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Radiological Bone Age Assessment by Appearance of Ossification Centers in Pediatric Age Group by Using X-Rays

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DEPARTMENT RADIO DIAGNOSIS AND IMAGING SCIENCES

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CERTIFICATE

This is to certify that the dissertation entitled **"RADIOLOGICAL BONE AGE ASSESSMENT BY APPEARANCE OF OSSIFICATION CENTERS IN PEDIATRIC AGE GROUP BY USING X-RAYS"** has been carried out by **DR TG AAI ARIVUDAI NAMBI** under my guidance. The progress and the results have been regularly checked by me



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Introduction

This study aims to find out the age of appearance of ossification centres of the bones radius, ulna, short bones, and lower end of humerus and compare with that of the Greulich-Pyle standard and

other studies done in India. This study also aims to find out if there is significant difference in the age of appearance of ossification centres of today's children of the population of Chennai (Madras) with that of Greulich-Pyle standard and other studies in India.

There are various methods of determining the bone age radiological assessment. The most widely accepted method of determining skeletal bone age is that of Greulich-Pyle, described in the book "Radiographic atlas of skeletal development of the hands and wrist"[1]. The atlas was derived from the American white children of upper class socio-economic level during 1930s.

The Indian population differs widely from the western population in hereditary, dietary, socio-economic and ethnic factors. Studies done in India are few. Galstaun[2] in 1930 and 1937 has done a study in Bengali population. Bajaj[3] in 1967 has done a study in Delhi. Other studies done in India are Pillai[4] (Madarasis) in 1936, Hepworth[5] (Punjabis) in 1929, Basu and Basu[6] (Bengalis) in 1938, Agarwal and Pathak[7] (Punjabis) in 1957, Das, Thapar and Grewal[8] (Punjabis) in 1965, Jit[9] (Punjabis) in 1971, which are all based on the fusion of ossification centres which is used for age determination after 12 years of age. This study is based on the appearance of ossification centres.

Key words

GP standard-Greulich and Pyle

OC-Ossification centre

RUS-radius, ulna and short bones

RUSH- radius, ulna, short bones and humerus

6y8-means 6 years and 8 month

Aim of study

- To determine the bone age based appearance ossification centre in the left elbow, wrist and hand from apparently normal children between the age group of 1-12 years in the population attending the out patient department of Stanley medical college hospital.
- To find out the age at which the appearance of ossification centre is seen greater than 50% of cases.
- To compare the results with that of Greulich –Pyle standards and also with other studies done in India.
- To assesses if there is significant difference between the bone age of today's population with that of that the standard charts.
- To find out whether the present study would help to standardise the bone age in South India

Materials and methods

This study was carried out in 507 children, 268 males and 239 females between age group of 1-12 years attending the outpatient department of the Stanley medical college hospital.

Inclusion criteria

- Apparently normal healthy children between age group of 1-12 years.

- Children who have documentary evidence for date of birth.
- Date of delivery details, birth certificates, school records.

Exclusion criteria

- Any chronic illness (e.g.) congenital heart disease
- Short stature.
- Severe malnutrition –weight age < 60%
- Endocrinal disorders.
- Chronic drug intake (e.g.) anti-epileptic drugs, steroids

Period of study

One year from October 2000 to September 2001

Methodology

Ethical committee permission obtained

- 10 consecutive cases per day with the above criteria and who know the correct date of birth is selected
- Their height weight and sex is recorded.
- 20 cases in male and female is selected in each age group between 1-12 years. Each year is considered as one age group. So they are divided into 12 age groups
- Consent of parents obtained
- X-ray of left elbow, wrist, and fingers- Antero-posterior view is taken
- Radiological assessment of the appearance of ossification centre is done using X ray lobby
- Finding the appearance of ossification centre of a particular bone in >50% of cases
- Comparison of the study result with Greulich-Pyle standard and also with other Indian studies
- Critical evaluation of the results

Radiological specification

X ray left hand and wrist-AP view

KV- 45 (centering midway between tip of mid finger and wrist) mAs-8-12

X ray left elbow -AP view

KV- 50 (centering at elbow joint) mAs- 16

Tube distance-36 inches

Tube of 200mA

Films used

25 cm x 20 cm or 20 cm x 15 cm

Review of literature

Most datas of appearance of ossification centres are based on White children from the upper socio-economic level. Data given by Francis (’40) and Francis and associates (’39) are the most reliable.[10, 11]

There are other tabulations of epiphyseal appearance available, for example, by Davies and Parsons (‘27/28) [12], Flecker (‘32/’33’42) [13, 14] Hodges (‘35) [15], Girdany and Golden (‘52) [16] Drennan and Keen (’53)[17], Kjar (’74)[18]. The studies by Flecker are by far the best to emphasize variability.

The values given by them in principle represent the optimum values, i.e. they give about the eightieth percentile, or age values for the best growing children. This situation in itself offers one explanation for the wide age differences so often noted in literature. Some authors cite the age of first appearance, others of the latest appearance. Some give an average age or fiftieth percentile; others give an age of total appearance in the sample (100th percentile). The eightieth percentile is an acceptable “norm” or “standard” to use, says Krogman, and Iscan.[19]

If the hand skeleton is reasonably complete, the X-rays may be compared with the norms of excellent radiographic atlas of the hand by Greulich – Pyle 1959[1].

Acheson (’54)[20] has developed the “Oxford method” for assessing skeletal age from X-rays but is of limited value for identification purposes until the majority of epiphysis should be found.

Paucity of adequate statistical studies in the appearance of ossification centres was overcome by the work of Pyle and Sontag. (’43)[21]. They reported the timing and order of onset of ossification in 61 centres in the hand and foot. Greulich – Pyle (’59)[1] gave means and standard deviation for the hand centres.

Disturbance in skeletal growth and maturation

The relationship of the endocrine glands to skeletal growth and maturation is very important. Roentgen examination of the growing skeleton may give valuable information concerning thyroid, pituitary and gonadal disturbances. They all cause generalized skeletal age abnormality.

Delay in appearance or fusion or retardation of epiphyseal centres may result from deficient secretion by one or more of these glands. Hyper secretion may accelerate this process.

Graham CB[60] in his study indicates a number of glandular disturbances and their effect on skeletal maturation.

Abnormalities of skeletal maturation

CONDITION	BONE AGE
CENTRAL & GENERAL	
Hyperpituitarism (gigantism)	N or (↓) (may fuse late)
Hypopitutarism (pituitary dwarfism)	↓↓ (may never fuse)
Primordial dwarfism (genetic, constitutional)	N or (↓)
CNS disorders	
Pinealoma	↑
Fibrous dysplasia	↑
Cranipharyngioma	↓
Hypothalmic dysfunction	↑ or ↓
Exogenous obesity	N or (↑)
Chondro – Osseous Dysplasis & Syndromes	↓ Occasionally
GONADS	
Hypergonadism (Hyperplasia, Neoplasm)	↑↑, Fuse early
Hypogonadism	
Eunuchoidism	N or (↓), fuse late
Pituitary	N
Gonadal “dysplasia”	
Turner’s syndrome	N or (↓), fuse late
Klinefelter’s syndrome	N or (↓), fuse late
Abnormal sexual differentiation	(N)
Sexual development variations	
Delayed adolescence	(↓) then N
Premature pubarche	(↑) then N
Premature thelarche	N or (↑)
Constitutional precocity	(↑) then N
ADRENALS	
Cortical insufficiency (Addison’s disease)	(↓)
Cortical hyperactivity (Cushing’s disease)	↓ occasionally
Adrenogential syndrome (hyperplasia, Neoplasm)	↑↑↑ fuse early
THYROID	

Hypothyrodism (Congential / Cretinism)	↓↓↓↓
Acquired	↓
Hyperthoridism	(↑)
PARATHYROIDS	
Hyperparathyroidism (Primary / Secondary)	(N)
Hypoparathyroidism	(N)
Pseudohypoparathyroidism	(N)

Modified from Graham CB: Assessment of bone maturation methods and pitfalls.

Radiol Clin North America 10: 198, 1972.

Legend

N – Normal, ↑ - Advanced, ↓ - retarded, (N) – Probably normal (↑) – Possibly advanced, (↑) – Possibly retarded

Focal increases in maturation are usually done to an increased blood supply or local hyperemia, associated with rheumatoid Arthritis, Tuberculous arthritis, Hemophilia or Healing fractures adjacent to the joint.

Focal increases in maturation may occur following infection, burns, frostbites, radiation therapy or trauma, particularly epiphyseal separations. These all impair the growth potential of the physia either by destroying the resting cells or by disrupting the blood supply and growth may cease.

Premature closure of the epiphysis may occur as the result of bone infarcts, particularly in sickle cell disease.

Ethnic and Racial Differences

This problem has not been systematically studied save for the possibility of differences in the first two decades of life and even studies have focused mainly on evidence gained from hand and wrist, the so called “carpal age”. There is a very serious limiting factor here. There are norms available for the American White Population. This raises the question of comparability. Can we assess the bone age in other racial samples via the American radiographic atlases of the hand? This question was raised by Iscan[19].

For American black children it was found that growth is a bit more advanced during the first year of life as observed by several studies such as Todd (’31)[22] ,Kelly and Reynolds(’47)[23], Christie (’49)[24] and Kessler and Scott[25] (’50).

Platt (’56)[26] found no differences between white and black children of age between 7-12 years. The Philadelphia finding was later confirmed by Bass(’58)[27].

Data from other racial groups also suggest that racial differences are genetically entrenched. For the Japanese, Sutow[28] (’53) suggested a real difference to account for skeletal retardation of 6-24 months in Hiroshima boys, 6-19 years of age and 9-24 months in Hiroshima girls, 6-19 years of age.

Greulich – Pyle[29] (’58) could find no such racial basis in his study of Japanese American boys in the U.S.

External Factors

For Guamanian Children, Greulich[30] ('51) felt that exogenous factors were the cause for retardation.

Cameron[31] ('38) on Asia children and Webster and de Sarem[32] ('52) on Ceylonese children also came to the same conclusion that exogenous factors are responsible for the growth retardation.

Abbie and Adey[33] ('53)found no difference in Central Australian aboriginal children aged 3 weeks to 19 years compared with the standard atlas.

Weiner and Thambipillai[34] found West African native children, aged 9-20 years to be generally smaller than the white population.

Similar observations were made in East African Native children by Mackay [35]('52) and in South African Native Children by Beresowski and Lunide[36]('52) but again the difference between these samples and the white norms was ascribed to exogenous rather than endogenous factors.

Newman and Collazos[37] ('57) found 2000 boys from Peruvian Sierra to be 3 years behind Greulich – Pyle atlas, but dietary, intestinal and parasitic factors were blamed.

Basu[6] ('38) tackled the problem of eiphyseal union rather than appearance in Bengalese children. He stated that diaphyseo – epiphyseal union had a "climatic and racial variability" questioning the comparability of American Standards. He doubted that "there may be evolved one common standard for the whole of the heterogenous population of India".

The most extensive tabulation for non-whites is that of Modi[38] ('57) for East Indian Children. He has stated that "Owing to the variations in climatic, dietetic, hereditary and other factors affecting the people of the different provinces of India it cannot be reasonably expected to formulate a uniform standard for the determination of age of the union of epiphyses for the whole of India. However, from investigations carried out in certain provinces it has been concluded that age at which the union of epiphyses takes place in Indians is 2-3 years in advance of the age in Europeans and epiphyseal union in Females is earlier".

Rikhasor RM, Quereshi[39] et al., from their study of skeletal maturity in Pakistani children found that male children during first year and female children during second year matured in conformity with Greulich – Pyle standards. After that period mean bone ages were lower than the American standards up to 15 years in males and 13 years in females which may be due to malnutrition, ill health or other environmental factors. Hence for the proper evaluation of skeletal age in a given region, a longitudinal study on individuals in that region to establish normal standards is necessary.

Murata[40] in his study compared skeletal maturation with population from U.K., Belgium, North India, South China and Japan. Japanese children were found to attain skeletal maturity 1-2 years earlier than present day European and Chinese children. A relative lack of data for North Indian population made comparison impossible.

Omtell H[41] et al., in their study concluded that using Greulich and Pyle standards to determine the bone age must be done with reservations, particularly in black and Hispanic girls and in Asian and Hispanic boys in late childhood and adolescence, when bone age may exceed chronologic age by 9 months – 11 months.

Socioeconomic status

Schmeling[42] et al., in their study concludes that time related difference in bone maturity is unaffected by ethnic identity. Socio economic status may be the decisive factor affecting the rate of ossification. Low socioeconomic status leads to underestimation of the person's age. They have arrived at this conclusion after a meta-analysis of 80 studies.

Lodder [43] et al., and Schmeling[42] et al., also mentions about the socioeconomic status of the patients and their bone age variation between different populations.

Lejarraga[44] et al., in their study in Argentina concludes that there was a marked advancement in bone age with regard to chronological age when using British standards and to a lesser extent when applying the Spanish standards. Italian scores were similar. The mean differences were 1.28, (SD 1.08) and 1.18(SD 1.09) years for girls and boys respectively. The differences have not been described before and require further investigation.

Ye and Wang[45] et al., in their study in Chinese population found the mean bone ages to be lower than the British standards up to puberty and after, higher than the British standards.

Variation with Time

Tanner[46] *et al.,* in their study in 1990 has given bone age values for North American children in a longitudinal study. Their results designated US 90 standards. These children matured considerably earlier than UK 60(for 1960) standard were based. They suggested US 90 standards to be used in North America pending a more extensive survey. This reflects the secular trend seen in growth and development of children over a period of some decades.

Himes JH[47] in his study compared a little-known "skiagraphic" atlas documenting radiographic changes in the bones of the hand and wrist published by Poland in 1898. Comparision of Poland's expected ages for onset and fusion of secondary ossification centres in the hand and wrist with most recent data indicated a secular increase in the rates of skeletal maturation of approximately 0.22 – 0.66 year/decade, with relatively greater changes in expected ages of fusion.

Comparison of methods

Cole[48] et al., after assessing bone age by TW 2 method and GP atlas concludes by saying that, given the relatively laborious and time consuming nature of TW 2 method there seems little point in promoting its use in the general hospital setting.

Milner[49] et al., in their study comparing the GP atlas and TW 2 method concludes that the atlas matching method still have a valuable place in non specialist hospitals concerned with critical diagnosis rather than long term care of growth problems.

Nutrition and Bone age

Gopalan[50] et al., in their study says that the incidence of malnutrition in India is 1-2% of which 80% are mild / moderate cases that frequently go unrecognised.

Alcazar[51] et al., in their study examined different degrees of malnutrition using X-ray wrist with GP atlas. In obese children the bone age was advanced. The more severe the under nutrition the more delayed the bone age. A greater delay in bone age was detected in undernourished children who were small for gestational age.

Alvear[52] et al., in their study of physical growth and bone age in survivors if protein energy malnutrition has concluded that the rehabilitated children were shorter than the control group but had similar bone age in follow up suggests that genetic or prenatal factors were important in their later poor growth. This suggestion is supported by their small birth size and the smaller size of their mothers.

Physical training and bone age

Thientz [53]et al., in their study among female gymnasts & swimmers concluded that their bone age was retarded when compared to chronological age and adult height was lower for gymnasts than other girls.

Observations

1. Total of 507 children were inducted in the study (268 males and 239 females) between the age group of 1-12 years.
2. Approximately 40 children in each age group (20 males + 20 females) were examined in the study.
3. A total of 15 individual bones, in the left arm – RUSH, were radio graphically assessed (Table 1 to 15).
4. The percentage of appearance of ossification centres for individual bones in both sex were calculated and the data is given below.
5. The age at which the appearance of ossification centres is seen in >50%, >75% and 100% were found and tabulated for comparison with the Greulich – Pyle standard.
6. Standards from other western and Indian studies are given along with the results of this study for comparison.
7. Charts for comparison of age between males and females at which ossification centre appears in >50% of cases where tabulated.

Table 1

APPEARANCE OF OSSIFICATION CENTRE OF METACARPAL-1

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	-	0	1-2	22	1	4
2-3	23	3	13	2-3	22	13	59
3-4	25	11	44	3-4	15	15	100
4-5	29	28	96				
5-6	28	24	85				
6-7	22	22	100				
Total	168	113		Total	59	29	

The appearance of ossification centres in >50% of children for Metacarpal I is at the age of 4-5 years in Males and at 2-3 years in Females. 100% appearance is seen at 6-7 in males and at 3-4 years in females

Table 2

APPEARANCE OF OSSIFICATION CENTRE OF METACARPAL-2

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	2	13	1-2	22	17	77
2-3	23	16	69	2-3	22	22	100
3-4	25	24	96				
4-5	29	29	100				
Total	92	71		Total	44	39	

The appearance of ossification centres in >50% of children for Metacarpal II is at the age of 2-3 years in Males and at 1-2 years in Females. 100% appearance is seen at 4-5 years in Males and at 2-3 years in Females

Table 3

APPEARANCE OF OSSIFICATION CENTRE OF METACARPAL-3

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	2	13	1-2	22	17	77
2-3	23	15	65	2-3	22	22	100
3-4	25	24	96				
4-5	29	29	100				
Total	92	70		Total	44	39	

The appearance of ossification centres in >50% of children for Metacarpal III is at the age of 2-3 years in Males and at 1-2 years in Females. 100% appearance is seen at 4-5 years in Males and at 2-3 years in Females

Table 4

APPEARANCE OF OSSIFICATION CENTRE OF METACARPAL-4

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	1	6	1-2	22	16	77
2-3	23	13	56	2-3	22	21	95
3-4	25	24	96	3-4	15	15	100
4-5	29	29	100				
Total	92	67		Total	59	52	

The appearance of ossification centres in >50% of children for Metacarpal IV is at the age of 2-3 years in Males and at 1-2 years in Females. 100% appearance is seen at 4-5 years in Males and at 3-4 years in Females

Table 5

APPEARANCE OF OSSIFICATION CENTRE OF METACARPAL-5

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	1	7	1-2	22	16	73
2-3	23	11	48	2-3	22	17	77
3-4	25	22	88	3-4	15	15	100
4-5	29	29	100				
Total	92	63		Total	59	48	

The appearance of ossification centres in >50% of children for Metacarpal V is at the age of 3-4 years in Males and at 1-2 years in Females. 100% appearance is seen at 4-5 years in Males and at 3-4 years in Females

Table 6

APPEARANCE OF OSSIFICATION CENTRE OF TRAPEZIUM

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
4-5	29	2	6	4-5	21	5	23
5-6	28	0	0	5-6	26	12	46
6-7	22	4	18	6-7	20	13	65
7-8	26	11	42	7-8	17	17	100
8-9	21	20	95				
9-10	20	18	90				
10-11	29	29	100				
Total	175	84		Total	84	47	

The appearance of ossification centres in >50% of children for Trapezium is at the age of 8-9 years in Males and at 6-7 years in Females. 100% appearance is seen at 10-11 years in Males and at 7-8 years in Females

Table 7

APPEARANCE OF OSSIFICATION CENTRE OF TRAPEZOID

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
4-5	29	2	6	4-5	21	6	28
5-6	28	3	10	5-6	26	10	38
6-7	22	9	40	6-7	20	14	70
7-8	26	16	61	7-8	17	17	100
8-9	21	18	85				
9-10	20	18	90				
10-11	29	29	100				
Total	175	94		Total	84	47	

The appearance of ossification centres in >50% of children for Trapezoid is at the age of 7-8 years in Males and at 6-7 years in Females. 100% appearance is seen at 10-11 years in Males and at 7-8 years in Females

Table 8

APPEARANCE OF OSSIFICATION CENTRE OF SCAPHOID

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
5-6	28	1	3	4-5	21	6	14
6-7	22	5	22	5-6	26	11	42
7-8	26	16	61	6-7	20	14	70
8-9	21	17	76	7-8	17	17	100
9-10	20	18	85				
10-11	29	29	100				
Total	146	84					
				Total	84	47	

The appearance of ossification centres in >50% of children for Scaphoid is at the age of 7-8 years in Males and at 6-7 years in Females. 100% appearance is seen at 10-11 years in Males and at 7-8 years in Females

Table 9

APPEARANCE OF OSSIFICATION CENTRE OF LUNATE

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
3-4	24	2	8	2-3	22	2	9
4-5	29	8	27	3-4	15	3	20
5-6	28	13	46	4-5	21	7	33
6-7	22	15	68	5-6	26	18	69
7-8	26	23	88	6-7	20	14	70
8-9	21	18	85	7-8	17	17	100
9-10	20	20	100				
Total	170	99					
				Total	121	61	

The appearance of ossification centres in >50% of children for Lunate is at the age of 6-7 years in Males and at 5-6 years in Females. 100% appearance is seen at 9-10 years in Males and at 7-8 years in Females

Table 10

APPEARANCE OF OSSIFICATION CENTRE OF TRIQUITRUM

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
2-3	23	9	39	1-2	22	8	36
3-4	25	17	68	2-3	22	14	63
4-5	29	23	79	3-4	15	12	80
5-6	28	24	85	4-5	21	20	95
6-7	22	22	100	5-6	26	26	100
Total	153	120		Total	106	80	

The appearance of ossification centres in >50% of children for Triquitrium is at the age of 3-4 years in Males and at 2-3 years in Females. 100% appearance is seen at 6-7 years in Males and at 5-6years in Females

Table 11

APPEARANCE OF OSSIFICATION CENTRE OF PISIFORM

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
10-11	29	3	10	7-8	17	1	14
11-12	18	2	11	8-9	26	3	11
12-13	12	4	33	9-10	17	4	23
				10-11	25	16	64
				11-12	10	7	70
				12-13	18	18	100
Total	59	9		Total	113	49	

The appearance of ossification centres in >50% of children for Pisifrom is at the age of 10-11 years in Females. 100% appearance is seen at 12-13 years in Females

For males it starts appearing at 10-11 years and at 12-13 years it is found only in 33% of the cases. The study has to be extended further to find out the appearance in >50% of the cases and the age of total appearance

Table 12

APPEARANCE OF OSSIFICATION CENTRE OF DISTAL RADIUS

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
1-2	15	7	46	1-2	22	22	100
2-3	23	17	73				
3-4	25	25	100				
Total	63	49		Total	22	22	

The appearance of ossification centres in >50% of children for Distal radius is at the age of 2-3 years in Males. 100% appearance is seen at 3-4 years. For Females 100% is found at the age of 1-2 years itself

Table 13

APPEARANCE OF OSSIFICATION CENTRE OF DISTAL ULNA

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
7-8	26	9	34	4-5	21	3	14
8-9	21	12	57	5-6	26	2	7
9-10	20	14	70	6-7	18	6	33
10-11	29	25	86	7-8	17	15	88
11-12	18	18	100	8-9	26	26	100
Total	114	78		Total	82	52	

The appearance of ossification centres in >50% of children for Distal ulna is at the age of 8-9 years in Males and at 7-8 years in Females. 100% appearance is seen at 11-12 years in Males and at 8-9years in Females

Table 14

APPEARANCE OF OSSIFICATION CENTRE OF HEAD OF RADIUS

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
4-5	29	7	24	3-4	15	3	20
5-6	28	7	25	4-5	21	6	28
6-7	22	10	45	5-6	26	23	88
7-8	26	20	76	6-7	20	12	60
8-9	21	20	95	7-8	17	17	100
9-10	20	20	100				
Total	146	84		Total	99	61	

The appearance of ossification centres in >50% of children for Head of radius is at the age of 7-8 years in Males and at 5-6 years in Females. 100% appearance is seen at 9-10 years in Males and at 7-8 years in Females.

Table 15

APPEARANCE OF OSSIFICATION CENTRE OF MEDIAL EPICONDYLE

Age (years)	No of cases where OC is present in **Males**			Age (years)	No of cases where OC is present in **females**		
	Total no of cases	Total appeared	Percent appeared		Total no of cases	Total appeared	Percent appeared
6-7	22	2	9	3-4	15	2	13
7-8	26	3	11	4-5	21	11	52
8-9	21	16	76	5-6	26	14	53
9-10	20	16	80	6-7	20	12	60
10-11	29	29	100	7-8	17	17	100
Total	118	66		Total	99	56	

The appearance of ossification centres in >50% of children for Medial epicondyle is at the age of 8-9 years in Males and at 4-5 years in Females. 100% appearance is seen at 10-11 years in Males and at 7-8 years in females

Results

The Result based on the appearance of ossification centres is summarised as per table below

Age	Male	Age	Female
Table A: Ossification timetable			
2-3 years	Metacarpals II, III, IV Distal radius	1-2 years	Metacarpals II, III, IV, V
3-4 years	Metacarpal V	2-3 years	Metacarpal I Triquitrium
4-5 years	Metacarpal I	4-5 years	Medial epicondyle
6-7 years	Lunate	5-6 years	Lunate
7-8 years	Trapezoid, Scaphoid Head of radius	6-7 years	Trapezium Trapeziod Scaphoid
8-9 years	Trapezium Distal ulna	7-8 years	Distal ulna
	Medial epicondyle	10-11 years	Pisifrom

Table B: Comparison of age of appearance of ossification centres with Greulich-Pyle standard in Males

SI No.	Bone	Greulich –pyle standard (1959) mean age (in years)	Appearance in the of Ossification present study (in years) Centres		
			Seen in >50%	Seen in 75%	Seen in 100%
1	Metacarpal I	2y6	4-5	4-5	6-7
2	Metacarpal II	1y5	2-3	3-4	4-5
3	Metacarpal III	1y9	2-3	3-4	4-5
4	Metacarpal IV	2y	2-3	3-4	4-5
5	Metacarpal V	2y4	3-4	3-4	4-5
6	Trapezium	5y4	8-9	8-9	10-11
7	Trapeziod	5y4	7-8	8-9	10-11
8	Scaphoid	5y	7-8	8-9	10-11
9	Lunate	3y10	6-7	7-8	9-10
10	Triquitrium	2y3	3-4	4-5	6-7
11	Pisifrom	-	-	-	-
12	Distal radius	1y1	2-3	3-4	3-4
13	Distal ulna	6y10	8-9	10-11	11-12
14	Head of radius	5y4	7-8	7-8	9-10
15	Medial epicondyle	6y2	8-9	8-9	10-11

Table C:Comparison of age of appearance of ossification centres with Greulich-Pyle standard in females

SI No.	Bone	Greulich –pyle standard (1959)	Appearance in the of ossification present study (in years) Centres		
		Mean age (in years)	Seen in >50%	Seen in 75%	Seen in 100%
1	Metacarpal I	1y8	2-3	3-4	3-4
2	Metacarpal II	1y1	1-2	1-2	2-3
3	Metacarpal III	1y2	1-2	1-2	2-3
4	Metacarpal IV	1y4	1-2	2-3	3-4
5	Metacarpal V	1y5	1-2	2-3	3-4
6	Trapezium	3y11	6-7	7-8	7-8
7	Trapeziod	4y	6-7	7-8	7-8
8	Scaphoid	4y	6-7	7-8	7-8
9	Lunate	2y11	5-6	7-8	7-8
10	Triquitrium	2y	2-3	3-4	5-6
11	Pisifrom	-	10-11	12-13	12-13
12	Distal radius	11 m	-	-	1-2
13	Distal ulna	5y3	7-8	7-8	8-9
14	Head of radius	4y	5-6	5-6	7-8
15	Medial epicondyle	3y5	4-5	7-8	7-8

m-months, y-years

SI No.	Bone	Fransics et Al., 1939	Garn 1967 50th percentile	Galstaun 1930&37 (begalis)	Bajaj 1967 (delhi)	This study (seen in >50% cases
Table D: Comparison of age (in years) of appearance of ossification centres of MALES with other studies						
1	Metacarpal I	1y10m	2y7	4y	4.2y	4-5
2	Metacarpal II	1y1	1y7	3-4	1.07y	2-3
3	Metacarpal III	1y3	1y9	3-4	1.07y	2-3
4	Metacarpal IV	1y4	2y	3-4	1.07y	2-3
5	Metacarpal V	1y6	2y	3-4	1.07y	3-4
6	Trapezium	4y2	5y1	7y	7.5y	8-9
7	Trapeziod	4y8	6y3	NA	NA	7-8
8	Scaphoid	3y2	5y8	7y-11y	8.4y	7-8
9	Lunate	2y	4y1	5y	6.5y	6-7
10	Triquitrium	10m	2y5	3y-4y	3.7y	3-4
11	Pisifrom	NA	NA	12y-17y	13.05y	NA
12	Distal radius	7m	1y	1y	1.7y	2-3
13	Distal ulna	4y6	7y1	10y-11y	7.4y	8-9
14	Head of radius	3y10	5y3	8y	6.2y	7-8
15	Medial epicondyle	NA	6y3	7y	7.4y	8-9
NA-data not available, m-months, y-years						

SI No.	Bone	Fransics et Al., 1939	Garn 1967 50th percentile	Galstaun 1930&37 (begalis)	Bajaj 1967 (delhi)	This study (Seen in >50% cases
Table E: Comparison of age (in years) of appearance of ossification centres of FEMALES with other studies						
1	Metacarpal I	1y2	1y7	3y	2.1y	2-3
2	Metacarpal II	10m	1y1	2-3	1.6y	1-2
3	Metacarpal III	10m	1y1	2-3	1.6y	1-2
4	Metacarpal IV	11m	1y3	2-3	1.6y	1-2
5	Metacarpal V	1y1	1y4	2-3	1.6y	1-2
6	Trapezium	2y8	4y1	5y-6y	6.6y	6-7
7	Trapeziod	3y	4y2	NA	NA	6-7
8	Scaphoid	3y2	4y1	6y	5.5y	6-7
9	Lunate	2y	2y8	5y	4.8y	5-6
10	Triquitrium	10m	1y8	2-3y	3.2y	2-3
11	Pisifrom	NA	NA	9-12y	10.2y	10-11
12	Distal radius	6m	10m	1y	3.5y	1-2
13	Distal ulna	4y6	5y5	8y-10y	6.5y	7-8
14	Head of radius	3y	3y11	6y	3.5y	5-6
15	Medial epicondyle	2y9	3y5	5y	5y	4-5
NA-data not available, m-months, y-years						

Table F: Comparison of age (in years) at which ossification centre appears in >50% and 100% of cases between males and females

SI No.	Bone	OC in >50% Appearance in MALES		OC in >50% Appearance in FEMALES		OC in >100% Appearance in MALES		OC in >100% appearance in FEMALES	
		Age	Total No.of cases	Age	Total No.of cases	Age	Total No.of cases	Age	Total No.of cases
1	Metacarpal I	4-5	29	2-3	22	6-4	22	3-4	15
2	Metacarpal II	2-3	23	1-2	22	4-5	29	2-3	22
3	Metacarpal III	2-3	23	1-2	22	4-5	29	2-3	22
4	Metacarpal IV	2-3	23	1-2	22	4-5	29	3-4	15
5	Metacarpal V	3-4	25	1-2	22	4-5	29	3-4	15
6	Trapezium	8-9	21	6-7	20	10-11	29	7-8	17
7	Trapeziod	7-8	26	6-7	20	10-11	29	7-8	17
8	Scaphoid	7-8	26	6-7	20	10-11	29	7-8	17
9	Lunate	6-7	22	5-6	26	9-10	20	7-8	17
10	Triquitrium	3-4	25	2-3	22	6-7	22	5-6	26
11	Pisifrom	NA	-	10-11	25	-	-	12-13	18
12	Distal radius	2-3	23	-	-	3-4	25	1-2	22
13	Distal ulna	8-9	21	7-8	17	11-12	18	8-9	21
14	Head of radius	7-8	26	5-6	26	9-10	20	7-8	17
15	Medial epicondyle	8-9	21	4-5	21	10-11	29	7-8	17

NA-data not available

Discussion

The first Metacarpal in **males** appears 1 ½ years later than that of GP Standard[1].

Metacarpals II and V appear 6 months after the GP standard[1]. Metacarpals III and IV appearance is same as that of the GP standard[1].

Comparing with Indian study (Galstaun 1930 & 1937) [2] all metacarpals appear 1 year earlier. In **females** the age of appearance of Metacarpals I to V more or less correlates with that of the GP standard[1].

Comparing with Galstaun[2] study all metacarpals appear 1 year earlier.

Comparison of carpal bones in **males** with GP standard[1], Triquitrum appears 8 months late, whereas the other carpal bones show a wider variation. Trapezium appears 2 ½ years late, Trapezoid appears 1 ½ years late, and scaphoid and lunate appear 2 years late. This is a very significant observation.

Pisiform could not be compared because GP atlas[1] does not have a standard and also in this study only 33% of boys at 12 years had the Ossification centre. The study has to be extended beyond 12 years to find out 50% appearance of pisiform ossification centre.

In **females** the carpal bones Triquitrum correlates well with GP standard[1]. Whereas the other carpal bones, Trapezium, Trapezoid, Scaphoid and Lunate, similar to **males** appears 2 years later. Pisiform appears at 10-11 years of age in females.

Ontell [41]*et al*., in their study has observed that in White and Asian girls bone age approximated Greulich – Pyle[1] throughout childhood, the discrepancy being in adolescent girls where the bone age exceeded chronological age by 4 months. Whereas in this study the results show a wider variation.

Also in his observation in preadolescent Asian boys showed significant delay particularly in middle childhood when bone age by GP standard[1] lagged behind by nearly 15 months. This study also substantiates the finding. But the variation is $1^1/2$ to 2 years in this study.

Comparing the carpal bones with the Galstaun [2]study, in **males** Trapezium and Lunate appears 1 year late. Scaphoid and Triquitrum correlates well. No date is available for Trapezoid. In **females** all carpal bones correlates with the Galstaun[2] study.

Comparing other centres with the GP standard[1], Distal radius appear 11 months late in **males** and in **females** 100% has appeared between 1-2 years. For finding out the age of appearance of ossification centre in 50% of the children, the study has to be done from birth itself.

Distal ulna in **males** appears 1 year late, Head of Radius appear $1^1/2$ years late and medial epicondyle appear 10 months late.

Distal ulna in **females** appears 1 year and 9 months late, Head of Radius appear 1 year late and Medical epicondyle appears 7 months late than the GP standard[1].

Comparing other centres with the Galstaun[2] study, in **males** Distal radius and Medical epicondyle appear 1 year late. Head of radius correlates with the Galstaun[2] study. Distal ulna differs from other observation by appearing 1 year early than the Galstaun[2] study.

In **females** Distal ulna and Medical epicondyle appear 1 year early. Distal radius and head of radius correlated with the Galstaun[2] study.

Comparison of Galstaun[2] study with the study done by Bajaj in 1967 at Delhi varies in their appearance of metacarpal ossification centre for males and Females by 1-2 years. Other ossification centres, age of appearance is more or less the same as the Galstaun[2] study of 1930. Comparing with Bajaj[3] study in Females the metacarpals correlates with his observations but in males it is 1 year late. Other comparisons are similar to Galstaun[2] study.

Though the Galstaun [2]study done in 1930 and 37 varied with Greulich – Pyle standard[1] the study done by Bajaj[3] in 1967 differed with the Galstaun[2] study. Till date no standardization has been done for the Indian Population.

Comparison with the GP standard[1] shows a very significant delay in the bone age of this population. Similar studies done in other parts of the world like Pakistan[39], South Korea[54], Japan[40], Argentina[44], has substantiated that there could be racial and ethnic differences in the appearance of ossification centres and the GP atlas[1] cannot be taken as a standard for all children of different countries.

Studies done by Garn[55] *et al*., in low income Black children exceeds that of White American children by 0.5 standard deviation.

The variation could also be due to dietary and Nutritional factors[51,56]. The population understudy predominantly is undernourished[50]. As also observed by previous studies by authors like Beresowski [36]et al., Cameron[36] et al., there could be other external factors like climate which cause a difference in skeletal maturity in different population.

Socio economic status could also be a possible cause as quoted in some studies. Greulich – Pyle study [1]was done in children of the upper socio economic status White children in 1931-1942. This study population is all of the lower socio-economic status.

Observations from this study and comparison with the Galstaun[2] study (India) done in 1930 & 1937, indicates that uniformly the Females bone maturity has advanced 1 year, but in males in some bones it coincides with the age and in others it is delayed a year or more.

This raises the possibility that in females the maturity is advanced because of an advancing pubertal age. Pubertal age is found to advance by 4 months per decade throughout the world.[57, 58, 59] Variation in males where the opposite seem to occur could be due to regional or ethnic variation.

Galstaun[2] study was done in Bengali population and Bajaj[3] et al., study was done at Delhi. There is no study done at Chennai so far to make a comparison. The study done by Pillai at Madras is based on fusion of ossification centers.[4]Observations from the study also indicates Females maturing 1-2 years earlier than males and this is in conformity with previous observations.[57]

Conclusion

There is a significant difference between the age of appearance of ossification centres of the study population both in Males and Females when compared with the Greulich – Pyle standard[1]. This difference is clinically significant enough in diagnosing conditions with retarded bone age or advanced bone age and in follow up of endocrine disorders, where an error is likely to occur if the GP standard[1] is followed.

The difference between the skeletal maturity in Males and Females correlates with previous observation. Females mature 1-2 years earlier than Males.

There is also a significant difference between other studies done in India (Galstaun[2], et al.,) in 1930 and 1937. Skeletal maturity in Females is earlier and in males it is delayed in some and correlated in some centres. This could be due to regional or ethnic variations. Advancing skeletal maturity in females could be due to advancing pubertal age.

The difference with GP standard[1] and this study could be due to factors like racial, genetic, socio economic, nutritional and climate factors, which need to be evaluated.

This study also gives the age of appearance of ossification centres in 100% of the individuals i.e., the upper limit of normal. And also the earliest appearance of ossification centres.

X-rays Section



Figure 1.X-ray of three-year-old girl showing the ossification center of Triquetrum

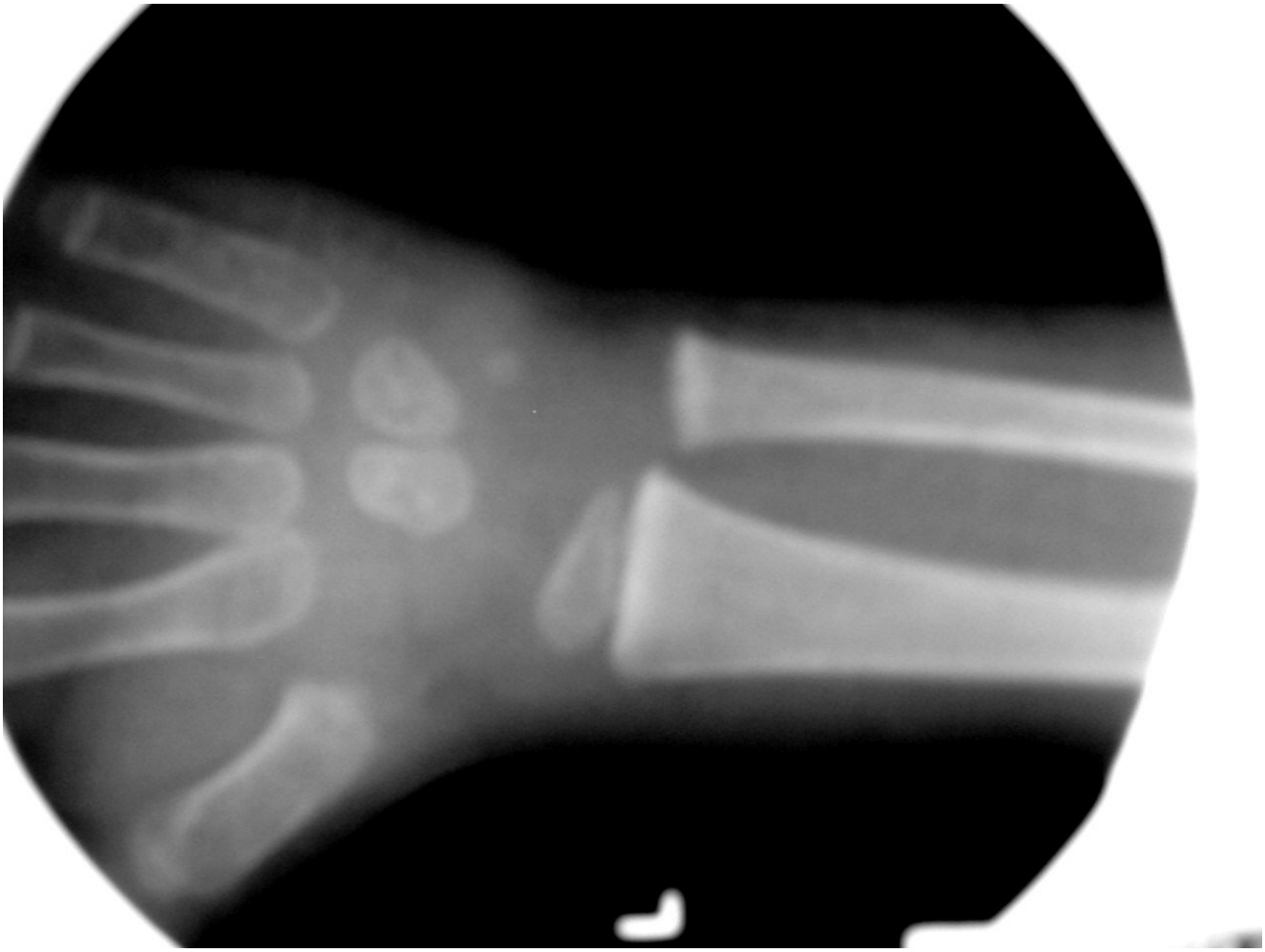


Figure2.X-ray of three-year-old boy showing the ossification center of Triquetrum



Figure 3.X-ray of six-year-old girl showing the ossification center of Lunate



Figure 4.X-ray of seven-year-old girl showing the ossification center of Medial epicondyle



Figure 5. X-ray of seven-year-old girl showing the ossification center of Trapezium, trapezoid and Scaphoid



Figure 6.X-ray of seven-year-old boy showing the ossification center of Trapezium and trapezoid



Figure 7.X-ray of eight year-old girl showing the ossification center of distal ulna

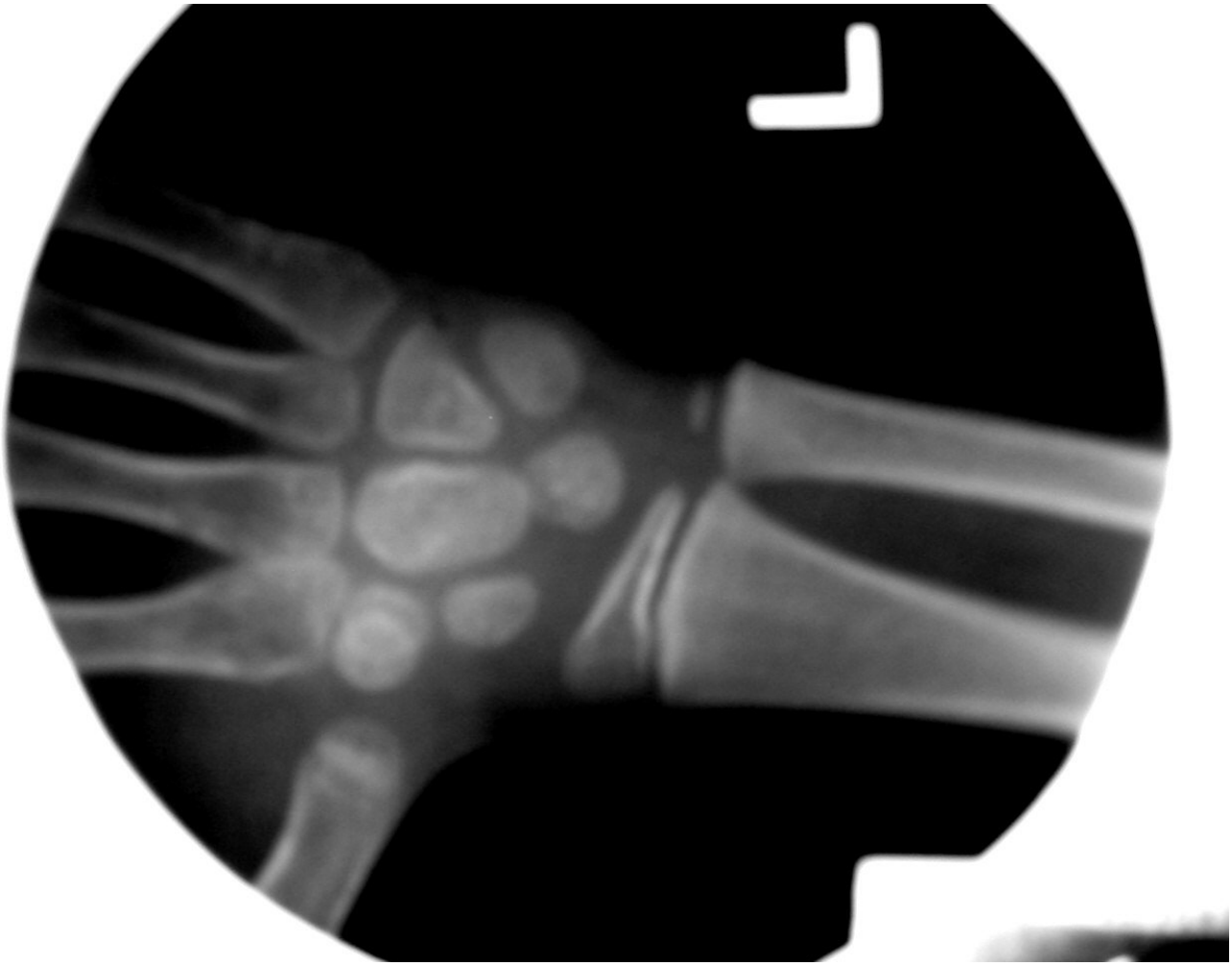


Figure 8. X-ray of eight year-old boy showing the ossification center of Trapezium and Distal ulna



Figure 9. X-ray of eight year-old boy showing the ossification center of Medial epicondyle

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