A DISCUSSION OF CAUSES OF ERROR IN THE DETERMINATION OF CHRONOLOGICAL AGE IN CHILDREN BY MEANS OF X-RAY STUDIES OF CARPAL-BONE DEVELOPMENT

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Following the introduction of X-rays at the beginning of the present century, extensive research has been conducted in many countries into the ossification of skeletal bones. These studies have shown that there is a definite sequence in the appearance of centres of ossification and that the time of their appearance follows a fixed pattern.

The age at which these centres appear is earlier in females than in males. According to Köhler[1] the difference in the postnatal ossification rate of the skeletal parts during the first 5 years of development is so marked in boys and girls that differences of even as much as 2 years in the appearance of the ossification centres may be found

TABLE I. AGE AND RELATIVE ORDER OF APPEARANCE OF CARPAL CENTRES OF OSSIFICATION IN CHILDREN AS FOUND BY DIFFERENT INVESTIGATORS IN THE USA AND CENTRAL EUROPE

Ossification centre	Flory				Greulich and Pyle				Siegert						Schinz and Baensch	
	Female		Male		Female		Male		Female			Male			Female and male	
	Months	Order*	Months	Order	Months	Order	Months	Order	Months	Average months	Order	Months	Average months	Order	Months	Order
Os capitatum ..	6	1	6	1	3	1	3	1	2		1	4		1	3	1
Hamatum ..	6	1	6	1	3	1	3	1	4		2	5		2	4	2
Epiphysis radii ..	9	2	15	2	12	2	18	2	8-11	9½	3	15-18	16½	3	18	3
Triquetrum ..	23	3	24	3	24	3	36	3	32-35	33½	4	33-36	34½	4	36	4
Lunatum.. ..	36	4	42	4	42	4	42	4	40-48	44	5	48-50	49	5	48	5
Multang. major..	50	5	72	5	50	5	60	5	48-54	51	6	55-72	58½	6	60	6
Multang. minor..	53	6	73	6	52	6	75	7	48-54	51	6	56-72	64	7	60	6
Naviculare ..	56	7	72	5	52	6	72	6	54-59	56½	7	60-72	66	8	60	6
Epiphysis ulnae ..	68	8	80	7	78	7	78	8	65-72	68½	8	74-85	79½	9	72	7
Pisiforme ..	108	9	140	8	108	8	120	9	93-129	111	9	109-138	123½	10	120	8

* In cases where the same number occurs more than once in the same column, the particular carpal bones concerned appear at the same time.

between the sexes during this period. He concluded that, even though girls are smaller than boys, the ossification centres appear earlier and develop more rapidly in females than in males.

In the case of the carpal bones the appearance and development of the centres of ossification take place only after birth. Only a delicate cartilaginous structure is present at birth, from which the ossification centres develop.

Studies on the time of appearance of the carpal bones and on the differences in this respect between males and females have been made by a number of investigators. The findings of 2 American and 2 European research groups with regard to the age and relative order of appearance of the carpal ossification centres are summarized in Table I. Flory's[2] data and those of Greulich and Pyle refer to White American children. The figures of Siegert and Schinz-Baensch are considered satisfactory by Köhler for European conditions, but he also approves of Flory's data. The *Radiographic atlas of skeletal development of hand and wrist* by Greulich and Pyle[5] is also very useful.

If bone development in the prepubertal stage proceeded undisturbed by external or internal factors, it would naturally not be difficult to estimate chronological age from bone age. The determination of chronological age can be of importance for research purposes and is also of use to pathologists, radiologists, and workers in medical jurisprudence (e.g. in court cases). While, however, the ages at which the carpal bones appear are taught to students almost as a law, it should be noted that deviations from the normal plan of development of the carpal bones do occur. Such deviations may lead to confusion and faulty diagnosis of the chronological age.

Examples of deviations observed in the course of nutritional-status surveys carried out by the National Nutrition Research Institute are shown in Figs. 1 - 3. In Fig. 1 the presence of only 3 carpal bones would suggest, according to the usually accepted standards, an age of only 2 years 9 months (i.e. an error of 4 years). In Fig. 2 the state of development would indicate an age of 7 years 10 months, whereas the subject was only 6 years 9 months old. In Fig. 3 the presence of the os capitatum, os hamatum, and os triquetrum indicates an age of 2 years 6 months, while the stage of development of the epiphysis ulnaris indicates an age of 6 years 3 months. The subject was 5 years 4 months old.

It must be mentioned at the outset that certain pathological abnormalities of the wrist joint occur owing to such factors as congenital endocrine disturbances, pre- and postnatal infections, traumatic and parasitological conditions, osteoporosis, osteosclerosis, and benign and malignant neoplasms. These pathological conditions, however, present characteristic radiological features and will not be further discussed here, since they are primarily of pathological interest.

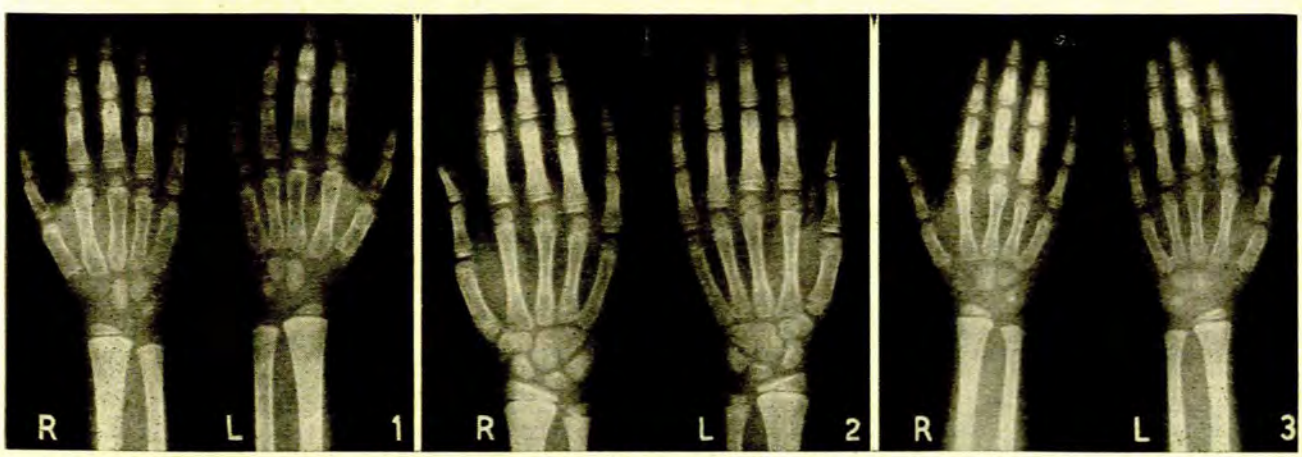

Fig. 1. Gross retardation of carpal-bone development in a male White child aged 6 years 9 months.
Fig. 2. Acceleration of carpal-bone development in a female Bantu child aged 6 years 9 months.
Fig. 3. Retardation and acceleration of carpal-bone development in a female Bantu child aged 5 years 4 months.

While most American investigators have reported little or no difference in carpal-bone development between the 2 sexes, we have found evidence of minor sex differences in the development of the carpal bones in approximately 18 - 20% of the Bantu and European children studied in our surveys. We have also found that the ossification is not always symmetrical and that in some cases there is a difference in development between the 2 hands (up to 6 months). The last-named differences are too small, however, to be of practical importance in the determination of chronological age. Köhler[3] has made the interesting remark that, according to Wilms and Göttsche, the ossification centres show advanced development in cases of tuberculosis and that this is more marked in the wrist of the affected side of the body than in that of the healthy side.

ABNORMALITIES

The main abnormalities which we have found to hamper the determination of chronological age by means of the state of carpal-bone development are listed and discussed below.

1. *Retardation of Carpal-bone Development*

An example of this condition is shown in Fig. 1. Factors which may be responsible include: constitution, race, environment, climate, insufficient light, physical inactivity, inadequate supply of fresh air, hypophysial dwarfism, hypogonadism, eunuchoidism, cretinism, thyreoprivism, hypothyroidism, diabetes mellitus, Addison's disease, deficiency of minerals in the diet, rickets, chronic suppurations, severe illness, neurovascular defects, neurological aberrations, coeliac disease, protein loss, and, according to Gillman and Gillman,[7] serious undernutrition or malnutrition.

According to Flory[2] there is no doubt that severe physical disorders can interrupt the rhythm of a child's development. On the other hand, however, he wrote: 'Yet developmental disruptions occur, when no physical symptoms can be attached to the break in growth-rate'.

Flory[2] studied, individually, 15 schoolgirls who showed sharp breaks in skeletal development. Eight of these girls had suffered from one or more of the following diseases: whooping cough, neurodermatitis, measles, glandular dysfunctions, unhealthy tonsils, chronic constipation, nervousness, repeated colds, persistent fatigue, headaches, rheumatic fever, bronchitis, laryngitis, and malnutrition. He remarked: 'Any one of these disorders might conceivably slow up the ossification temporarily. Recovery from illnesses requires a short or long period and may be even several years of time'.

2. *Acceleration of Carpal-bone Development*

For an example see Fig. 2. In this case constitution, race, hypophysial gigantism, precocious puberty, tumours of the pineal body, thyrotoxicosis, chronic suppurations, adrenal tumours, and rheumatic fever may be responsible.

3. *Acceleration and Retardation in the same Carpal-bone Area*

An example is shown in Fig. 3. The identity of the factors responsible is not clearly known, but the possibility exists that the occurrence of conditions of chronic undernutrition or malnutrition or continuous loss of protein, simultaneously with chronic infections or rheumatic fever, may contribute to the appearance of such phenomena. Further research will be necessary in this direction in order to determine the causes of these anomalies.

4. *Other Abnormalities Observed*

Abnormalities have been observed in our studies with regard to: (*a*) the sequence of carpal-bone development, (*b*) the presence of additional carpal bones, (*c*) the presence of supernumerary epiphyses, (*d*) the presence of synostosis, and (*e*) notch formation at the radial side of the os capitatum.

It has been suggested[5] that genetic factors may be responsible for abnormalities (*a*) - (*d*) above. An abnormality which appears to be similar to (*e*) has been described by Beresowski and Lundie.[6] It is suggested that genetic factors may also be responsible here.

It seems unlikely that abnormalities (*a*) - (*e*) can have any important effect on the determination of bone age, but further knowledge is required on this aspect.

THE INTERPRETATION OF 'GROWTH LINES' IN THE DISTAL METAPHYSIS OF THE RADIUS

The significance of these so-called 'growth lines' in proximity to the epiphysial cartilage is still somewhat obscure. Archer[9] has commented that single, thickened, transverse lines of increased density at the ends of the shafts, from an excess of calcified primary cartilage, may be caused by any growth disturbance, but he did not consider them as pathognomonic of any particular disturbance. Köhler[3] and others hold the same opinion. A number of conditions are known, however, in which growth lines appear, for instance after rickets, especially when an excess of vitamin D has been administered, and in congenital scurvy, syphilitic infections, osteitis, osteomalacia, fragilitas ossium, neurofibromatosis, Paget's disease, fractures, lead poisoning, parenteral bismuth therapy of the mother while pregnant, bacterial infections, and foetal erythroblastosis.

These observations suggest that 'growth lines' may be an indicator of previous physical disorder. Our own observations also suggest that growth lines occur more frequently in subjects showing other deviations in bone development than in subjects with normal bone development. Growth lines in themselves, however, are unlikely to cause error in the determination of chronological bone age. They should be considered as temporary interruptions of longitudinal bone growth during early childhood.

X-RAY DETERMINATION

Photographic Technique

The technique is of importance if bone age is to be determined accurately. We have found that attention must be paid to the following points:

1. 'Standard position'. The long axis of the third metacarpal must be in the extension of the long axis of the forearm.
2. The saggital dorso-volar ray direction must be used.
3. The axis ray must be perpendicular to the Carter 'quadrilateral'[3] and pass through the 'cross line' (Fig 4).
4. In order to bring the volar surface of the wrist as closely as possible to the surface of the film and parallel to it, the fingers must be held relaxed, but in a slightly flexed position.

Fig. 4. Diagram showing 'quadrilateral' and 'cross line' of Carter.[8]
——— = quadrilateral.
– – – = cross line.

5. The child must be seated on a chair while the film is exposed, and the height of the seat must be such that the forearm and the upper arm are at an angle of 90° to each other. The whole arm must be flat on the table and must be immobilized with sandbags.

6. Both wrists must be X-rayed.

7. The time of exposure must be on the 'soft' side for the sake of visualization of ossification centres which radiologically are hardly visible before calcification.

8. The time of exposure must be the same for both hands.

9. The distance from the focal point to the hand must not be less than 100 cm., to prevent distortion.

Assessment of Bone Development

No completely reliable method is as yet available for the determination of bone development. For the general purpose of X-ray diagnosis of the carpal bones the 'qualitative inspection technique' is a rapid method, by means of which the experienced specialist can obtain a good impression of the state of the skeletal elements of the hand. It must be remembered, however, that the interpretation is subjective and may lead to differences in the evaluation.

Two other methods which have been proposed for the determination of carpal-bone growth are the 'skeletal month rating method' of Flory[2] and the 'ossification rates method' of Carter.[3,4] In addition, many other research workers have studied the subject of carpal-bone development and have given descriptions of several other possible techniques for the determination of carpal-bone growth.

On the basis of a study of more than 2,500 X-ray photos of wrist joints of White and Bantu children of both sexes, we have come to the conclusion that the simple inspectional interpretation of X-ray films of the wrist is not satisfactory unless previous history, somatometry, results of general medical examination, and possibly the mental condition and other particulars are taken into consideration.

The indications as to height and weight and clinical and mental condition often give a reasonable indication of the general state of bone development in a patient. A complete history can also give valuable information and should, if possible, begin with sociological data, illness in the family, the antenatal period of the individual, including the birth itself, and the postnatal period, with particulars of diet and diseases.

Special Conditions found in South Africa

There are several reasons why particular difficulty is likely to be encountered in South Africa in the determination of chronological age by means of X-ray studies of carpal-bone development. These include the following:

1. The White population of South Africa is composed of several population groups with their origin in Europe. The inhabitants of the European continent are descendants of different human races which are classified by Günther[10] as follows: Westphalian, Nordic, Dinaric, Blond- and Dark-Alpine, and Atlantic races. All these have contributed to the White population of South Africa.

2. The non-European population of South Africa is made up of various racial groups, e.g. the Bantu, Indians and Malayans, with mixtures of all these and Whites, generally termed the 'Coloured' group.

3. Considerable social differences exist between the different sections of the population.

4. There are differences in diet and food habits between the various groups of the population.

5. Differences may occur with respect to environmental factors, such as climate and exposure to diseases (e.g. bilharzia, malaria, amoebiasis, fluorosis, and goitre) in certain areas of the country.

In conclusion, it can be said that, unless the history, nutrition, somatometry and clinical findings are taken into consideration, misleading conclusions can be reached or a diagnosis of the chronological age even rendered impossible in cases such as that illustrated in Fig. 3.

SUMMARY

Certain difficulties and sources of error in the determination of the chronological age in children by means of the state of carpal-bone development are discussed with special reference to South African conditions. Abnormalities of carpal-bone development, the presence of which can be a source of error, are described and factors responsible for their occurrence are discussed. Attention is drawn to certain details of technique and interpretation which have been found important. The need for a consideration of factors such as history, nutrition, somatometry and clinical findings is particularly stressed.

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