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Computer-aided estimation of skeletal age and comparison with bone age evaluations by the method of Greulich-Pyle and Tanner-Whitehouse

Abstract  Bone age (BA) is usually estimated using the atlas of Greulich-Pyle (GP) or Tanner-Whitehouse (TW) and depends on the individual experience of the investigator. A computer-aided method, computer-assisted skeletal age scores (CASAS), based on the TW2-radius, ulna, short bones (RUS) method has been created to increase reliability and validity. We compared the results of the three different methods (CASAS, GP, TW2) in three groups of children with Turner's syndrome (TS), growth hormone deficiency (GHD), and familial short stature (FSS). The practicability and reliability of CASAS was investigated and the results compared with those obtained by the other methods. Each method was applied by one investigator, with up to six consecutive BA estimations per subject being carried out in 5 patients with TS, 6 with GHD and 18 with FSS. Using CASAS, individual bone evaluations had to be repeated once in 7.3 % and twice in 2.7 % of all probands on request of the computer system because of doubtful results. Manual interventions by the investigator were necessary in 12.3 % of evaluations in TS, 8.5 % in GHD and 9.0 % in FSS. The frequency of a “warning” insert, indicating uncertainty of CASAS, was also higher in TS than in GHD and FSS (19.0 % vs. 15.0 % and 13.0 %). The majority of external corrections for CASAS were necessary for evaluations of the fifth finger and the thumb. On three occasions with TS the progress of BA determined by CASAS demonstrated a regressive course with age. CASAS and manual TW2 BA data were comparable and generally higher than BA data obtained by GP (mean + 1.1 years). In conclusion, CASAS represents a useful method for analysing skeletal age and seems to increase reliability by rating on a continuous scale. However, difficulties with abnormally shaped bones restricts its use in some pathologic conditions.

Introduction

For evaluation of skeletal age the methods of Greulich-Pyle (GP) and Tanner-Whitehouse (TW2) are generally used in clinical practice [1, 2]. Bone age (BA) is an important parameter when children with growth disorders are investigated, and it is the basis for calculation of height prediction. However, evaluation strongly depends on the method used and on the investigator’s experience, leading to considerable inter- and intraindividual variation in results [3] which may influence the clinical diagnosis and therapy.

A computer-aided method, computer-assisted skeletal age scores (CASAS), based on TW2-radius, ulna, short bones (RUS), for estimation of skeletal age has been created by Tanner and Gibbons [4]. The problems of measuring errors caused by the semi-quantitative GP method and the discrete-integer progression of manual
Table 1 Percentage of repetitions, manual interventions and “warnings” in individual bone ratings in patients with Turner’s syndrome (TS), growth hormone deficiency (GHD) and familial short stature (FSS)

<table>
<thead>
<tr>
<th></th>
<th>TS</th>
<th>GHD</th>
<th>FSS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(5 patients,</td>
<td>(6 patients,</td>
<td>(18 patients,</td>
</tr>
<tr>
<td></td>
<td>30 films)</td>
<td>36 films)</td>
<td>34 films)</td>
</tr>
<tr>
<td>Repetitions (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once</td>
<td>7.0</td>
<td>7.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Twice</td>
<td>2.6</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Manual interventions (%)</td>
<td>12.3</td>
<td>8.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Warnings (%)</td>
<td>19.0</td>
<td>15.0</td>
<td>13.0</td>
</tr>
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</table>

TW2 bone scores, which often proves insufficient for intermediate developmental stages, may be overcome by rating on a continuous scale. Recently, Tanner et al. [5] reported the reliability and validity of CASAS in comparison with the manual TW2 method in healthy subjects. As evaluation of BA is of particular interest in pathologic conditions we tested the applicability of CASAS in three groups of patients. We present BA data generated by CASAS version 3.6 and compare these data with the traditional methods for BA evaluation.

Patients and methods

We analysed BA data from patients with Turner’s syndrome (TS), growth hormone deficiency (GHD) and familial short stature (FSS). To obtain longitudinal BA data, six radiographs were chosen from each of five patients with TS and six patients with GHD. Thirty-four radiographs from 18 patients with FSS were also studied. Chronological age (CA) of the patients was 2.4 to 18.9 years. Each of the 100 radiographs was evaluated by means of GR manual TW2 and CASAS. Each method was applied by one investigator, who was blinded for the results of the other investigators and the patients’ data.

Computer-aided method (CASAS)

The equipment consists of a light box, a video camera for digitizing the radiograph and a commercial computer set equipped with the BA determination program. The radiograph is reconstructed on the screen in real-time mode and one individual bone can be focused. According to the developmental stage of the bone, the investigator selects one of nine stages which are schematically depicted on both sides of the screen. Consequently, the enlarged template of this bone appears on the screen and, after fitting in the radiograph by altering the position by hand, zooming and focusing, the analysis is started. CASAS is based on the TW2-RUS method in which 13 bones (radius, ulna, first, third and fifth rays) are analysed. The computer calculates probabilities for each stage and a rating between 1.00 and 9.00 is obtained. In addition, it can weight each stage (+/−), depending whether the rating is in the upper or lower range of this stage (e.g. B + = 1.83–2.16; B − = 2.17–2.49; C = 2.50–2.82). The total score is calculated by the computer, which also calculates the actual BA. The system also provides a short method (six bones) which only rates the third ray and apportions the values obtained to the first and fifth rays.

If the CASAS-determined stage of a bone does not deviate more than ± 2.00 scores from the score predicted by the investigator, the result is accepted. In case of inaccuracies, i.e. high probabilities for non-adjacent stages, the computer shows a “warning”, recommending a repeat of the rating procedure. In any case, the investigator can enter the CASAS and feed it with a rating. If the determined stage differs more than ± 2.00 scores from the selected stage the computer “refuses” and requests either a re-grade or manual entry of the CASAS. Because of the possibility of manual interventions we have standardized the evaluation process as follows: manual corrections were carried out after the CASAS had failed in three attempts, i.e. if deviations from selected stages remained either > ± 2.00 or > ± 1.50 plus warning insert.

Results

Practicability and reliability of CASAS

Repetitions, manual interventions, and warnings

Table 1 shows the percentage of repetitions, manual interventions and warnings of individual bone estimations in the three groups of patients. One and two repetitions, which were necessary to obtain an acceptable result, were similar in all groups of patients (average 7.3 % and 2.7 %, respectively). Manual interventions were necessary most often in patients with TS (12.3 %). Similarly, the warning frequency was highest in radiographs of TS patients (19.0 %).

Concordance between selected and determined stages

Table 2 shows the percentage of concordance between investigator-selected and CASAS-determined stages of individual bones. The best concordance was achieved in stages with no epiphyses and mature stages, and low concordance (< 20 %) in some middle stages of bones of the fifth ray and the thumb.

Time

The time spent on evaluating one radiograph (13-bone model) was 15 to 25 min dependent on necessary repetitions. Using a 486 processor, the analysis operation itself lasted 35 s per bone.

Continuity of longitudinal BA determinations

Figure 1 shows BA data of six consecutive radiographs of a girl with GHD and a girl with TS, respectively. The variation within individual bone progression can be seen.