BIOLOGICAL AGE

SEDLAK

Biological Age

Biological age determines the degree of biological maturity of a child's organism. It characterises the complex state of an individual's growth and development, and it represents an index that helps to define its morphological and functional traits. Biological age can be regarded generally as a process of physiological, biochemical, mental and anatomical ageing. It determines the state of a child's development in respect to a definite age standard and classifies its position in the so-called 'zones of growth velocity' (acceleration, average development, retardation). Biological age may differ significantly from chronological age if it exhibits disproportions from normal growth in various periods of development (Fig. 1). Biological age is an indispensable index of somatic development in a number of fields of study, e.g. in forensic medicine, in the medicine of sports and physical education, etc.

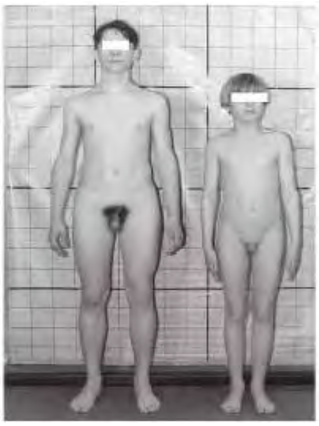

Figure 1 – Different development trend in boy sat the same chronological age (13.5 yrs. and 13.1 yrs.)

The biological age of a child may be measured in a number of ways, based on applying various markers. Not all of them reflect the development and growth of a child's body as an organic whole. That is why we choose convenient methods of measuring biological maturity according to the specific needs of a given field of study (endocrinology, orthopedics – bone age, orthodoncy – dental age etc.) and also according to the availability of appliances for examinations (roentgenogram, anthropometrical examination, etc).

Growth Age

Growth age evaluates the degree of the child's somatic growth. To determine growth age various age-specific growth standards are required, represented mostly by percentile graphs of body height (or body mass) (Fig. 2, 3). The state of growth in a particular child is evaluated by comparing the position of its body height on a percentile graph. A higher degree of precision can be reached by taking into consideration the growth mainstream, which is defined by the genetic growth potential expressed by the average height of parents (midparent height).

Precise values of growth age can be obtained by counting the values of age (in tenths of a year), corresponding to the 50th percentile of the child's body height, on the percentile graph of growth.

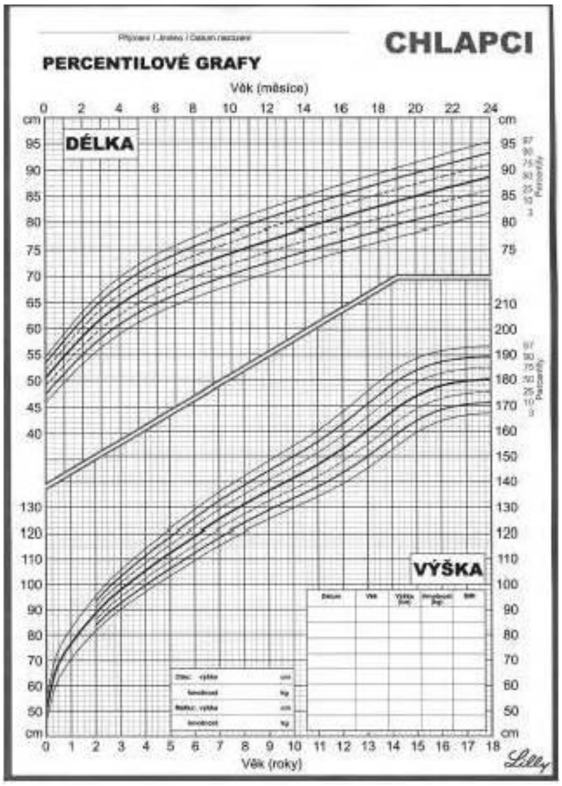

Figure 2 – Body height percentil charts for boys – Czech child population standards 2004

The growth age of a child may also be determined by comparing the values of height and body mass in relation to chronological age:

$$RV = \frac{a + b + 2c}{4}$$

(Riegerová 1982)

or

$$RV = \frac{a + b + c}{3}$$

(Przeweda, 1981)

a = height age, i.e. chronological age represented by the child's height as the 50th percentile
b = body mass age, i.e. chronological age represented by the child's body mass as the 50th percentile,
c = chronological age, determined with respect to the date of examination

All values are counted from percentile graphs given in national referential studies.

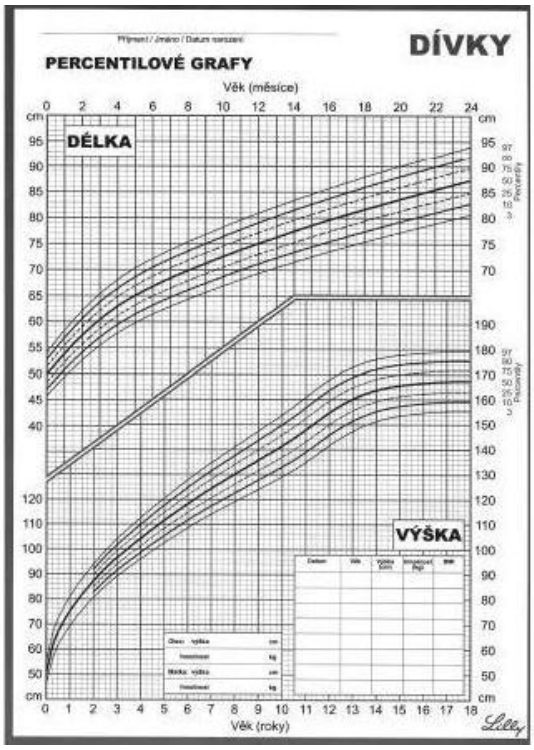

Figure 3 – Body height percentil charts for girls – Czech child population standards 2004

The methods of determining growth age do not require demanding measurements, but their informative import is relatively low because, owing to the high inter individual variability of growth, they do not convey much information about the child's complex biological development. This is why they are regarded as insufficient for the needs of clinical auxology.

Dental Age

Dental age is determined according to the state of maturity in the first denture (milk teeth) and the second (permanent) denture. The index of dental age is evaluated by comparing the stages of eruption in different teeth by means of direct aspection or on the basis of X-ray photos. Counting developmental stages from X-ray photos also makes it possible to observe the state of denture before eruption, i.e. from the rise of the dental pouch to the complete formation of the tooth root.

It is also possible to use the method of so-called dental degrees, the evaluation of which is based on determining the number of teeth cutting their way from jaws or scrutinising the state of eruption in a definite group of teeth. An adequate number of teeth, present in a given chronological age, is considered as the index of maturity. This is based on the assumption of linear dependency between dental stages and chronological age. This method is characterised by simple diagnostics and does not presuppose X-ray examination.

The use of dental age in auxological diagnostics is limited owing to its well-known disproportion with skeletal age. Various methods of measuring dental age pay little heed to differences in the eruption of teeth in the upper and the lower jawbone (incisors and canines cut their way in the mandible approximately one year earlier), inter-sexual differences (the teeth of girls cut their way out two months (for M1) to eleven months (for C) sooner than those of boys). The lower canine of girls often starts its eruption earlier than the first upper premolar tooth. We also come across the sequence P2, M2 more frequently.

Skeletal Age

This characterises the degree of ossification in various areas of the child's skeleton from birth to final stages of growth. It implies estimating the number and size of different cores of ossification as well as the closure of epiphysial slots. Various methods make use of analysing the X-ray photographs of different sections in a child's skeleton and comparing their state with standards published in X-ray atlases. Most heed is paid to the skeleton of the hand and distal parts of the forearm, to the skeleton of legs and distal epiphyses of shinbones. Other areas of considerable interest are the knee joint (dist. epiph. femur + prox. epiph. tibia) and the process of ossification in cervical vertebrae or in vertebrae in the proximal segment of the chest backbone (the 2nd to 7th vertebra in the chest area).

Current clinical practice makes most frequent use of methods based on evaluating the skeleton of the hand and distal epiphyses of the forearm (Fig. 4). In this part of the skeleton it is possible to find a great number of various bones with different types of ossification in a relatively small area. While carpal bones ossify according to the typical model of short bones (always enchondromatously from one centre), the bones of the metacarpus and fingers recall the types of ossification common in long bones. They ossify from the body and one epiphysis (monoepiphysial bone), in the metacarpus os-sification starts from its head (with the exception of the metacarpus of the thumb) and in the fingers it begins at the base. The complex characteristic is completed by estimating the state of ossification in the distal epiphyses of the forearm bone (long bone).

An important advantage of these methods is a relatively small strain due to expos-ing to the X-ray radiation concerning only the acral part of the children's body.

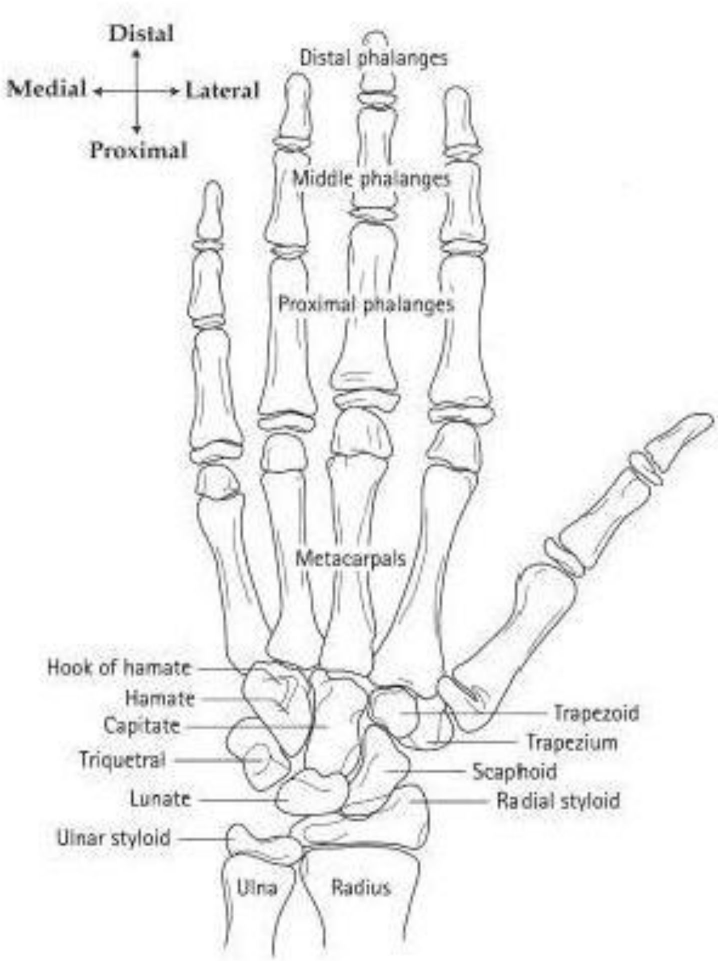

Figure 4 – Hand bones and antebrachium distal epiphyses scheme (according to Tanner et al., 2001)

Methods:

1. quantitative methods evaluate X-ray photographs of the hand as a whole. They were derived from procedures of measurements proposed by T. W. Todd (1937), which were later developed into techniques of measurement outlined by Greulich and Pyel (1959).

The method of Greulich and Pyel (GP) (1959) relies on comparing X-ray photo-graphs of the left hand and the distal epiphyses of the forearm as a whole with standards published in the GP atlas (there are 29 patterns for girls and 31 pat-terns for boys). Standards were constructed on the basis of the original X-ray photographs made by Todd (the project of the Brush Foundation Growth Study in 1929 to 1931, Cleveland in the USA.). In the course of the years 1932–1942 these were completed by X-ray photographs of children aged from 3 months to 14 years. Children chosen for examination descended from upper social classes and families with higher education. Every standard in the atlas was chosen from one hundred photographs of children in the same category of sex and age.

The GP method is used worldwide thanks to its simplicity and fast evaluation, and it is still very popular. Recent studies show that although it is one of the earliest methods, it may also be applied with great success to the present-day population. Its disadvantage lies in evaluating the X-ray photograph of the hand as a whole, which has a negative effect in neglecting the inter individual variability of ossification in various bones (it is very difficult to apply this method in case of asynchronous ossification). Another limitation is an insufficient regard to differences in ossification between sexes and the fact that its classification is age groups is too rough. A further disadvantageous trait is the fact that the scale of skeletal maturation is defined in years, which need not be equivalent to units of chronological age (on the scale of maturity an individual may pass through different types of ossification during one period of time – for instance in the course of the first year ossification is more intensive in girls than in boys).

2. qualitative (descriptive) methods evaluate the bones in the X-ray photograph of the hand separately without regard to one another. The most elaborate method is that of Tanner and Whitehouse, which is also most widely used in current practice. These authors were the first to introduce the so-called point scoring system' as a method of observation. So the comparative evaluation of the X-ray picture was replaced by exact measurements giving results in the numeral value of 'score of skeletal maturation' (SMS), which represents the sum of all scores obtained by a descriptive evaluation of 20 bones of the left hand, including the distal epiphyses of the forearm. SMS is then redefined as a value of skeletal age by means of tables of regressive values.

The method of Tanner and Whitehouse 2 (TW 2) (1975) used 7 to 8 degrees to evaluate the progress of ossification in 20 bones of the left hand, including the distal epiphyses of the forearm. These degrees are also denoted by letters B–H, occasionally also B–I (Fig. 5). Various degrees of maturity in bones are given specific evaluation in points determined according to the TW 2 atlas, boys and girls being estimated separately. Referential data were created on the basis of a collection of 3000 healthy children. They were screened in the 50s of the 20th century in Lon-don, its suburbs and close neighbourhood. They were born in lower-middle-class and lower-class families and lived in poorer social conditions. The collection also included children from asylums for orphans (Harpenden Growth Study).

The method makes it possible to evaluate various sections of the skeleton of the hand:

a) RUS (Radius – Ulna – Short bones) = distal epiphyses of the radius and ulna, epiphyses of the metacarpus and phalanges in the 1st, 3rd and 5th finger

b) CARP (Ossa carpi) = ossification and development in the shape of all carpal bones

c) TW 20 = the skeleton of the hand and distal forearm as a whole (system RUS + CARP)

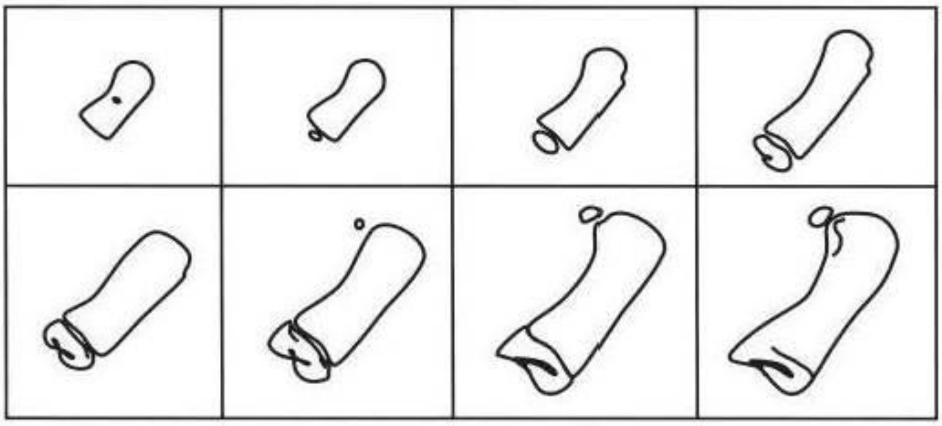

Figure 5 – Scheme of hand bones epiphyses development periods (according to Tanner et al., 2001)

The score of skeletal maturation found in different systems always corresponds to a given value of the skeletal age. In atlases it is given with the precision of one tenth of a year, which is a great advantage of this method. A constant part of the TW 2 atlas is formed by regressive equations for the exact prediction of the final body height.

Its disadvantage lies in its tediousness, laboriousness and time-consuming applications, as well as in requirements of long-term experience in evaluating X-ray pictures.

The method of Tanner and Whitehouse 3 (TW 3) originated as an innovation of the original TW 2 method (Tanner, Healy, Goldstein, Cameron; 2001). It takes into consideration the influence and effects of the secular trend on skeletal maturation in contemporary populations of Europe. The method is based on collections of data obtained from recent populations of children: Belgium – 21,174 boys (12 to 20 years of age) and 9,698 girls (6 to 19 years of age), (Leuven Growth Study, 1969–1980); Spain – 1,800 children (Bilbao); USA – Texas (Heartbeat Project) – 1,096 children of European descent (8 to 17 years of age).

The TW 3 method works on the same principle as the TW 2 method. It is evaluated by the compartments of RUS and CARP while the complex of TW 20 was, omitted. The principal change consisted in lowering the age for reaching a definite score of skeletal maturation and taking into account the secular trend. For instance, in the process of reaching adult maturation (score of 1000), in contrast to TW 2, the age is lowered by the value of 0.9 year in girls and by 1.5 year in boys. However, the value of the score of skeletal maturation (in contrast to the value of skeletal age) is a quantity independent of the secular trend and factors of environment.

Proportional Age

Proportional age is evaluated according to one of basic morphological traits, ac-cording to proportionality in body parameters, which may change from birth to adult-hood. This means that a given degree of development corresponds to a definite correlation between different parts of the body. The evaluation of proportionality is basedon observations of anthropometrical parameters, and it directly reflects the age specific dynamics of the child's growth.

The original method of determining proportional age was elaborated by Wutscherk (1974), who applied the so-called 'complex sign of the body build' (KC) for expressing the degree of development. The latter is determined by eight anthropometrical parameters and calculations of the final index (KC), which is given by the mutual proportion between the sign of extremities (KA) and the sign of the trunk (KB).

KA comprises the length and girth parameters of extremities:

$$KA = (a \times b) + (c \times d)$$

a – the length of the upper extremities
b – the girth of the arm in a relaxed state
c – the length of the lower extremity
d – average girth of the thigh

KB is based on breadth parameters of the trunk, body height and body mass in an individual:

$$KB = \frac{(\text{biacromial breadth ofshoulders} + \text{bispinal breadth ofthe pelvis}) \times \text{body height}}{2 \times \text{body mass}}$$

The complex sign of body build (KC) is then given by the ratio of both signs:

$$KC = \frac{KB}{KA}$$

While the sign of extremities (KA) increases with the progress of age (it is conditioned by the lengthening of extremities and increasing of their girth parameters), the sign of the trunk (KB) declines (the growth of the breadth of shoulders and the pelvis, the growth of the body in height and increase in body mass). Owing to the development, the values of KC decrease with growing age, from about 5 in children to 1 in adulthood.

The simplified procedure of determining of proportional age was published by Brauer (1982). It is based on the original method of Wutscherk and it makes use of the socalled 'index of body build development' (KEI – Körperbauentwicklungsindex) as the chief criterion of biological maturity. Its calculation includes five anthropometrical in-dices – body height and body mass, biacromial breadth of shoulders, bispinal breadth of the pelvis, maximal girth of the forearm (in boys), average girth of the thigh (in girls) and values of Rohrer' index (RI).

The formula for calculating KEI:

$$KEI(boys) = \frac{(biacromial\ breadth + bispinal\ breadth)\times(2max.\ girth\ of\ forearm - 16RI)+18,1}{20\times body\ height}$$

The basic criterion for evaluating the course of biological development is the range x ± s, or x ± 0.5 s (x = average value of KEI in the respective age category, s = respective standard deviation):

acceleration + difference >+ 12 months
average 0 difference = ± 12 months
retardation – difference>– 12 months

Table 1 – Normatives KEI of Czech population – boys

Boys / Age	x	s	dif. ± 12 monts
3.00–3.99	0.46	0.05	0.46–0.5
4.00–4.99	0.5	0.05	0.46–0.56
5.00–5.99	0.56	0.05	0.50–0.59
6.00–6.99	0.59	0.06	0.56–0.61
7.00–7.99	0.61	0.06	0.59–0.64
8.00–8.99	0.64	0.07	0.61–0.66
9.00–9.99	0.66	0.07	0.64–0.69
10.00–10.99	0.69	0.06	0.66–0.71
11.00–11.99	0.71	0.06	0.69–0.74
12.00–12.99	0.74	0.06	0.71–0.78
13.00–13.99	0.78	0.07	0.74–0.84
14.00–14.99	0.84	0.07	0.78–0.86
15.00–15.99	0.86	0.06	0.84–0.89
16.00–16.99	0.89	0.06	0.86–0.90
17.00–17.99	0.9	0.07	0.89–0.90
18.00–18.99	0.9	0.07	0.90–0.46

Table 2 – Normatives KEI of Czech population – girls

Girls / Age	x	s	dif. ± 12 monts
3.00–3.99	0.43	0.05	0.46–0.43
4.00–4.99	0.47	0.05	0.43–0.53
5.00–5.99	0.53	0.05	0.47–0.59
6.00–6.99	0.59	0.06	0.53–0.62
7.00–7.99	0.62	0.06	0.59–0.65
8.00–8.99	0.65	0.06	0.62–0.69
9.00–9.99	0.69	0.06	0.65–0.72
10.00–10.99	0.72	0.07	0.69–0.77
11.00–11.99	0.77	0.07	0.72–0.80
12.00–12.99	0.8	0.07	0.77–0.84
13.00–13.99	0.84	0.08	0.80–0.87
14.00–14.99	0.87	0.07	0.84–0.90
15.00–15.99	0.9	0.07	0.87–0.91
16.00–16.99	0.91	0.08	0.90–0.91
17.00–17.99	0.91	0.07	0.91–0.92
18.00–18.99	0.92	0.07	0.92–0.46

The techniques of determining proportional ages show a high degree of agreement with skeletal age (TW 2 method), with the progress of development of secondary sexual traits and with the beginning of menarche in girls. It also corresponds well to the peak of maximal pubertal growth acceleration (PHV). KEI documents the typological dependence of girls upon the speed of sexual maturation and the ascent of PHV in a very clear and distinct way. Parallel studies devoted to boys found looser correlations (Riegerova, 1996). Absolutely reliable methods of determining biological age are possible by means of KEI in children with a proportional relation body mass / body height (the body height itself does not play a decisive role here). A greater difference in the point of higher retardation was found in children with a slim or asthenic body build (RI < 1.06). As a criterion of proportional age, KEI did not only exhibit high validity in aver-age populations of children but also in selected groups of children's populations (slim children, obese children with overweight) in a wide age interval from 3 to 15, eventually to 18 years of age) and similar groups (Sedlak, Riegerová; 1998). The disadvantage of this method lies in the absence of regressive equations or nomogrammes for calculating the values of KEI on the decimal scale of age.

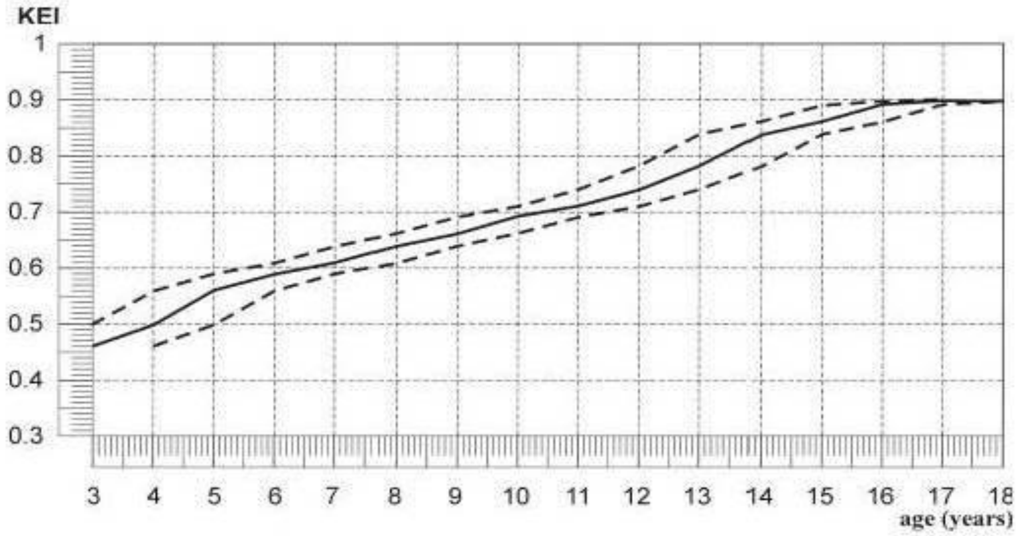

Figure 6 – Change of body build development index values (KEI) in Czech children boys (according to Riegerová, Sedlak, 1996)

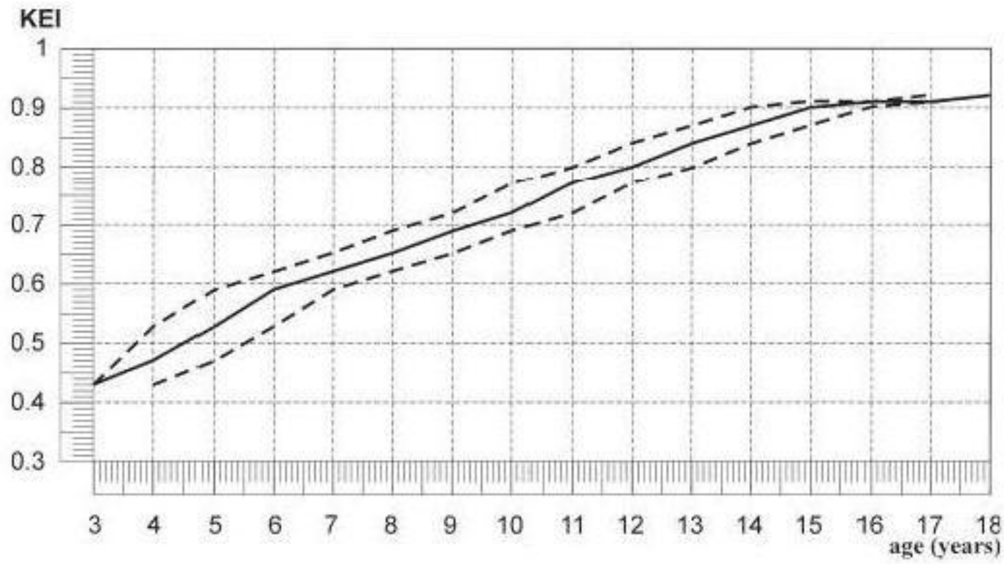

Figure 7 – Change of body build development index values (KEI) in Czech children – girls (according to Riegerová, Sedlak, 1996)

Developmental Age

This evaluates the degree of development of secondary sexual traits and judges the state of sexual maturity. Its evaluation makes use of a wide range of scales proposed by different authors. Many of them attempted to transfer degree of development in different traits under scrutiny into the final score denoted as developmental age. Contemporary approaches to the diagnostics of degrees of sexual maturity abandon evaluation in indices and apply estimations of the stages of development of various traits in comparison to the sequence of their occurrence.

Current practice tends to use the scale of sexual maturation proposed by Tanner (1963). In girls we evaluate stages of the growth of the breasts (M), pubic (P) and axillar hair (A) and the beginning of the menarche. In boys we determine the appearance of the external genital (G) and the degree of development of pubic (P) and axillar hair (A). Tanner's scale of evaluating secondary sexual traits applies five-degree classification, where Degree 1 characterises the prepubertal stage of developmental tranquillity and Degree 5 denotes the stage of adulthood (Tab. 3).

Table 3 – Stages of sexual development (according to Marshall, Tanner, 1969, 1970)

Stadium	Breast development
M1	Preadolescent: the infantile stage with persists until puberty begins. Only the nipple is raised above the level of the skin.
M2	Budding stage: bud-shaped elevation of the areola and papilla. Areola increased in diameter and surrounding area slightly elevated.
M3	Further elevation of the breast. Diameter of areola further enlarged. Shape of small adult mammary gland with a continuous rounded contour.
M4	Increasing fat deposist. Areola and papilla further anlarget. The areola forms a secondary elevation above that of the breast. This secondary mound apparently occurs in roughly halt of the girls, and may persist in adulthood.
M5	Adult stage: the areola recessed to the general contour the breast.

Stadium	Male genitalia development
G1	Preadolescent: testes, scrotum and penis are the same size and shape as in the young child.
G2	Enlargement of testes and scrotum. The skin of the scrotum becomed redder, thinner and wrinkled. Penis no larger of scarcely so.
G3	Enlargement of the penis, especially in lenght. Further enlargement of testes and scrotum.
G4	Continued enlargement of the penis and sculpturing of glans. Further enlargement of testes and scrotum, scrotal skin shows increased pigmentation.
G5	Genitalia are adult in size and shape.

Stadium	Pubic hair development
P1	Preadolescent. No growth of pubic hair.
P2	A few, lightly pigmented hairs, usually straight or only slightly curled, appearing at base of the penis and chiefly along the labia.
P3	Still sparse, yet definitely pigmented, coarser and more curly hair around base of the penis or on labia.
P4	Hair adult in type, but the area covered is still considerably smaller than that in the adult, not going further than the inguinal fold.
P5	Adult hair in quantity and type; in an inverse triangle with horizontal lining on mons in girls and spreading up to medial surface of the thighs, but not upwards linea alba, to boys.

An important criterion of the beginning of puberty in boys is the growth of the testes, which are measured by palpation by means of Prader's orchidometer (Fig. 8). The volume of the testes up to 3 ml signals the prepubertal stage, an increase of volume up to 4 ml and more signals the start of puberty. Observing pubertal changes in boys can be completed by data concerning the growth of laryngeal cartilages associated with the mutation of voice.

The sequence of development of secondary sexual signs and their relation to the course of pubertal growth acceleration is described in Chapter on Onthogenetic de- velopment.

Figure 8 – Prader's orchidometer

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