CLINICAL STUDY

Effect of 6 months of GH treatment on myosin heavy chain composition in GH-deficient patients

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Abstract

Objective: To investigate the effect of GH on myosin heavy chain (MHC) isoform composition, physical fitness and body composition in GH-deficient (GHD) patients.

Design: Twenty-two GHD patients were randomized in a double blind manner and half were treated with recombinant human GH (rhGH) and half were treated with placebo for 6 months. Twelve age-matched controls were also included in the study.

Methods: MHC isoform composition in biopsies obtained from the vastus lateralis muscle was determined using SDS-PAGE. Physical fitness was determined on a bicycle ergometer and body composition was determined using bioelectrical impedance analysis.

Results: More MHC IIX (28.9 ± 4.1% and 10.0 ± 3.1% in GHD and controls respectively (means ± S.E.M.)) and less MHC I (36.2 ± 2.4% and 51.7 ± 3.9% in GHD and controls respectively (means ± S.E.M.)) were present in the GHD patients compared with the controls. No significant difference in the amount of MHC IIA was detected. Linear regression was used to determine the relationship between variables. There were no significant relationships between the concentration of insulin-like growth factor-I (IGF-I) or the body composition and the MHC composition. Maximal oxygen uptake (VO2max) per kg body weight (BW) (litres/min per kg) correlated significantly with the amount of MHC I (r = 0.60) and MHC IIX (r = -0.72) but not with the amount of MHC IIA (r = 0.35). Treatment of GHD patients with rhGH for 6 months increased the concentration of IGF-I, lean body mass and decreased fat mass but had no effect on MHC composition and physical fitness.

Conclusions: We conclude that a major part of the differences in MHC composition between GHD patients and age-matched controls can be explained by variation in physical fitness. The severity of the GHD and the body composition does not seem to be important for the MHC composition. Furthermore, treatment with GH for 6 months does not affect MHC composition in GHD patients.

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Introduction

The myosin molecule consists of two heavy chains and four light chains expressed in a cell-specific manner and both the myosin light chains and especially the myosin heavy chains (MHCs) have been shown to be important in determining the contractile properties of skeletal muscle (1). In human skeletal muscle the MHCs can be classified as MHC I, MHC IIA and MHC IIB on the basis of differences in their electrophoretic mobility. Since the transcript from the fastest human isoform (MHC IIB) is homologous to the rat MHC IIX isoform (2), and thus may correspond to rat MHC IIX (3), MHC IIX was chosen to designate the fastest human isoform in the present paper.

Growth hormone (GH) is an anabolic, lipolytic and diabetogenic hormone. The anabolic effects of GH are the most important and include promotion of linear growth in children (4) and maintenance of muscle strength and size in adults (5). In GH-deficient (GHD) patients fat mass may be increased (6) and skeletal muscle mass (6), exercise capacity (7) and skeletal muscle strength (8) decreased compared with age-matched controls. Since the relative proportions of MHC I, MHC IIA and MHC IIX are the major determinants of the maximum velocity of shortening in human skeletal muscle (1), the impaired muscle function in GHD patients could therefore be caused by an altered MHC composition.

In genetically GH-deficient rats (dw/dw) and in hypophysectomized rats there is a decreased proportion of
type I fibres and MHC I and an increased proportion of type II fibres and MHC II in skeletal muscle compared with a group of age-matched control rats (9, 10). Since treatment with GH in hypophysectomized and dw/dw rats has been shown to change fibre type composition in some (9–11) but not all studies (12, 13) and since treatment with GH to GHD patients has been shown to significantly increase skeletal muscle mass, exercise capacity and skeletal muscle strength (6, 7, 14, 15), a relationship between muscle function and muscle fibre composition could exist.

The aim of the present study was to investigate MHC isoform composition in GHD and the effects of GH treatment. Furthermore, we investigated the severity of GHD, physical fitness and body composition in GHD and the relation to MHC isoform composition.

Materials and methods

Subjects

Fifteen male and seven female GHD patients were included in the study according to the following criteria: (1) age 20–65 years; (2) a maximal GH concentration peak of less than 9 mIU/l following provocation with either insulin-induced hypoglycaemia, arginine or clonidine; (3) deficient in GH for more than 12 months; and (4) patients with multiple deficiencies must have been on stable replacement therapy for more than 6 months. One patient (patient no. 1) was treated with simvastatin, cholestyramine and diuremoral. The individual characteristics of the patients are shown in Table 1. Twelve normal age-matched male controls were selected on the basis of being clinically healthy and receiving no medication. The patients and the controls received both written and verbal information about the study, and their written informed consent was obtained. The study was approved by the Ethics Committee at Lund and Helsinki University. Lean body mass (LBM) was determined using bioelectrical impedance analysis (BIA) (Akern RJL, Florence, Italy). Fat mass was calculated as body weight (BW) minus LBM, and body mass index (BMI) was calculated as BW/height².

GH administration

The patients were randomized in a double-blind manner and instructed to treat themselves with daily subcutaneous injections of recombinant human GH (rhGH) (Genotropin, Pharmacia & Upjohn, Stockholm, Sweden) (GHD-GH) or placebo (GHD-PLA). Ten patients received an rhGH dose of 0.125 IU/kg per week (0.04 mg/kg per week) for 1 month followed by 5 months’ treatment with 0.25 IU/kg per week (0.08 mg/kg per week). In 12 patients the dose of GH was 0.20 IU/kg per week (0.07 mg/kg per week) during the entire treatment period. In GHD-PLA an equivalent volume of placebo was injected.

Table 1 Characteristics of the GHD patients.

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Sex</th>
<th>Age (yr)</th>
<th>Aetiology</th>
<th>Pituitary deficiency</th>
<th>Estimated duration of GHD (yr)</th>
<th>GH peak at stimulation (mIU/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>54</td>
<td>A</td>
<td>A,T,G</td>
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<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>38</td>
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<td>A,T,G</td>
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</tr>
<tr>
<td>3*</td>
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<td>NS</td>
<td>A,T,G</td>
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</tr>
<tr>
<td>4</td>
<td>M</td>
<td>46</td>
<td>NS</td>
<td>A,T,G</td>
<td>12</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>39</td>
<td>I</td>
<td>A</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>47</td>
<td>A</td>
<td>A,T,G</td>
<td>15</td>
<td>0.2</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>44</td>
<td>NS</td>
<td>A,T,G</td>
<td>7</td>
<td>0.1</td>
</tr>
<tr>
<td>8*</td>
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<td>C</td>
<td>A,T,G,V</td>
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<tr>
<td>9</td>
<td>M</td>
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<td>A,T,G</td>
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<tr>
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<td>A,T,G</td>
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<tr>
<td>17</td>
<td>M</td>
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<td>0.1</td>
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<td>I</td>
<td>G</td>
<td>23</td>
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<tr>
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<td>54</td>
<td>NS</td>
<td>G</td>
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<td>4.9</td>
</tr>
<tr>
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<td>M</td>
<td>42</td>
<td>NS</td>
<td>A,T,G</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>22</td>
<td>F</td>
<td>58</td>
<td>I</td>
<td>A,T,G</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* Previously GH-treated.

Etiology: NS, nonsecreting adenoma; A, treated acromegaly; PRL, prolactinoma; C, craniopharyngioma; I, idiopathic; H, hypophysitis.

Pituitary insufficiency in addition to GHD: A, ACTH; T, TSH; G, gonadotrophin; V, ADH.

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Physical fitness evaluation

Of the 22 GHD patients the physical fitness was evaluated in the last 12 patients before and after treatment with either placebo or rhGH. The physical fitness was evaluated in all the age-matched controls. For half of the GHD patients and for all the controls a submaximal exercise test (which lasted for 6 min with continuous monitoring of heart rate) was performed on a bicycle ergometer using a workload of 100–250 W depending on weight and self-reported physical activity. Mean heart rate during the last 2 min of work (steady state >120 beats/min) was used for calculation of maximal heart rate and maximal oxygen uptake (VO\textsubscript{2}max) according to Astrand (16). Results obtained by using this method have been shown to correlate well with direct measurements of VO\textsubscript{2}max (16). The other half of the GHD patients performed a maximum exercise test on an electrically braked bicycle ergometer (Bosch EAG 551). Subjects exercised to exhaustion, with the load increased every minute by 10 W for women and 15 W for men. Expired gas was sampled continuously via a mixing chamber and analysed for the concentration of O\textsubscript{2} and CO\textsubscript{2} (Sensor Medics 2900). Measurements were obtained every 20 s during rest in the sitting position on the bicycle and every 20 s during exercise. VO\textsubscript{2}max was determined as the highest value recorded during the last minute of exercise and according to the levelling-off criterion (17). Finally, although two different methods were used for determining the VO\textsubscript{2}max in the present study, subjects were always tested with the same method following treatment. During exercise testing, heart rate was continuously recorded using an electrocardiograph.

Plasma analysis

Plasma insulin-like growth factor-I (IGF-I) levels were determined using a commercial RIA kit from Nichols Institute (San Juan Capistrano, CA, USA). The inter- and intra-assay coefficient of variation was less than 5%.

Muscle biopsies

Muscle biopsies were taken under lignocaine anaesthesia from the vastus lateralis muscle using a Bergstöm needle (18). The tissue was embedded in Tissue-Tek (Mills Inc., IN, USA) and immediately frozen in isopentane cooled in liquid nitrogen. Muscle samples were stored at −70 °C until analysed.

MHC analysis

MHC analysis was performed on the muscle samples using SDS-PAGE. The protocol for analysing the samples was based on the procedure described by Betto et al. (19). Briefly, in a cryotome five to ten serial cross-sections were cut (20 μm thick) and placed in 0.5–1.0 ml lysing buffer consisting of 10% (w/v) glycerol, 5% (w/v) 2-mercaptoethanol and 2.3% (w/v) SDS in 62.5 mmol/l Tris(hydroxymethyl)aminomethane (Tris) buffer (pH 6.8) and heated for 10 min at 60 °C. Small amounts (1–3 μl) were loaded on SDS-PAGE gels, containing 6% polyacrylamide and 37.5% glycerol. Gels were run for 20 h at 70 V followed by 4 h at 200 V, silver stained using a kit (Pharmacia Biotech, Uppsala, Sweden) whereafter the MHC content was quantified. Densitometric scanning was performed using a onedimensional software (CREAM by Kem-En-Tec Software Systems, Copenhagen, Denmark). By using this technique it is possible to distinguish three bands corresponding to MHC I, MHC IIA and MHC IIX based on differences in their electrophoretic mobility (Fig. 1).

Statistics

Sigma Stat version 2.01 (Jandel Corporation, San Rafael, CA, USA) was used for statistical analysis. Data in the text, tables and figures are given as means ± S.E.M. Non-parametric tests, Wilcoxon signed rank test (paired data) and Mann–Whitney rank sum test (unpaired data) were used where appropriate. Additionally, linear regression analysis was performed. P values <0.05 were considered statistically significant.

Results

Characteristics of the patients and the control subjects

The age was 47 ± 3, 45 ± 3 and 37 ± 2 years and the height was 175 ± 5, 174 ± 3 and 180 ± 2 cm in GHD-GH, GHD-PLA and in the controls, respectively. No significant differences in age and height were observed between the groups. Before treatment the BW and the BMI were significantly higher in GHD-PLA than in both the GHD-GH group and the controls (Table 2). Before treatment the fat mass was higher in the two groups of
Effects of GH on skeletal muscle composition in GHD

GHD patients compared with the controls and LBM was the same in the three groups (Table 2). Treatment with rhGH for 6 months significantly increased LBM and decreased the fat mass. No significant changes were seen in BW and BMI (Table 2). The plasma IGF-I concentration before treatment was identical in GHD-PLA and GHD-GH and for both groups significantly lower than in the controls (Table 2). rhGH treatment significantly increased the plasma IGF-I concentration (Table 2).

**Physical performance**

Physical performance measured as VO$_2$max, VO$_2$max per kg BW and VO$_2$max per kg LBM were significantly ($P < 0.05$) lower in both groups of GHD patients compared with the controls (Table 3). Physical performance was not affected by treatment with rhGH for 6 months (Table 3). Furthermore, no difference in maximal heart rate could be found between the two groups and treatment with rhGH for 6 months had no significant effect on maximal heart rate in GHD patients (Table 3).

**Amount of MHC**

In the entire group of GHD patients, the amount of MHC I was $36.2 \pm 2.4\%$, the amount of MHC IIA was $34.8 \pm 3.5\%$ and the amount of MHC IIX $28.9 \pm 4.1\%$ ($n=22$) (Fig. 2). In the controls, the amount of MHC I was $51.7 \pm 3.9\%$, the amount of MHC IIA was $38.3 \pm 3.3\%$ and the amount of MHC IIX $10.0 \pm 3.1\%$ ($n=12$) (Fig. 2). The amount of MHC I and MHC IIX was found to be significantly ($P < 0.05$) different from the age-matched control group but no difference in MHC IIA could be seen between the groups (Fig. 2). Similar results were found after excluding the women from the study and after excluding the two patients with childhood onset GHD (nos 8 and 19 (Table 1)) (data not shown). Treatment with rhGH for 6 months had no effect on the skeletal muscle MHC isoform composition in GHD (Table 4). Thus, both before and after treatment with rhGH the MHC composition in both GHD groups was significantly ($P < 0.05$) different from the age-matched control group (Table 4) with an amount of MHC I which was significantly ($P < 0.05$) lower and an amount of MHC IIX which was significantly ($P < 0.05$) higher in the GHD patients (Table 4) compared with the age-matched control group. No difference in the amount of MHC IIA was found between the groups (Table 4).

**Linear regression**

For the entire group of GHD patients and controls, significant correlations were found between the amount

### Table 2 Body composition and plasma IGF-I concentration in GHD patients before and after treatment with either placebo (GHD-PLA) or rhGH (GHD-GH) for 6 months and in normal age-matched control subjects (Control). Values are mean ± S.E.M. P values were obtained using Wilcoxon signed rank test (before-after) and Mann-Whitney rank sum test (after comparisons).

<table>
<thead>
<tr>
<th></th>
<th>GHD-PLA Before (n=11)</th>
<th>GHD-PLA After (n=11)</th>
<th>GHD-GH Before (n=11)</th>
<th>GHD-GH After (n=11)</th>
<th>Control (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW (kg)</td>
<td>95.7 ± 4.9†</td>
<td>93.8 ± 4.6</td>
<td>91.7 ± 5.8</td>
<td>91.9 ± 6.2</td>
<td>81.2 ± 2.7</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>68.4 ± 4.4</td>
<td>67.4 ± 4.3</td>
<td>69.0 ± 4.7</td>
<td>62.9 ± 5.3‡</td>
<td>65.0 ± 1.4</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>27.3 ± 3.3*</td>
<td>26.4 ± 3.2</td>
<td>22.7 ± 2.4*</td>
<td>19.2 ± 1.9‡</td>
<td>16.2 ± 2.5</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>31.7 ± 1.8†</td>
<td>31.1 ± 1.8</td>
<td>26.6 ± 1.4</td>
<td>26.4 ± 1.5</td>
<td>25.1 ± 1.0</td>
</tr>
<tr>
<td>IGF-I (µg/l)</td>
<td>115 ± 12*</td>
<td>102 ± 11*</td>
<td>114 ± 26*</td>
<td>306 ± 47‡</td>
<td>152 ± 8</td>
</tr>
</tbody>
</table>

* Significantly ($P < 0.05$) different from Control.
† Significantly ($P < 0.05$) different from GHD-GH Before.
‡ Significantly ($P < 0.05$) different from Before.

### Table 3 Physical performance in GHD patients before and after treatment with either placebo (GHD-PLA) or rhGH (GHD-GH) for 6 months and in normal age-matched control subjects (Control). Values are mean ± S.E.M. P values were obtained using Wilcoxon signed rank test (before-after) and Mann-Whitney rank sum test (after comparisons).

<table>
<thead>
<tr>
<th></th>
<th>GHD-PLA Before (n=6)</th>
<th>GHD-PLA After (n=6)</th>
<th>GHD-GH Before (n=6)</th>
<th>GHD-GH After (n=6)</th>
<th>Control (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal heart rate (beats/min)</td>
<td>159 ± 5</td>
<td>159 ± 6</td>
<td>153 ± 5</td>
<td>171 ± 7</td>
<td>ND</td>
</tr>
<tr>
<td>VO$_2$max (l/min)</td>
<td>2.4 ± 0.2*</td>
<td>2.9 ± 0.2</td>
<td>2.4 ± 0.1*</td>
<td>2.4 ± 0.2</td>
<td>4.1 ± 0.3</td>
</tr>
<tr>
<td>VO$_2$max per kg BW (ml/min per kg)</td>
<td>25.7 ± 3.0*</td>
<td>31.5 ± 2.4</td>
<td>33.5 ± 3.3*</td>
<td>32.0 ± 1.6</td>
<td>51.3 ± 4.5</td>
</tr>
<tr>
<td>VO$_2$max per kg LBM (ml/min per kg)</td>
<td>35.3 ± 4.4*</td>
<td>42.0 ± 2.5</td>
<td>46.5 ± 5.1*</td>
<td>42.3 ± 2.5</td>
<td>63.1 ± 4.7</td>
</tr>
</tbody>
</table>

* Significantly ($P < 0.05$) different from Control.
ND, not determined.
of MHC I (positive), MHC IIX (negative) and the VO₂max per kg BW (Fig. 3), the VO₂max (data not shown), and to the VO₂max per kg LBM (data not shown). No significant relationship was found to MHC IIA.

Within-group statistical analysis revealed that the significant positive correlations between MHC I, the significant negative correlation to MHC IIX and the not significant relationship between MHC IIA on the one hand and the VO₂max per kg BW on the other hand were maintained in the group of age-matched controls (data not shown). In the group of GHD patients only the significant negative relationship between MHC IIX and VO₂max per kg BW was maintained and no significant relationship between MHC I, MHC IIA and VO₂max per kg BW could be seen (data not shown).

We searched for a relationship between the severity of GHD (measured as IGF-I concentration) and the MHC composition. Both for the entire group of GHD patients and for the individual groups, no significant correlations

Table 4  Electrophoretically determined amount of MHC isoforms in GHD patients before and after treatment with either placebo (GHD-PLA) or rhGH (GHD-GH) for 6 months. Values are mean ± S.E.M.

<table>
<thead>
<tr>
<th></th>
<th>GHD-PLA</th>
<th>GHD-GH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td></td>
<td>(n = 11)</td>
<td>(n = 11)</td>
</tr>
<tr>
<td>MHC I (%)</td>
<td>32.9 ± 2.9</td>
<td>34.0 ± 4.0</td>
</tr>
<tr>
<td>MHC IIA (%)</td>
<td>34.1 ± 5.1</td>
<td>27.1 ± 5.5</td>
</tr>
<tr>
<td>MHC IIX (%)</td>
<td>32.9 ± 5.3</td>
<td>39.0 ± 6.4</td>
</tr>
</tbody>
</table>
Hybrid fibres are taken into account (25). Method, variations in fibre size and the presence of MHC straty, we determined the amount of the different MHC classes. GH deficiency did not significantly influence the results. Furthermore, in contrast to previous studies using histochemistry for determining fibre type composition, we and others have shown that both GH and thyroid hormones are important in determining the MHC composition in skeletal muscles (9, 32). As the patients were euthyroid before and during the treatment, an influence from thyroid hormone seems unlikely. If GH is important in determining the MHC composition, it could be speculated that there was a time-dependent relationship between the duration of GHD and the proportion of MHC II in the skeletal muscles. This hypothesis seems unlikely since no correlation was found between the amount of MHC II and the estimated number of years the patients had been deficient in GH (r = 0.06, P = 0.78). Furthermore, no correlation was found between the amount of MHC II and the IGF-I concentration before treatment, meaning the severity of GHD is not important for the MHC composition. A more likely explanation for the increased amount of MHC II is the low physical fitness in the GHD patients. In the present study the physical fitness was expressed as VO\(_2\) max, VO\(_2\) max per kg BW and VO\(_2\) max per kg LBM, and was in all instances found to be significantly lower in the GHD patients compared with the controls (Table 3). Since the physical fitness could be important in determining the MHC composition, we hypothesize that the high amount of MHC II is a result of a low activity level. This is supported by the relatively strong correlations found between the MHC isoform composition and the VO\(_2\) max per kg BW (Fig. 3). However, since the r values never exceed 0.72 it is equally important to note that only around 50% of the variation in MHC composition can be explained by the VO\(_2\) max per kg BW. Doing similar calculations using the VO\(_2\) max or the VO\(_2\) max per kg LBM did not further increase the r values. Furthermore, including body composition (BMI, LBM or fat mass) in the equation did not significantly increase the r values, suggesting less importance of these variables compared with the physical fitness. Thus, the ability to take up oxygen, independently of BW, LBM and fat mass, seems to be of primary importance for the muscle function (1), this means that the muscle function in the GHD patients can be expected to be different from the normal population. Several (8, 26, 27), but not all groups (23) have reported an altered muscle performance in GHD patients. Our results showing an increased proportion of MHC IIX would indicate a faster muscle in GHD compared with the control group. This is supported by Rutherford et al. who recently found in a group of GHD patients a significantly faster quadriceps muscle with a possible greater fatigability compared with a group of age-matched controls (8). Other possible consequences of a high proportion of MHC IIX includes decreased insulin sensitivity (28), increased glycolytic and decreased oxidative capacity and a decreased capillarization (29). The mechanism behind the altered MHC composition in GHD patients is not known but from our data it is possible to give plausible explanations. In addition to heredity (30) there are a variety of factors important for the muscle composition, including neural input, functional usage pattern, ageing and hormone levels (reviewed in ref. 31). In rats, we and others have shown that both GH and thyroid hormones are important in determining the MHC composition in skeletal muscles (9, 32). As the patients were euthyroid before and during the treatment, an influence from thyroid hormone seems unlikely. If GH is important in determining the MHC composition, it could be speculated that there was a time-dependent relationship between the duration of GHD and the proportion of MHC II in the skeletal muscles. This hypothesis seems unlikely since no correlation was found between the amount of MHC II and the estimated number of years the patients had been deficient in GH (r = 0.06, P = 0.78). Furthermore, no correlation was found between the amount of MHC II and the IGF-I concentration before treatment, meaning the severity of GHD is not important for the MHC composition. A more likely explanation for the increased amount of MHC II is the low physical fitness in the GHD patients. In the present study the physical fitness was expressed as VO\(_2\) max, VO\(_2\) max per kg BW and VO\(_2\) max per kg LBM, and was in all instances found to be significantly lower in the GHD patients compared with the controls (Table 3). Since the physical fitness could be important in determining the MHC composition, we hypothesize that the high amount of MHC II is a result of a low activity level. This is supported by the relatively strong correlations found between the MHC isoform composition and the VO\(_2\) max per kg BW (Fig. 3). However, since the r values never exceed 0.72 it is equally important to note that only around 50% of the variation in MHC composition can be explained by the VO\(_2\) max per kg BW. Doing similar calculations using the VO\(_2\) max or the VO\(_2\) max per kg LBM did not further increase the r values. Furthermore, including body composition (BMI, LBM or fat mass) in the equation did not significantly increase the r values, suggesting less importance of these variables compared with the physical fitness. Thus, the ability to take up oxygen, independently of BW, LBM and fat mass, seems to be of primary importance for the muscle function (1), this means that the muscle function in the GHD patients can be expected to be different from the normal population. Several (8, 26, 27), but not all groups (23) have reported an altered muscle performance in GHD patients. Our results showing an increased proportion of MHC IIX would indicate a faster muscle in GHD compared with the control group. This is supported by Rutherford et al. who recently found in a group of GHD patients a significantly faster quadriceps muscle with a possible greater fatigability compared with a group of age-matched controls (8). Other possible consequences of a high proportion of MHC IIX includes decreased insulin sensitivity (28), increased glycolytic and decreased oxidative capacity and a decreased capillarization (29).
MHC composition. These findings are in accordance with Utriainen et al. who, in a group of young healthy men, found a positive relationship between the number of type I fibres and the VO$_2$max per kg BW and a negative relationship between the number of type IIB (IIX in the present study) fibres and the VO$_2$max per kg BW (28). Furthermore, a positive relationship has been shown both between the area occupied by and the number of type I fibres on one hand and the VO$_2$max per kg BW on the other hand (33, 34). In contrast, Wade et al. showed that the proportion of type I fibres in a group of normal men is closely related to the percentage of body fat but not to VO$_2$max per kg LBM (35). The reason for this discrepancy is not clear.

Thus, the importance of GH in muscle fibre differentiation seems questionable, since 6 months of treatment with rhGH had no effect on the MHC composition. Previously published work studying the effect of GH treatment in GHD patients has used traditional histochemistry for determining fibre type composition (20, 21) and the fibre types have only been classified as type I fibres and type II fibres. Since in human skeletal muscle large differences in both contractile and metabolic properties exist within the type II fibres (29), the myosin composition of these fibres was determined in the various subgroups in the present study. Our results support the conclusions drawn by the earlier studies that there is no change in the number of type I and type II fibres (amount of MHC I and MHC II) following 6 months of GH treatment in human skeletal muscle (20, 21). We can now further conclude that no change in the amount of MHC IIA and MHC IIX takes place during treatment of GHD patients with rhGH. So, although several direct effects on skeletal muscle undoubtedly can be evoked by GH treatment (7, 27) we and others have found no effect of treatment with GH on fibre type or MHC composition in GHD patients (20, 21), and in normal humans (36, 37), leaving a primary role for GH in muscle fibre differentiation unlikely.

Our GHD patients were treated for 6 months but it is possible that extending the treatment period could have showed an effect of GH on MHC composition. However, since the GHD patients responded well to the rhGH treatment (as judged by the increase in IGF-I) and since significant changes in human skeletal MHC composition have been shown to occur both following exercise training for 12 and 19 weeks (38, 39) and following electrical stimulation for 6 months (40), we do not think that treating the GHD patients for a longer time would have changed the conclusion of the present study.

Finally, one could speculate why the GHD patients are unfit. Since the VO$_2$max to a large extent is determined by the pump capacity of the heart (41) and since a low maximal heart rate (6), and a low cardiac output (42) have been reported in GHD patients this could be part of the explanation for the reduced physical fitness. We did not measure maximal heart rate in the group of controls but if we estimate it from the mean age of the subjects a value around 180 beats/min is obtained. Since this value is higher than the maximal heart rate obtained in the group of GHD patients, it is possible that a reduction in pump capacity could be responsible for the reduced fitness.

In conclusion, MHC isoform composition in GHD patients is changed compared with age-matched controls. In these patients the amount of MHC IIX is higher and the amount of MHC I is lower than in controls. Treatment with rhGH for 6 months does not change the MHC isoform composition in GHD patients, leaving a primary role of GH in muscle fibre differentiation unlikely. The mechanism behind the differences in MHC content can to a large extent be explained by differences in physical fitness.

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