Computer estimation of skeletal maturation on the basis of cervical vertebrae maturation

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Abstract. The article describes skeletal maturation applied in medicine to estimate biological development of a human being. The method, devised by Baccetti and co-workers (CVM method – Cervical Vertebral Maturation) to determine the moment of pubertal growth basing on a lateral cephalogram, was presented. On the basis of the existing method, a program which determines a CVM stage basing on characteristic points, was written. The list of the results repeatability in traditional assessment as well as with the use of the program is presented in the article.

Introduction

Skeletal maturation, similarly to e.g. the development of secondary sex features, teeth calcification and their eruption, is one of the means of evaluating biological development of a human being. Skeletal maturation is estimated on the basis of the presence of secondary ossification nuclei, changes in their shape and the range of joining diaphysis with its epiphysis. The moment epiphysis is joined to its diaphysis, its growth is completed. Skeletal maturation is not closely correlated to human chronological age. It can be noticed by observing a group of children at the age of e.g. 11, although they are in the same calendar age, their growth can be considerably different, some of them can have permanent dentition while other children can still have primary teeth. Some children in this group may be prior to maximum pubertal growth, others during it, and among some, the pace of growth can be declining. The moment of the beginning of maximum pubertal growth is very varied, it usually occurs between the age of 8 and 11 with girls, whereas with boys between the age of 10 and 14 [1].

Predicting the beginning and ending of maximum pubertal growth, which is correlated to intensive development of upper jaw and mandible [2], is indispensable to estimate proper time of orthodontic therapy and the choice of a treatment method [3].
Methods

In medicine, two basic methods of evaluating skeletal age are applied:
- based on the analysis of hand and wrist radiographs
- based on the analysis of the change in the shape of cervical vertebrae

Analysis of hand and wrist radiographs

Hand and wrist consist of 30 bones, which compose about 10% of bones of the whole human skeleton. As a result, the advance in the development of hand bones constitutes a reflection of the development of the whole skeletal system.

Atlas method

The evaluation of the stage of skeletal development can be determined by comparing radiographs with atlas photos which display particular stages of wrist bones development. On the basis of similarity, the most similar atlas equivalent is chosen and skeletal age ascribed to the radiogram is read. Greulich and Pyle’s atlas [4], which enables evaluating if a child development is delayed or accelerated with reference to their calendar age and sex, is the most frequently applied one. This method is mainly applied in pediatrics or sports medicine.

Skeletal age on the basis of hand bones according to Björk and Helm

On the basis of a series of hand radiographs of growing children, Björk and Helm described dependence of maturation of hand skeleton on the auxetic curve. Observing wrist radiographs, they distinguished bones, maturing of which informs a doctor about a place on auxetic curve where a child is [5–6]. In their estimation, they used evaluation of:
- an extent of joint of epiphysis and diaphysis of proximal phalanx of the third finger (A)
- an extent of joint of middle phalanx and diaphysis of third finger (B)
- extents of joint of diaphysis and epiphysis of distal phalanx of third finger (C)
- ossification of ulnar sesamoid of the matacarpopahangelal joint of thumb (D)
- joint of epiphysis and diaphysis of radius (E)
Fig. 1. Hand and wrist radiogram with selected points which undergo evaluation according to Björk and Helm

Analysis of change in the shape of cervical vertebrae CVM

Baccetti, Franchi and McNamara [7–8] have modified the method of evaluating skeletal age on the basis of a change in the shape of cervical vertebrae during growth. In this method (CVM), C2, C3, C4 vertebrae, which are visible on a lateral cephalogram taken as a rule in orthodontic diagnostics, are evaluated. Initial bottom border of all the vertebrae is flat. Gradually, starting from top to bottom, a concavity appears and simultaneously the shape of C3 and C4 vertebrae changes from a trapezium to a rectangle, a square, till a “standing” rectangle [Fig. 2].

Fig. 2. Scheme of a change in the shape of cervical vertebrae according Baccetti

Evaluating skeletal age on lateral cephalograms [Fig. 3] taken routinely before starting orthodontic treatment, it is not necessary to take any additional radiographs.
In CVM method, 6 stages, from CS1 to CS6, are distinguished. According to Baccetti, maximum pubertal growth begins in CS3 stage, and finishes in CS4 stage.

**Stage CS1**

Lower border of all the cervical vertebrae is flat. The shape of C3 and C4 vertebrae is similar to a rectangular trapezium, there are minimum 2 or more years left to the beginning of maximum pubertal growth.

**Stage CS2**

A concavity appears on the lower border of C2 (over or equal to 0.8 mm), the lower border in C3 and C4 vertebrae is flat. The shape of C3 and C4 vertebrae is similar to a rectangular trapezium. There is about 1 year left to the beginning of maximum pubertal growth.

**Stage CS3**

The lower border of C3 vertebra becomes concave (the concavity on C2 is over or equal to 0.8 mm), the shape of C3 and C4 vertebrae stays without considerable changes. It is the beginning of maximum pubertal growth.
**Stage CS4**

All the vertebrae have a concavity on the lower border, the shapes of the vertebrae turn into a rectangle. It is the end of maximum pubertal growth.

**Stage CS5**

The concavity on the lower border and the shape of C3 and (or) C4 changes into a square. It has been about a year since maximum pubertal growth.

**Stage CS6**

There is a concavity on the lower borders and the proportion of the length of the borders of C3 or (and) C4 changes – the vertical borders
become longer than the horizontal ones. There have been 2 years or more since maximum pubertal growth.

Computer estimation of skeletal maturation basing on cervical vertebrae

On the basis of the Baccetti method, an algorithm to estimate skeletal maturation was devised. Its function is to determine a CVM stage basing on
the characteristic points indicated by a user. The algorithm is based on the assumptions formulated by Baccetti, i.e. skeletal maturity is estimated on the basis of calculated concavities on the lower border of diaphyses of cervical vertebrae and the lengths of the borders of cervical vertebrae diaphyses. Characteristic points are the utmost points of the vertebrae diaphyses as well as the points which define the largest depth of the concavity. Three points are marked on the second vertebra, on the third and fourth vertebra five points are marked in order given on [Fig. 11].

![Fig. 11. The order of marking points](image)

Points A, B, C are the characteristic points on the diaphysis of C2 vertebra – top left, bottom right and the point defining the largest concavity respectively.

Points D, E, F, G, H are the characteristic points on the diaphysis of C3 vertebra – top left, top right, bottom right, bottom left and the point defining the largest concavity respectively.

Points I, J, K, L, M are the characteristic points on the diaphysis of C4 vertebra – marked similarly to C3 vertebra.

After the points are marked, the depths on CS2, CS3, CS4 vertebrae are calculated. The depth of the concavity is determined as a distance of the point defined by a user as the deepest point from the straight line that emerged from the combination of two points on the bottom border of the diaphysis [Fig. 12].
On the basis of obtained values, CVM stage is defined according to the method devised by Baccetti
- the concavity on C2 vertebra is below 0.8 mm – CS1 stage is ascribed to the examined photo
- the concavity on C2 is over or equal to 0.8 mm, and on the others it is below 0.8 mm – CS2 stage
- the concavities on C2 and 3 are over or equal to 0.8 mm and on CS4 below 0.8 mm – CS3 stage
- if all the concavities are over or equal to 0.8 mm, the relation of the sum of vertical borders to the horizontal ones on C3 and C4 vertebrae is examined.
  • if the obtained relation on any vertebra oscillates around value 1 (from 0.9 to 1.1), it is assumed that the shape of the vertebra is similar to a square thus the photo is classified as stage 5.
  • if on any vertebra the relation of the sum of vertical borders to the horizontal ones is over value 1.1, then stage 6 is assumed (the vertical borders are longer than the horizontal ones)
  • if the relation of the sum of vertical borders to the horizontal ones is below value 0.9 on both vertebrae, then the algorithm turns to stage 4.

Comparison of the obtained results

The method proposed by Baccetti and co-workers was tested from the point of view of repeatability of the results evaluating the same photos. For this purpose, cephalograms taken in Orthodontic Department of the
Medical Faculty, Palacký University in Olomouc from the period of 1.07.2004 to 11.03.2008 were used. 43 X-ray pictures of good quality were chosen from 132 cephalograms of girls and boys. The examination was done by the second author at 2 month intervals.

The repeatability of the results in a traditional assessment was achieved with 74% of photos. Among 21% of other pictures the difference was at the level of one stage, the rest 4% of photos differed with more than one stage.

After that, the author examined 43 earlier discussed pictures with the use of the devised algorithm. All the pictures were scanned in 150 dpi resolution. Two evaluations of the stages according to CVM were accomplished at a week interval. The repeatability of the results at the level of 78% was achieved. A difference of one stage occurred in 16% of the cases, whereas the difference of more than one stage occurred in 7% of the cases.

The table below [Tab. 1] presents the list of the results obtained in a traditional assessment as well as with the use of the program.

Tab. 1. Comparison of the repeatability of the results

<table>
<thead>
<tr>
<th></th>
<th>Nr of picture</th>
<th>Repeatable result</th>
<th>Difference of 1 stage</th>
<th>Difference &gt; 1 stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>43</td>
<td>32</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>analysis</td>
<td>100%</td>
<td>74%</td>
<td>21%</td>
<td>5%</td>
</tr>
<tr>
<td>Analysis with the</td>
<td>43</td>
<td>33</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>use of the program</td>
<td>100%</td>
<td>77%</td>
<td>16%</td>
<td>7%</td>
</tr>
</tbody>
</table>
In the computer analysis, the biggest difference in the stages assigned to the same photo was of 2 stages, whereas in a traditional analysis the biggest difference was of 3 stages.

### Tab. 2. Spread of the obtained results

<table>
<thead>
<tr>
<th></th>
<th>Difference of 1 stage</th>
<th>Difference of 2 stages</th>
<th>Difference of 3 stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional analysis</td>
<td>9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Analysis with the use of the program</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Analyzing the obtained results, it is worth paying attention to the fact that in the assessment with the use of the computer algorithm the difference of the stages of 2 applies to the pictures which also in a traditional assessment were not evaluated at the level of the same stage (the difference was of 1).

Among 20 pictures, in the case of which the agreement of the results in a computer assessment was not achieved, 4 pictures were also assessed at the level of different stages in a traditional assessment.

The most frequently occurred differences in a traditional assessment of one picture concerned CS4 and CS5 stages. It can be assumed that the problem is in the assessment of the proportion of the sides, i.e. whether the diaphysis of cervical vertebrae is still similar to a rectangle, or whether its shape resembles a square yet. However, in the assessment with the use of the algorithm, a particularly dominating boundary of the stages, at the level of which the differences most frequently appeared, did not occur. The differences of the assessment spread proportionally to all the stages. Minimal differences in the arrangement of characteristic points, which cause the shift of the assessment from one stage to the other, are the reason for that.

### Conclusions

The application of the computer assessment of CVM stages allows to achieve the repeatability of the results similar to the repeatability of the results obtained in a traditional assessment, however, it is worth paying attention to the fact that the program simplifies calculating the depth of the concavity and the proportion of the sides considerably. The assessment
made by a doctor happens not to be much accurate (whether the depth of the concavity achieved the value of 0.8mm or whether the shape of the diaphysis of cervical vertebrae is similar to a square or rectangle), therefore considerable differences in the assessment of one picture occur.

The difference in the CVM stage in a traditional assessment as well as with the use of the program concerned the same cephalograms to a high degree. Therefore, it is probable that the X–ray was taken at the turn of two CVM stages and it is impossible to interchangeably classify it to any of the stages. It is however significant clinical information to a practitioner, whereas one has to decide on one of the stages for the purpose of the statistics. Estimated information about an approximate beginning or ending of a pubertal growth is significant information which allows to take proper measures in treatment.

Applying the algorithm has also some disadvantages: the algorithm is very sensitive to minimal shifts of characteristic points since it makes calculations very accurately. A little shift can cause relocation of an assessment from one stage to the other. However, as it was mentioned earlier, such a difference is of not a significant importance in the process of orthodontic diagnosis.

REFERENCES
