*

In 44 patients, corticotroph function was investigated by cortisol peak levels during ITT. In the remaining patients, adrenal insufficiency was established either by repeatedly low early morning serum cortisol or by corticotropin-releasing hormone (CRH) testing. Parameters used for characterization of gonadotroph function were testosterone, luteinizing hormone (LH) and follicle-stimulating hormone (FSH) (males); history of regular menses along with estradiol, progesterone, LH and FSH (premenopausal females); LH and FSH only (postmenopausal females). Selected cases also underwent gonadotropin-releasing hormone (GnRH) testing. Thyrotroph function was assessed by thyroid-stimulating hormone (TSH) and peripheral thyroid hormones, with additional thyreotropin-releasing hormone (TRH) testing in some cases.

*Interpretation of endocrine parameters*

Similar to the approach published by Biller et al., reduced responses to testing of the corticotropic, gonadotropic and thyrotropic axes as well as evidence of diabetes insipidus were separately considered as PHD (5). Therefore, the possible range for grading the severity of PHD was one to four, with two or more insufficiencies (i.e., other than GHD) being classified as multiple PHD (MPHD). As already outlined by Biller et al., prior studies have shown that the latter group has an approximately 90% chance of having severe GHD (22, 23). Patients with less than 2 PHD were classified as GH sufficient (GHS).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Clinical characteristics of patients.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GHD</td>
</tr>
<tr>
<td></td>
<td>Females</td>
</tr>
<tr>
<td>Number (n)</td>
<td>21</td>
</tr>
<tr>
<td>Age (years)</td>
<td>49.6±2.8</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.2±1.3</td>
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<tr>
<td>Sellar mass with surgery (n)</td>
<td>14</td>
</tr>
<tr>
<td>Sellar mass without surgery (n)</td>
<td>5</td>
</tr>
<tr>
<td>Hormonal impairment without sellar mass (n)</td>
<td>2</td>
</tr>
<tr>
<td>Pituitary hormone deficiencies (n)</td>
<td>3.0±0.1</td>
</tr>
</tbody>
</table>

BMI, body mass index; GH, growth hormone; GHD, growth hormone deficiency.
Clinical Study

T Deutschbein and others

BMI and sex: impact on GH after GHRH–arginine

Measurement of samples and calculation of estimates

Serum GH was measured by an automated immunoassay (iSYS, Immunodiagnostic Systems (IDS), Boldon, UK) calibrated against the latest International Standard code 98/574 (NIBSC, Hertfordshire, UK). Validation and characterization of the assay had been performed according to recommendations by the clinical laboratory standards institute (CLSI), and results were published in detail elsewhere (21). The epitopes of the monoclonal antibodies used in this assay ensure specific measurement of the 22kDa isoform of GH. Performance of the assay during the study was routinely monitored by internal quality control, longitudinal assessment of serum pools and participation in external quality control programs.

Statistical analysis

Multiple stepwise regression analysis was performed with the following covariates in the model: age, BMI and sex. Groups were compared by Mann–Whitney test, where appropriate. The diagnostic accuracy of GARG and ITT was determined by ROC analysis and its corresponding area under the curve (AUC). That way, we aimed to establish cutoffs (with a specificity of $\geq 95\%$ for GHD) under special consideration of the most relevant anthropometric factors. Statistical significance was taken as $P<0.05$. Results are expressed as the mean ± standard error of the mean (s.e.m.) unless otherwise stated. GraphPad Prism 6.0 software (GraphPad Software) and JMP10 (SAS Institute Inc., Cary, NC, USA) were used for statistical calculations.

Results

Influence of age, BMI and sex on GH peak levels in healthy subjects

The control group comprised 200 healthy subjects: 102 males (age 39.7 ± 1.5 years (range 19–75 years), BMI 27.8 ± 0.5 kg/m$^2$ (range 19.0–49.9 kg/m$^2$)) and 98 females (age 39.2 ± 1.3 years (range 18–68 years), BMI 27.7 ± 0.6 kg/m$^2$ (range 18.0–46.5 kg/m$^2$)). If male and female controls were compared, no significant differences between mean age and mean BMI were detected. Multiple stepwise regression analysis revealed that both BMI (21%, $P<0.0001$) and sex (20%, $P<0.0001$) accounted for most of the variability of GH peak levels during the GARG test, whereas the influence of age (5%, $P<0.001$) was much less dominant. Mean peak GH levels were significantly higher in females compared with males (27.4 ± 1.73 ng/mL vs 13.7 ± 0.95 ng/mL, $P<0.0001$) and higher in lean (34.1 ± 2.46 ng/mL in females vs 20.7 ± 1.67 ng/mL in males, $P<0.0001$) compared with overweight (31.4 ± 3.38 ng/mL in females vs 12.1 ± 1.34 ng/mL in males, $P<0.0001$) and obese subjects (14.4 ± 1.52 ng/mL in females vs 7.19 ± 0.68 ng/mL in males, $P<0.0001$) (Fig. 1).

As changes in sex hormones during menopause could be interfering and potentially explain some of the sex differences in peak GH levels, we performed additional analyses in 139 healthy subjects (age 18–50 years) of whom females were presumably premenopausal and 60 subjects (age >50 years) of whom females were presumably menopausal. Peak GH remained significantly higher in 67 females between 18 and 50 years of age compared with 72 males (29.8 ± 2.19 ng/mL in females vs 15.2 ± 1.14 ng/mL in males, $P<0.0001$), and in 31 females who were >50 years old compared with 29 males (22.1 ± 2.5 ng/mL in females vs 9.8 ± 1.52 ng/mL in males, $P<0.0001$).

Patient cohort

Out of the 87 subjects with hypothalamic-pituitary diseases (51 males, 36 females; age 48.7 ± 1.5 years (range 18–74 years), BMI 27.6 ± 0.6 kg/m$^2$ (range 16.7–43.2 kg/m$^2$)), 17 patients were investigated specifically due to suspicion of pituitary insufficiency (7× clinical symptoms; 3× traumatic brain injury; 2× congenital panhypopituitarism; each 1× cerebral lymphoma after cranial radiotherapy, congenital isolated growth hormone deficiency, empty sella syndrome, 3× prolactinomas, 1× congenital adrenal hyperplasia due to 21-hydroxylase deficiency, 1× congenital diabetes mellitus type 1). GH levels at baseline and during the GARG test in patients with pituitary hypofunction are shown in Table 1.
Sex-specific BMI-dependent cutoffs in the combined arginine-GHRH test for GH as measured by the IDS iSYS assay with a specificity of ≥95% for GHD.

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Lean (BMI &lt;25kg/m²)</th>
<th>Overweight (BMI ≥25–&lt;30kg/m²)</th>
<th>Obese (BMI ≥30kg/m²)</th>
<th>Lean (BMI &lt;25kg/m²)</th>
<th>Overweight (BMI ≥25–&lt;30kg/m²)</th>
<th>Obese (BMI ≥30kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cutoff (ng/mL)</strong></td>
<td>3.9</td>
<td>6.5</td>
<td>3.5</td>
<td>2.2</td>
<td>9.7</td>
<td>8.5</td>
<td>4.4</td>
</tr>
<tr>
<td><strong>Sensitivity (%)</strong></td>
<td>86</td>
<td>100</td>
<td>92</td>
<td>91</td>
<td>83</td>
<td>100</td>
<td>67</td>
</tr>
<tr>
<td><strong>Specificity (%)</strong></td>
<td>95</td>
<td>95</td>
<td>96</td>
<td>97</td>
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<td>97</td>
<td>97</td>
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<tr>
<td><strong>ROC AUC</strong></td>
<td>0.97</td>
<td>&lt;0.0001</td>
<td>0.99</td>
<td>&lt;0.0001</td>
<td>0.97</td>
<td>&lt;0.0005</td>
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<tr>
<td><strong>P value</strong></td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
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<td>&lt;0.0005</td>
<td>&lt;0.0001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

BMI, body mass index; GH, growth hormone; GHD, growth hormone deficiency; ROC, receiver-operating characteristics; AUC, area under the curve.

Establishment of new cutoffs for peak GH levels during the GHRH plus arginine test by comparison of growth hormone-deficient patients and control subjects

Considering the significant influence of BMI and sex for the GARG in normal subjects, we aimed to establish diagnostic cutoffs that were adjusted accordingly. Comparison of peak GH levels during the GARG test of patients with MPHD to those of a control group (consisting of patients with PHD <2 and healthy subjects) allowed calculation of cutoffs for peak GH (either as an overall threshold or as BMI-dependent thresholds with at least 95% specificity for GHD, with the latter being separately provided for both sexes). As shown in Table 2 as well as in Fig. 2, the overall cutoff for both sexes was 3.9 ng/mL (sensitivity 86% (95% confidence interval (CI) 74–94%), specificity 95% (95% CI 92–98%)); the BMI-adjusted thresholds were 6.5, 3.5 and 2.2 ng/mL for males and 9.7, 8.5, and 4.4 ng/mL for females (always for lean, overweight and obese subjects respectively). Of note, our group of patients with less than 2 PHD may contain some subjects with isolated GHD, which could influence our analysis. We therefore repeated our ROC analysis focusing on patients with MPHD in comparison to healthy controls.
controls alone. Interestingly, the results were very similar: the overall cutoff for both sexes was 3.8 ng/mL (sensitivity 86% [95% CI 73–94%], specificity 95% [95% CI 92–98%]).

Diagnostic performance of the insulin tolerance test

Forty-four of the 87 patients (51%) also underwent an ITT as additional reference test. ROC analysis suggested a GH cutoff of 2.0 ng/mL that categorized 29 patients as GHD and 15 patients as GHS (sensitivity 95% and specificity 93%). Hence, two cases were discordant to the classification by the degree of pituitary impairment (i.e., 1 GHS patient with 3 PHD and 1 GHD patient with 0 PHD).

If the ‘classical’ GH cutoff of 3.0 ng/mL was applied, 32 patients were regarded as GHD and 12 patients as GHS. Using ITT, 1 individual with ≥2 PHD was considered GHS, whereas 4 individuals (each with 0 PHD) were classified as GHD. As a result, sensitivity remained at 95%, whereas specificity dropped to 73%.

Discussion

The current study established reference data for peak GH during the GARG test, using a modern automated immunoassay, which had been developed in compliance with recent consensus guidelines and specifically measures the 22 kDa isoform of human GH. To establish diagnostic cutoffs, prospectively recruited subjects from the general population underwent careful questioning and examination, thereby including only well-defined healthy controls. Multiple stepwise regression analysis was performed to determine the influence of various anthropometric variables on GH, identifying BMI and sex as the most relevant parameters. Consequently, adjusted cutoffs with at least 95% specificity for GHD were derived from ROC analysis, investigating patients with proven hypothalamic–pituitary diseases (using the number of PHD as gold standard).

Although measurement of GH and IGF-I is a cornerstone of the diagnostic and therapeutic monitoring of diseases associated with an impaired somatotroph function, considerable difficulties exist with respect to the comparability of currently available measurement techniques and their respective analytical performance (20, 24). Therefore, the recent consensus guidelines on GH assay performance have called for method-specific cutoffs for each GH assay (20). Noteworthy, the need to establish cutoffs not only for each individual hormone and dynamic test but also for each of the different measurement techniques used to quantify the hormones has already been demonstrated for other hormones (25). The cutoff data presented here apply for the specific GH assay used, and conversion of data obtained by one GH assay into another GH assay is explicitly discouraged by the guidelines. However, especially in a pediatric population where ethical reasons might prohibit the re-establishment of cutoffs with each new assay, it is helpful to know that a recent publication has proposed formulas allowing a comparison of GH concentrations obtained by the IDS iSYS GH assay to other commercially available immunoassays (26). To date, robust reference ranges for other parameters associated with somatotroph function (IGF1 and IGF-BP3) measured on the same analytical platform have already been established (27, 28, 29), but the present study is the first to provide assay-specific cutoffs for GH stimulation tests for this assay.

In patients with suspicion for GHD, current guidelines regard testing with well-established dynamic endocrine procedures as mandatory (1, 2, 7). Over the last years, the GARG test has repeatedly been described as a reliable alternative to the traditional gold standard ITT, which is nowadays regarded as unpleasant, cumbersome and potentially life-threatening (1, 2, 5, 7, 17, 18, 19).

Of note, a significant relationship between anthropometric parameters and GH levels during dynamic endocrine testing has been described, e.g. for the oral glucose tolerance test (30) and the GARG test (5, 13, 14). With respect to the latter test, BMI-dependent cutoffs for peak GH have been suggested, mainly to overcome overlapping GH responses between GHD and obese patients (13, 14). We also identified BMI as the most relevant confounder in our current analysis, accounting for 21% of the variability of peak GH during the GARG test. Unfortunately, though, a further analysis of the underlying pathophysiological mechanism for this finding was not feasible, as additional parameters of metabolic disturbance (e.g. visceral fat mass, visceral fat mass, fasting insulin levels and waist circumference) were not routinely determined.

Interestingly, multiple stepwise regression analysis revealed that sex had a very comparable effect to BMI (i.e., accounting for 20% of peak GH variability). We therefore decided to establish combined BMI- and sex-adjusted cutoffs rather than various cutoffs only adjusted for one of these potential confounders.

It has to be pointed out that these newly established thresholds were markedly lower in males (6.5, 3.5 and 2.2 ng/mL for lean, overweight and obese subjects) than those in females (9.7, 8.5 and 4.4 ng/mL) and not well
Another drawback of our current analysis is that previous 
the good agreement between clinical annotations and 
hyopituitarism. This assumption is also supported by 
that this approach allows for a reliable identification of 
line with current recommendations, we strongly believe 
reviewed, with special emphasis on symptoms and 
Nevertheless, all of our patients were carefully clinically 
cluded a comparably large cohort of healthy subjects, 
and 4.0 to 15.0 ng/mL respectively) (threshold values in 
both studies always given for lean, overweight and obese 
subjects) (13, 14). As discussed previously, variations in 
the assay methods used in the former studies certainly 
contribute to the differences in concentrations reported. 
However, these differences might also point to other 
confounders in the respective cohorts investigated 
(e.g. anthropometric factors other than BMI, which 
appears to have a relatively robust inverse correlation to 
GH). With respect to age, some groups have reported that 
peak GH levels during the GARG test were substantially 
decreasing in the elderly (14), whereas others did not 
observe such a decline (addressing either the GARG test 
only (31) or several GH stimulation tests at the same 
time) (5). Divergent results have also been published for 
the role of sex, with reports ranging from no (14, 31) to a 
significant (5) impact on peak GH levels during the GARG 
test. Our study confirms the influence of sex, which 
appears to be plausible in view of the known, significantly 
stimulating effect of estradiol on GH secretion (32, 33). 
Our current multiple stepwise regression analysis and the 
results published by Biller et al. (5) strongly suggest that 
sex may have a more dominant effect on GH peak levels 
than age, with GH peak values more than twice as high 
in females compared with males. As a result, we believe 
that the use of cutoffs adjusted for BMI and sex could be a 
reasonable approach to improve diagnostic accuracy.

Our study has limitations. For instance, although we 
cluded a comparably large cohort of healthy subjects, 
our patient cohort was smaller than that in some of the 
previous studies on this topic. Although the rarity of 
GH-related disorders needs to be considered, larger 
investigations are certainly needed to better define the 
impact of sex and BMI on patients. Such studies should 
ideally be designed as large prospective multicenter 
studies to also account for other potential confounders.

Nevertheless, all of our patients were carefully clinically 
reviewed, with special emphasis on symptoms and 
biochemical signs suggestive of (additional) PHD. In 
line with current recommendations, we strongly believe 
that this approach allows for a reliable identification of 
hyopituitarism. This assumption is also supported by 
the good agreement between clinical annotations and 
the corresponding ITT in a subgroup of the patients. 
Another drawback of our current analysis is that previous 
studies of GARG have demonstrated limited sensitivity to 
diagnose GHD in patients with prior irradiation (34, 35). 
It has been speculated that the GH response to arginine 
may be somehow resistant to the effects of radiation (36). 
As our patient cohort contained only 2 patients after 
radiation, we believe that the results are not biased by this 
treatment, but like to emphasize that the results may not 
apply to patients after cranial irradiation. Furthermore, 
the GARG test itself has certain pitfalls. For instance, 
GHRH is not easily available, making the test quite 
cumbersome. Moreover, as many potential confounders 
need to be considered, different cutoffs values have to be 
memorized (which are only valid for the specific assay 
applied). Consequently, each center needs to establish its 
own normative data.

In conclusion, here we provide method-specific 
cutoffs for a new automated immunoassay specifically 
measuring the 22 kDa isoform of human GH. Furthermore, 
we defined the effects of anthropometric factors on peak 
GH levels during the GARG test. We demonstrated that 
BMI and sex account for most of the variability in peak 
GH, thereby having important impact on the diagnosis of 
GHD. Consequently, the diagnostic accuracy of the GARG 
test is significantly improved by application of BMI- and 
sex-adjusted cutoffs.

Declaration of interest
The authors declare that there is no conflict of interest that could be 
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Author contribution statement
Timo Deutschbein and Stephan Petersenn conducted the statistical 
analyses. All authors collected samples, provided patient data and wrote 
the manuscript.

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