Growth hormone deficiency during young adulthood and the benefits of growth hormone replacement

M Ahmid, C G Perry, S F Ahmed and M G Shaikh

1Developmental Endocrinology Research Group, Royal Hospital for Children, School of Medicine, University of Glasgow, Glasgow, UK
2Department of Endocrinology, Queen Elizabeth University Hospitals, Glasgow, UK

Abstract

Until quite recently, the management of children with growth hormone deficiency (GHD) had focussed on the use of recombinant human GH (rhGH) therapy to normalise final adult height. However, research over the past two decades that has demonstrated deficits in bone health and cardiac function, as well as impaired quality of life in adults with childhood-onset GHD (CO-GHD), has questioned this practice. Some of these studies suggested that there may be short-term benefits of rhGH in certain group of adolescents with GHD during transition, although the impact of GHD and replacement during the transition period has not been adequately investigated and its long-term benefits remain unclear. GH therapy remains expensive and well-designed long-term studies are needed to determine the cost effectiveness and clinical benefit of ongoing rhGH during transition and further into adulthood. In the absence of compelling data to justify widespread continuation of rhGH into adult life, there are several questions related to its use that remain unanswered. This paper reviews the effects of growth hormone deficiency on bone health, cardiovascular function, metabolic profile and quality of life during transition and young adulthood.

Introduction

Growth hormone deficiency (GHD) is an endocrine condition that can potentially impact on an individual’s life from childhood, adolescence to young adulthood and beyond. In UK, the prevalence of congenital childhood-onset GHD (CO-GHD) has been estimated to be about 1 in 3500–4000 live births, whereas the prevalence of adult onset (AO-GHD) in addition to those with previous CO-GHD is also about 1 in 3000 of the UK adult population (1, 2). In addition to linear growth, the GH–IGF axis has important metabolic effects on a variety of target tissues (Fig. 1). Historically, treatment with recombinant human GH (rhGH) was discontinued at final height as defined by a growth velocity less than 2 cm/year (1). However, extensive research over the past two decades that has demonstrated deficits in bone health and cardiac function, together with impaired quality of life in adults with CO-GHD after completion of childhood treatment (3, 4, 5, 6), has questioned this practice. Although there are a number of reports of a beneficial impact on continuation of rhGH therapy beyond attainment of final height, there

Key Words

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- transition

Correspondence

should be addressed to M G Shaikh
Email
guftar.shaikh@nhs.net
are several studies where the results are less conclusive in determining the clinical and cost effectiveness of rhGH treatment during transition, especially with treatment costing up to £5000 per year in adulthood (7). The current guideline has approved continuation of GH replacement in those who were confirmed to have persistent GHD through the transition phase, although the evidence base underlying this recommendation is limited (8).

The primary aim of this review was to identify what evidence is available on the risks of GHD and the benefits of rhGH therapy during the transition period in the following areas: bone mass, body compositions, metabolic profiles and quality of life.

The literature search was conducted in the following databases: MEDLINE(Ovid), PubMed, Cochrane Library databases, Web of Science and Scopus in December 2015. The inclusion criteria for studies were randomised controlled clinical trials, longitudinal and case–control studies comparing discontinuation/continuation/recommencing rhGH therapy in young adult with CO-GHD (aged between 15 and 30 years). Exclusion criteria were animal studies, studies of adults with CO-GHD, adult-onset GHD, short stature and other endocrine conditions. Key outcome measures of selected studies are reported in tables and in the text. Figure 2 presents a brief summary of the literature review process and selection of studies.

Consequences of rhGH cessation and replacement during transition

Bone mass and risk of fracture

Bone mass: Cross-sectional and observational studies of bone density in rhGH-treated children with CO-GHD at time of completing linear growth have shown inconsistent findings with either low areal bone mineral density (BMD) (g/cm²), normal or slightly reduced total body (TB) BMD, bone mineral density (BMC) and lumber spinal (LS) volumetric mineral apparent density (RMAD) (g/cm³) (9, 10, 11, 12, 13) (Table 1). Early rhGH treatment in
childhood results in better indices of bone mass on completion of treatment at final height (9). Beyond transition, a longitudinal study reported a delayed timing of peak bone mass at LS, and a rapid decline over the following 2 years was observed in adolescents with CO-GHD who discontinued rhGH after final height compared with controls (14).

Therefore, there was a concern that childhood rhGH-treated subjects with CO-GHD may not achieve peak bone mass as a consequence of discontinuing GH treatment at final height.

Over the past few decades, a series of clinical trials studies have been conducted to examine the effects of continuation, discontinuation, and recommencement of rhGH during the transition phase of adolescents with CO-GHD, but thus far, they yield conflicting results (Table 2). Continuation of rhGH is reported to be associated with an increase in TB-BMC and LS-BMD in the range 3–6% after either 1 year (4) or 2 years (15, 16, 17) as assessed with dual-energy X-ray absorptiometry (DXA). However, this net gain is similar to what would be expected in the normal population during this stage (18, 19). It was also reported that bone mass does continue to increase in adolescents who discontinue rhGH therapy, yet the net gain is about half of that achieved by adolescents who continue rhGH therapy (15, 16).

By contrast, other studies have shown no change in BMD up to 2 years following discontinuation of rhGH after attainment of final height (11) and no benefit from continuation of rhGH 2 years after final height (20, 21). It was, therefore, proposed that 2 years was a safe period to be without rhGH, after which rhGH treatment would be recommenced in confirmed GHD patients. However, according to Tritos and coworkers, an interval of
### Table 1  Summary of cross-sectional studies, non-interventional observational studies of the effects of GHD adolescents with CO-GHD.

| Reference | N   | MPHD/IGHD Design | Age (years) | Tool Groups | TB | LS | Body composition | CVS risks | Glucose metabolism | QOL |
|-----------|-----|-------------------|-------------|-------------|----|----|------------------|-----------|-------------------|-----|
| (38)      | 40  | 28/12             | 2 years     | DXA         | n=22 GHD | † 5% BMC | † 4% BMD | † 8% in LM in GHD | † in GHD | ↔ ↔ ↔ ↔ |
| (11)      |     |                   | 3           |             | n=19 GH-sufficient |       |       |                   |           |                   |     |
| (3)       |     |                   | 16 control  |             | n=16 control |       |       |                   |           |                   |     |
| (63)      |     |                   |             |             |       |       |                   |           |                   |     |
| (14)      | 16  | 0/16              | 6 years     | DXA         | n=16 GHD |       |       |                   |           |                   |     |
| (26)      | 90  | CS                | 18–30       | PQCT        | n=37 GHD |       |       |                   |           |                   |     |
|           |     |                   |             |             | n=53 GH-sufficient |       |       |                   |           |                   |     |
| (13)      | 18  | CS                | 18–30       | DXA         | n=9 GHD |       |       |                   |           |                   |     |
|           |     |                   |             | isokinetic dynamometer | n=9 GHD |       |       |                   |           |                   |     |
|           |     |                   |             |             | n=18 control |       |       |                   |           |                   |     |

*Nottingham Health Profile, Psychological General Well-Being, Mood Adjective Check List, visual analog scale and more.
†, increase; ‡, decrease; ↔, no significant changes or different; Long, longitudinal; CS, cross-sectional; n, number of patients; GHD, growth hormone deficiency; IGHD, isolated growth hormone deficiency; MPHD, multiple pituitary hormone deficiencies; DXA, dual-energy x-ray absorptiometry; PQCT, peripheral quantitative computed tomography; BMD, bone mineral density; BMAD, bone mineral apparent density; BMC, bone mineral content; LM, lean mass; FM, fat mass; LS, lumbar spine; TB, total body; CVS, cardiovascular system; HDL, high-density lipoprotein; LDL, low-density lipoprotein.

It is also increasingly recognised that the bone health and fracture prediction is dependent not only on bone density but also on bone geometry and microstructure in addition to the risk factors for osteoporosis. The consequences of GHD and rhGH replacement in bone geometry and structure are important research questions that require further investigation.

In conclusion, the results of this study suggest that adolescents with GHD have a higher risk of developing bone density and fracture compared to healthy controls. The implications of these findings need to be explored further in larger studies to confirm these conclusions.
### Table 2  Summary of RCT and longitudinal studies of the effects of GH and rhGH therapy in adolescents with CO-GHD.

| Reference | N | MPHD/IGHD | Age (years) | Design | Groups | rhGH doses | TB | LS | Body composition | CVS risks | Glucose metabolism | QOL |
|-----------|---|-----------|-------------|---------|--------|------------|-----|----|------------------|-----------|-------------------|-----|
| (39) (56) | 18 | 15/3 | 20.2 ± 1 | 2 years RCT | n = 9 on rhGH n = 10 on placebo | 3.61U/day | – | – | ↑ 6% in LM in rhGH ↓ 6% FM in rhGH | – | – | – |
| (4) (40) | 24 | 20/4 | 17 ± 1.4 | 1 year RCT | n = 12 on rhGH n = 12 no rhGH | 17μg/kg/day | ↑ 6% -BMC in rhGH ↓ 5% BMC in placebo | ↑ 3.3% BMD adult GH ↑ 5% BMD in paed-GH ↑ 1.3% BMD placebo | – | ↑ LM of 13.4% in rhGH vs 3.1% in placebo | – | – |
| (16) | 64 | 52/12 | 23 ± 4.2 | 2 years RCT | n = 20 on adult GH n = 23 on paed GH n = 21 Placebo | 12.5 and 25.0μg/kg/day | ↑ 9% BMC in rhGH ↑ 5% BMC in placebo ↑ 3% BMC in rhGH | – | ↑ 14% LM in rhGH vs 2% in no GH ↓ FM | – | – |
| (15) (41) (65) | 92 | 72/20 | 19 ± 2.8 | 2 years RCT | n = 59 on adult -GH n = 58 on paed-GH n = 32 on Placebo | 12.5 and 25.0μg/kg/day | ↑ 9% BMC in rhGH ↑ 5% BMC in placebo ↑ 3% BMC in rhGH | – | ↑ 14% LM in rhGH vs 2% in no GH ↓ FM | – | – |
| (20) | 58 | 25/33 | 15.8 | 2 years RCT | n = 25 on rhGH n = 15 on placebo n = 18 GH-sufficient | 20μg/kg/day | ↔ BMD across all groups at baseline and after 2 years | ↔ ↔ ↔ HOMA-IR-QUICKI | ↔ ↔ ↔ | ↔ ↔ ↔ |
| (47) | 10 | 5/5 | 17–20 | 1 year long | n = 10 on rhGH n = 10 control | 8–10μg/kg/day | – | – | – | – | + effect on lipids ↔ in IMT in GHD ↓ HOMA in GH-sufficient | – |
| (48) | 23 | 9/14 | 15–20 | 2 years RCT | n = 15 on rhGH n = 8 GH-sufficient n = 23 control | 0.2–0.4 mg/day | ↔ BMD | ↔ ↔ ↔ | ↔ ↔ ↔ | ↔ ↔ ↔ |
| (17) (27) | 160 | 35/125 | 18–25 | 2 years, RCT | n = 109 on rhGH n = 51 no rhGH | 0.2–0.4 mg/day | ↑ 3.5% BMD in rhGH | – | – | – | – | – |
| (21) | 40 | 12/28 | 15.6–17.3 | 2 years long | n = 23 on rhGH n = 17 no rhGH | 0.4–1.3 mg/day | ↔ BMD SDS | ↔ BMAD | ↓ FM in untreated | – | – | – |

*General Health Questionnaires (GHQ); aAGHDA; bQLS-H questionnaires. ↑, increase; ↓, decrease; ↔, no significant changes or different; long, longitudinal; RCT, randomised control trial; n, number of patients; rhGH, recombinant human growth hormone; BMD, bone mineral density; BMAD, bone mineral apparent density; BMC, bone mineral content; LM, lean mass; FM, fat mass; LS, lumbar spine; TB, total body; CO, childhood-onset GH deficiency; IGHD, isolated growth hormone deficiency; MPHD, multiple pituitary hormone deficiencies; CVS, cardiovascular system; IMT, intima-media thickness; HOMA-IR, homeostasis model assessment-insulin resistance; IS, insulin sensitivity; QUICKI, quantitative insulin sensitivity check index.
imaging (high-resolution magnetic resonance imaging (micro-MRI)) investigated the bone structure of ten young adults with hypogonadism and/or CO-GHD and reported that the ratio of apparent bone volume to total volume (appBV/TV) and apparent trabecular number (appTbN) was significantly lower in GHD than in the age-matched control group (29), although the relationship between trabecular size and number to bone fragility and fracture risk has not been established yet.

**Risk of fracture:** Although data on the association between bone density and fractures in children are limited, it is generally established that the fracture risk may be higher in healthy children and adolescents who have low BMC and bone accrual (30, 31). The association between GHD, low bone mass and subsequent fracture risk in adolescents and young adults with CO-GHD is less clear that observed in adults with GHD and hypopituitarism (32, 33). However, in these studies, it was not known if that is a result of being GH deficient per se or due to other pituitary hormone deficiencies. Accordingly, other studies showed no evidence that isolated GHD (IGHD) may increase fracture risk (34, 35). With regard to the impact of rhGH replacement therapy on fracture rates, childhood studies suggest a protective effect of rhGH treatment in children with GHD with a four-fold decrease in fracture frequency from diagnosis to final height compared with matched healthy controls, but fracture prevalence increased to 3% at final height particularly in those with reduced lumbar BMD (Z-score <1) (12). Studies in adults involving both CO- and AO-GHD reported a lower incidence of fracture risk in CO-GHD compared with AO (32, 34, 36), with a double incidence of non-osteoporotic fracture in women with CO-GHD compared with men with CO-GHD despite continuation of rhGH treatment (36) (Table 3). In view of these studies, CO-GHD was queried as a cause of osteoporosis due to the lack of evidence for increased fracture risk in children and adults with CO-GHD or severe GH resistance (37).

To summarise this section, data thus far demonstrate contradictory results with most studies, but not all, showing a small increase in bone density and mineralisation during rhGH therapy in transition. However, the extent of GHD and replacement with regard to bone density and architecture is unclear. Using more advanced non-invasive imaging tools, which assess bone quality, may provide a greater insight into the effects of GHD and rhGH on bone.

In addition, there is an insufficient evidence of increased fracture risk in patients with CO-GHD as the reporting of the risk of fracture in GHD had considerable

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**Table 3** GHD and fracture risk in young adults with COGHD.

| Reference | Design | Age (years) | Duration of rhGH (years) | Measurement of outcome | Fracture sites | Result | Comment |
|-----------|--------|-------------|--------------------------|------------------------|---------------|--------|---------|
| (12)      | Cross-sectional | 14.8-19.9 | 8.6 ± 1.6 lifetime | Prevalence of fractures | No different vs normal population | - | - |
| (29)      | Cross-sectional | >18 years | 27-OHMPHD | Total body, trabecular bone density | All sites, more at wrist | Prevalence of fracture risk | 20% in CO-GHD vs 25% in AO |
| (32)      | Cross-sectional | 21-OHMPHD | >18 years | Lumbar spine, cortical bone density | No bone density data | - | - |
| (33)      | Cross-sectional | 18-OHMPHD | >18 years | Lumbar spine | All sites, more at wrist | Prevalence of fracture risk | 20% in CO-GHD vs 25% in AO |
| (34)      | Cross-sectional | 709 ± 189 | 602 ± 107 | Lumbar spine | All sites, more at wrist | Prevalence of fracture risk | 20% in CO-GHD vs 25% in AO |
| (35)      | Cross-sectional | 1007 ± 189 | 689 ± 107 | Lumbar spine | All sites, more at wrist | Prevalence of fracture risk | 20% in CO-GHD vs 25% in AO |

*Osteoporotic fractures: vertebra, wrist, upper arm and hip.
*Fracture incidence rate ratio: COGHD vs control, COGHD vs AO-GHD.
*Fracture incidence rate ratio: COGHD vs control, COGHD vs AO-GHD.
*Fracture incidence rate ratio: COGHD vs control, COGHD vs AO-GHD.
*Fracture incidence rate ratio: COGHD vs control, COGHD vs AO-GHD.
*Fracture incidence rate ratio: COGHD vs control, COGHD vs AO-GHD.

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limitations. Therefore, it remains unclear whether early adulthood rhGH treatment would offer protection from osteoporosis and fracture risk in late adulthood. Prospective long-term follow-up studies are still lacking.

**Body composition and muscle strength**

During transition, studies indicate that patients who were reconfirmed to have persistent GHD and discontinued rhGH in the transition period showed decreased lean mass (LM) (−8%) and increased fat mass (FM) (10–17%) compared with either sufficient or those who continued rhGH after 2 years of observation (21, 38, 39, 40). A study measured the early changes in body composition in CO-GHD patients after a median of 6 months after cessation of rhGH in patients who attained final height. The authors stated that patients with persistent GHD (n=37) had a significantly lower muscle cross-sectional area (CSA) Z-score (−0.24±1.6 vs 0.44±1.42, P<0.03), a two-fold increase in fat CSA (1329±100 mm² vs 878±91 mm²) compared with patients who were no longer GH deficient at final height (26). Recom mencement of rhGH therapy was documented to result in a marked improvement in body composition, with an increase in LM by 14%, and a reduction in FM by −7% over 2 years of replacement (16, 41), yet long-term studies are scarce in determining the sustainability of these changes. A study by Maura and coworkers is the only one that showed no significant difference in the changes of LM and FM from baseline to 2 year between continuation of rhGH as compared with placebo-treated or control subjects (20).

In terms of the relationship between CO-GHD, rhGH and muscle strength, it has been reported that discontinuation of rhGH in CO-GHD for 2 years has potentially negative consequences on muscular strength in some studies (3, 42), but not all (20, 39). From a recently published cross-sectional study investigating muscle strength and body composition of 18 males with CO-GHD (aged 18–30 years), of those, 9 (4-IGHD) were reconfirmed to have GHD after re-evaluating them at final height during transition. This study suggested that muscle strength as measured by an isokinetic dynamometer was lower in those with persistent GHD compared with sufficient and healthy controls (P<0.05) (13). However, data so far do not support the use of rhGH therapy to increase muscle strength during transition and young adulthood (16, 21, 39).

The majority of research has shown favourable differences in body composition with recommencing rhGH during transition, although encouraging further research in the field with long-term follow-up is needed.

**Cardiovascular risks and glucose metabolism**

Epidemiological evidence shows negative effects of GHD on cardiovascular risk factors including unfavourable lipid profiles, hypercoagulability, atherosclerosis and endothelial dysfunction, which could contribute to increased morbidity and mortality of adults with GHD and hypopituitarism without rhGH therapy (43), with a higher hazard ratio in AO-GHD compared with CO-GHD (3.0 (2.1–4.4) vs 1.4 (1.0–1.8), respectively (44). Cardiovascular risk in CO-GHD and benefits of rhGH have been documented during childhood (45, 46) and adolescence (47).

**Lipid profiles**: It has been well established that discontinuation of rhGH therapy after final height results in an increase in unfavourable lipid profile (26, 41, 48, 49), while the effect of restarting rhGH therapy remains unclear. Some studies have shown reversal in the levels of unfavourable lipid profiles (50), whereas others report no change in lipid profile on either cessation or continuation of rhGH therapy during transition (16, 20, 40). A study of KIMS database (Pfizer International Metabolic Database) reported that those who were older at first starting childhood rhGH (short duration of childhood rhGH replacement) and had a longer time off rhGH during transition were more likely to have higher total cholesterol and triglyceride levels during transition (51).

**Cardiac structure and performance**: At final height, cross-sectional echocardiographic studies indicate that all cardiac dimensions of adolescents with GHD who were treated with rhGH during childhood were significantly smaller than their age- and sex-matched healthy controls after withdrawal of rhGH (5.7±4.5 years), whereas reinstituting rhGH results in a significant increase in LV mass and LV mass index after 16–24 months (52) with improvement in endothelial function within the first 6 months of restarting rhGH (53).

There is also conflicting data on alterations in carotid artery intima-media thickness (IMT), a surrogate marker of early atherosclerosis with increasing in IMT thickness, in subjects with CO-GHD. Murata and coworkers showed a significantly higher IMT in adults with CO-GHD compared with both adults with AO-GHD and healthy controls (54). However, this alteration in IMT was not evident in adolescents with CO-GHD during and after discontinuation of rhGH (48, 55). A study involving 23 subjects with CO-GHD (14-IGHD) (aged 15–20 years)
showed that 6 months off rhGH in adolescents with confirmed GHD did not result in a significant alteration of the common carotid arteries, whereas in adolescents who were not confirmed to have GHD, IMT increased during rhGH treatment and reversed to normal 12 months after rhGH withdrawal (48).

In summary, the current evidence suggests that discontinuation of rhGH during transition is associated with a pro-atherogenic lipid profile; however, the effects of recommencement of rhGH treatment and a prolonged period off treatment are less clear. There is no evidence demonstrating that discontinuation of rhGH therapy during transition has any detrimental consequences on the cardiovascular system in the short or long term.

**Glucose metabolism:** Few studies have investigated CO-GHD and its replacement on insulin and glucose metabolism during transition in relation to concomitant changes in body composition and metabolism. After cessation of rhGH at final height, some studies reported an increase in insulin sensitivity as estimated by either means of a hyperinsulinemic euglycaemic clamp (56) or homeostasis model assessment (HOMA) (40) and an increase in fasting glucose (39) in those who had persistent GHD, with similar changes reported elsewhere in those who were not confirmed to be GH deficient at final height (57). Inversely, significantly impaired insulin resistance as measured by HOMA was recorded within 6 months off rhGH, but returned to baseline levels after 6 months after restarting rhGH replacement (48). At 2 years of resuming rhGH therapy during transition, there was an insignificant or limited effect on insulin residence, insulin sensitivity and glycosylated haemoglobin (HbA1c) (16, 20, 56). In addition to the variation in techniques used to assess glucose homeostasis in these studies, other factors, particularly body compositions and short-term duration, results in limited evidence with regards to impairment of glucose homeostasis in GHD and rhGH replacement during transition. Long-term studies are necessary to identify the influence of different aspects of GHD and replacement on glucose homeostasis during transition.

Generally, there is weak evidence that GHD or rhGH replacement induces an increase in the risk of type 2 diabetes (T2DM) in subjects with GHD. With regard to GHD, the KIMS database has demonstrated that the prevalence of T2DM in untreated adults with AO-GHD and hypopituitarism was higher than expected with an overall standardised prevalence proportion ratio (1.13 (95% CI: 1.04–1.23%)), which was largely to be explained by high BMI and the adverse body composition (58). In terms of rhGH replacement, there is an uncertain relationship between rhGH treatment and the risk of T2DM, in particular in those with GHD, and whether rhGH therapy leads to increased risk of diabetes has not been established yet. Paediatric studies demonstrated modest increases in the incidence of T2DM in rhGH-treated children with predisposed risks relative to the general population, but not in those with GHD individually (59, 60).

In conclusion, in GHD, there is insufficient evidence available to conclude whether or not rhGH therapy in childhood or transition alters insulin sensitivity and increases the risk of T2DM in adulthood. More research is needed to clarify the elements of the dual effects of GH during transition in adolescents with CO-GHD with regards to both the impact on body composition/BMI and insulin resistance.

**Quality of life**

The health-related quality of life (QoL) issue has emerged as an important aspect in consideration of rhGH therapy in adulthood, but not during childhood or transition (8). In relation to QoL in individuals with CO-GHD, some studies reported that children and adolescents with GHD have some difficulties with psychosocial functioning, mood, behaviour and cognitive ability (61) despite the achievement of acceptable final height (62). A retrospective study suggested that adolescents with CO-GHD who were not treated with rhGH after attaining final height have some psychological difficulties with self-confidence and social contact, and this was worse in those who were either rhGH-treated after the age of 12 years or those who were shorter at the start of treatment (61). A report from the KIMS database showed a positive relationship between height gain during childhood treatment and improvement in QoL at transition and an inverse relationship between QoL and duration off rhGH therapy with a longer period off rhGH associated with a poorer QoL (51). Re-instituting rhGH treatment has a significant positive change in health-related QoL aspects (51, 63). However, longitudinal studies evaluated the effects of discontinuation and resumption of rhGH treatment on QoL in young adults with CO-GHD and showed that discontinuation of rhGH treatment for 1 year leads to a decrease in QoL within 6 months, which is counteracted in 3–6 months after re-initiating rhGH therapy (6, 64). This was disputed in follow-up and RCT studies showing that QoL is less affected in adolescents with GHD measured after discontinuation rhGH at final height (63) with no difference in being off rhGH therapy and after re-commencing rhGH (16, 20, 65).
However, using different questionnaire tools (generic and disease-specific questionnaires) which assess different dimensions of health-related quality of life in adolescents with CO-GHD makes comparisons of the outcomes of these studies difficult.

In summary, there is variability in the assessment of QoL by different studies in terms of the instruments used and the effects measured which may reflect the different outcome results in QoL. In addition, QoL is multifactorial and factors such as short stature combined with other pituitary hormones deficiency may influence QoL in this particular group of patients. To date, there is no clear consensus on the appropriate QoL measurement tools in children and adolescents with GHD. Therefore, there is currently no evidence of reduced QoL that rhGH may have beneficial effects on QoL in subject with CO-GHD during transition.

Conclusions

GHD is an important condition that has detrimental effects on both physical and psychological health throughout life, whereas rhGH therapy shows benefits in both children and young adults with GHD throughout each stage of their life. It seems from the current data that rhGH has less direct impact on bone density, with a greater impact on body composition and cardiovascular risk factors, including improvement in serum lipid profiles, and to a lesser extent on insulin sensitivity and QoL. Even with scarce evidence, substantial short-term studies during transition revealed that untreated GHD has a risk of alteration in somatic and metabolic consequences, although it is difficult to establish whether these mild alterations represent the early long-term consequences and whether subsequent rhGH treatment improves long-term health. Larger studies of longer duration of rhGH therapy will be required to determine whether the metabolic alterations in adolescent GH-deficient patients persist in later adulthood and if recommencement of rhGH therapy has a positive impact on these aspects.

Declaration of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of this review.

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