

EPIPHYSIAL CHANGES IN THE HAND/WRIST AREA AS INDICATORS OF ADOLESCENT STAGE*

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Introduction

Much of the treatment for growth anomalies, including the orthodontic correction of malocclusions, is dependent upon the intensity of skeletal growth and therefore, indirectly upon the prediction of the precise stages of skeletal growth. Because the post-natal skeletal growth rate in primates is dominated by the adolescent phase, so its prediction has assumed increasing importance in clinical orthodontics (Hellman, 1928; Helm et al, 1971).

The adolescent phase of growth varies for different individuals, in the age of onset, the intensity and the duration of the growth phase (Tanner, 1962). Maturation rates generally and adolescence specifically, are influenced by such diverse factors as genetic and racial factors (Garn, 1962; Ito, 1942), climatic and seasonal conditions (Ellis, 1950; Reymert, 1947), nutritional circumstances (Bruch, 1841; Garn and Haskell, 1960), socioeconomic conditions and even the secular changes resulting in earlier maturation of the different generations (Michelson, 1944; Tanner, 1962). Whilst adolescence is most frequently viewed clinically as a period of marked statural and secondary sex characteristic changes, Tanner (1962, 1969, 1970) has cautioned that the latter physical changes are not absolutely regular during adolescence and provide essentially retrospective information of the progress of adolescent growth.

Skeletal or bone age assessments comparing the individual with specific sex and age standards, have been suggested as indicating trends in adolescent development useful in orthodontic treatment (Hunter, 1966; Bergerson, 1972). But, Tanner (1962) has cautioned that skeletal age assessments do not provide a definite indication of the specific growth stages of individuals and Roche (1971) has stressed "skeletal growth" and 'skeletal maturation' although interrelated are not synonymous."

Historically the development of skeletal age assessments has progressed through chronological age related to carpal bone initial ossifications (Ranke, 1896), initial appearance of all ossification centres (Rotch, 1908), measurement of total ossified areas (Baldwin, 1941) to a combined system of evaluating epiphysal and carpal bone developmental stages (Todd, 1930a, 1930b). The latter utilised radiographic standards graded for sex and age (Greulich and Pyle, 1959) wherein skeletal ages have been assigned to every bone in the hand-wrist and knee areas. In an attempt to better correlate bone age with the degree of maturation, Acheson (1954, 1957) developed a method of assessment, subsequently adapted (Tanner and Whitehouse, 1959; Tanner, Whitehouse and Healey, 1962) to produce a weighted method of scoring the percentage of total maturity for each bone. This method tends to weight the carpal bone assessments heavily (Johnson and Jahina, 1965), although Roche and Johnson (1969) have shown that even exclusion of all the carpal bones may not alter appreciably the skeletal age assessments.

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Although marked differences may exist in ossification between the right and left sides (Long and Caldwen, 1911; Park, 1954), for general populations, discrepancies in ossification sequences and timing between the right and left sides are mostly insignificant (Roche, 1963). Nevertheless these possibilities should be born in mind, particularly when assessing the more deviant developmental malformations and congenital conditions.

Another important source of error in the subjective assessment of carpal and epiphysal growth stages is due to the alterations in the size and shape of bones in the hand-wrist area, under non-standardised conditions particularly when the hand or fingers are flexed or target film distances altered during radiography. (Carter, 1926). Various observers (Roche, 1971) have stressed the reproducibility of interpretations requires not only standardised techniques but also considerable training and preferably some calibration of interpreters. (Medicus et al, 1971).

Ossification sequence polymorphism (i.e. variation) and sexual dimorphism must be expected in the postnatal skeleton (Garn et al, 1966) and the true genetic nature of variations in osseous development realized. (Hertzog et al, 1969; Garn, 1969, 1971). Racial and interpopulation differences must be accepted as producing changes in ossification sequences and in skeletal maturation generally (Chan et al, 1961; Mass and Hunt, 1963; Malcolm, 1970) although these racial and genetic variations may be intimately related to the nutritional and environmental conditions. Environmental influences, including chronic malnutrition (Dreizen et al, 1954), may disproportionately retard any centre and confusion exists as to whether the phalangeal epiphyses or the carpals, especially capitate and hamate, are the most susceptible. (Hewitt et al, 1955; Dreizen et al, 1958). Garn (1965, 1966) has suggested that malnutrition tends particularly to upset the timing, but not the sequences of ossification nor the specific epiphysal stage changes. Other socioeconomic conditions, unrelated to nutrition also seem to influence the ossification process considerably.

Prediction of Adolescent Stage from Hand/Wrist Radiographs

Many attempts have been made to relate the ossification of specific bones and stages of bone fusion to maturational phenomena. Hellman (1928) was one of the earliest orthodontists to correlate the ages of ossification and the fusion stages of phalanges both with chronological age and with the largest increments in stature occurring during adolescence. Noback et al (1958) highlighted the fusion rate of epiphyses and commented on the ease of orthodontic treatment before fusion and the difficulty after fusion.

Florey (1936) showed that ossification of the ulnar sesamoid always appeared before menarche ($r = 0.75$) and Garn and Rohmann (1962) indicated that ulnar sesamoid ossification showed only a slightly better correlation with epiphysal union (tibia, $r = 0.70$) than sexual maturation (menarche, $r = 0.65$). Bjork and Helm (1967) indicated that initial radiographic appearance of the ulnar sesamoid occurred before the attainment of peak stature velocity. However, the relationship showed a degree of sexual dimorphism. Brown (1969) postulated the use of the sequential enlargement stages of the ulnar sesamoid to assess the stage of adolescent growth spurt. However, Bowden (1971) confirmed that not only was there a sexual dimorphism in the appearance of the ulnar sesamoid in relation to both the start and peak of the adolescent spurt but also polymorphism in the initial size and the rates of growth of the sesamoid.

Grave (1971) and Brown et al (1971) showed that some sexual dimorphism existed in the relationship between initial ossification of the pisiform, the hook of the hamate

"S1(T&W7)" and "S2(T&W8)" with peak statural growth. Helm et al (1971) showed a relationship in Danish males between various epiphysial fusion stages and the peak of the adolescent spurt with stage "PP2 (=)" occurring before the peak of the height spurt, stage "MP3 (=)" and sesamoid occurring either before or simultaneously with the peak of the height spurt, stage "MP3 (capped)" usually occurring at or 1 year after the peak of the height spurt, and the three stages (fusion of DP3, PP3 and MP3) invariably occurring after the peak of the height spurt.

Bowden (1971, 1973) on comparing specific Greulich and Pyle maturation stages of epiphysial development with the start, the peak and the end of adolescent spurt and with mature height, found a close relationship between the epiphysial fusion stages "G & P 6 (=)", "G & P 7 (caps)" and "G & P 8 (fusion)" for the middle phalanx and the start, peak and end of the adolescent height spurt, respectively and that stage "G & P 10 (fusion)" of the tibia, femur, and ulnar tended to occur up to one year before attainment of mature height, whilst the similar stage for the radius tended to occur at or 1 year after the age of attainment of mature height. This radiological evidence is in agreement with the histological findings of McKern and Stewart (1957) indicating that final fusion of the long bones proceeded from the distal ulnar to the distal radius, and finally the medial end of the clavicle.

Chapman (1972) confirmed the sexual dimorphism tendency of ulnar sesamoid appearance and its appearance before peak adolescent spurt, and found a relationship with proximal phalangeal fusion (digit I) and a deceleration in statural growth.

Material and Method

The data used in the present investigation were analysed from the records of 52 boys and 60 girls enrolled in a serial, multi-disciplinary study at the University of Melbourne Child Growth Study (Roche and Sunderland, 1954). The anteroposterior left hand-wrist radiographs analysed by a standardised technique were taken at quarterly intervals until 4 years, biannually until 6 years and then annually. The ages of the initial appearance of the detailed epiphysial changes were recorded after examining the whole series of radiographs for each individual. The assessments were made by a single trained observer throughout and all doubtful stages checked and confirmed by the investigator. Double determinations of reproducibility were conducted unknown to the recording observer. The skeletal age assessments were made by the same observer and described previously. (Roche, 1967). The epiphysial stages recorded were essentially those outlined by Greulich and Pyle (1959). They are summarised in Table 1 and Figures 1 and 2 and illustrate changes in the phalanges.

Estimations of the various adolescent growth stages were obtained from individual graphs (Figure 3) plotted by the computer from the annual increments in height calculated as a rate per year, allowing for attendances being within plus or minus 6 weeks of precise annual and biannual intervals. A mean rate of growth between the approximate ages of 5 years and 12 years for girls and 16 years for boys, was calculated for each individual and constructed on the graphs. The initial age for calculation of the mean was the minimum annual increment within 12 months of 5 years and the terminal age was the annual increment occurring 12 months before adolescent peak stature velocity. Adolescent spurts of growth were defined for the start of the adolescent spurt (S.A.S.), the pre-adolescent minimum when the rate of growth began its adolescent spurt, the peak of the adolescent spurt (P.A.S.) at the peak of the greatest increment, and the end of the adolescent spurt (E.A.S.) at the visit after the age when the spurt dropped below this calculated mean. The mature height

TABLE 1. Epiphysial — diaphysial growth stages.

SIZE (Epiphysis compared with diaphysis)	Radiological Stage (Greulich and Pyle)
No ossification	1
Initial ossification	2
Epiphysis 1/3 width shaft	3
Epiphysis 1/2 width shaft	4
Epiphysis 3/4 width shaft	5
Epiphysis equal width shaft	6
FUSION (Epiphysial union with diaphysis)	
Epiphysis caps diaphysis	7
Epiphysis fusion begins	8
Epiphysial fusion complete	9
Adult	10

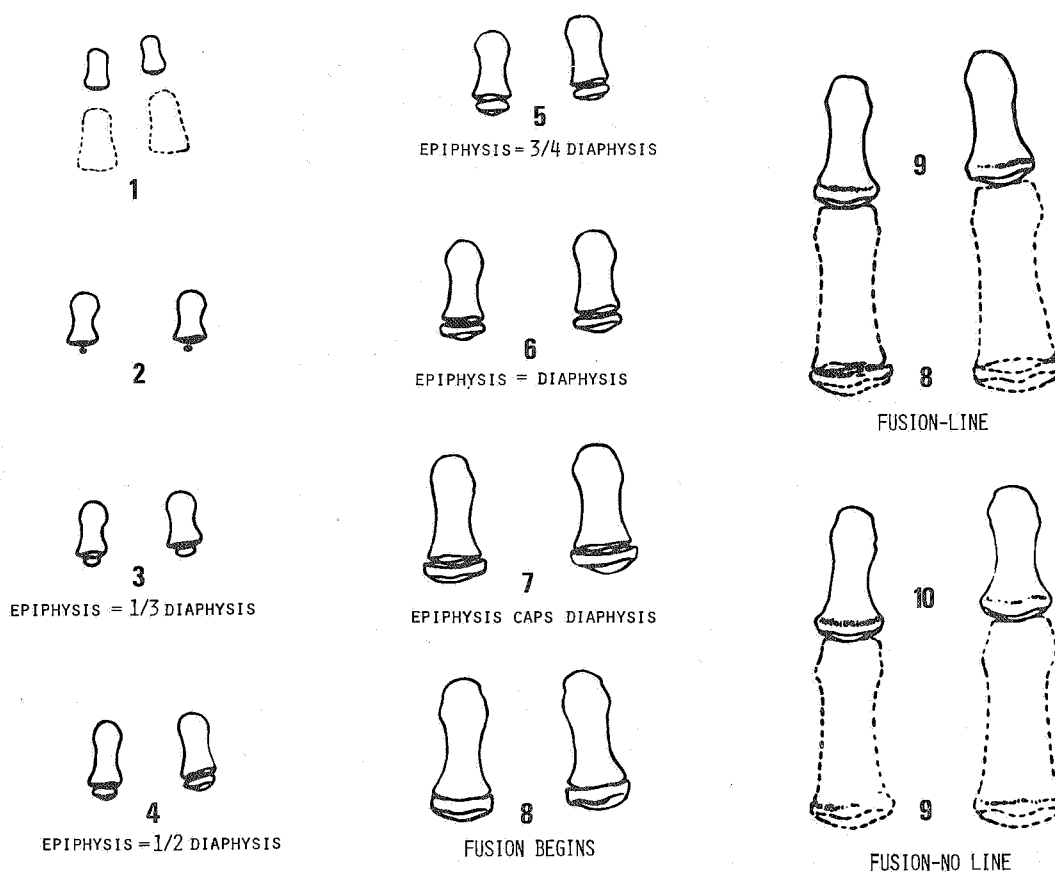


Fig. 1: Epiphysial stages in the distal phalanges of the hand.

was assessed as the first date recorded when the annual change did not exceed 0.5 cm. for three consecutive visits. This arbitrary method of establishing mature height was selected because minimal increments of growth may continue in selected individuals until 20-30 years of age. (Roche, 1975).

Results and Discussion

Ages of Attainment of Adolescent Spurt Stages

Start of Adolescent Spurt (S.A.S.)

Table 2 shows that the start of the adolescent spurt occurred at a mean chronological age in females of 9.99 years and in males of 12.0 years compared with mean skeletal ages of 10.51 and 12.28 years respectively. The first girl to commence her adolescent spurt had a chronological age of 6.51 years and a skeletal age of the same years, whilst the first male had a chronological age and skeletal age of 9.7 years. The last girl to commence the adolescent spurt had a chronological age of 12.5 and a skeletal age of 11.5 years in contrast to the last male with a chronological age of 13.5 years and a skeletal age of 14.0 years.

TABLE 2. Chronological and skeletal ages (years) at which various growth stages occur. The means, standard deviations and differences for males and females at each stage are shown.

	FEMALES			MALES			DIFFERENCES
	Number	Mean	S.D.	Number	Mean	S.D.	
<i>Chronological Age</i>							
Adolescent – Start	50	9.99	1.26	47	12.00	0.95	2.04*
– Peak	48	11.67	1.01	41	13.91	0.96	2.63*
– End	40	12.88	0.87	36	15.42	1.14	2.74*
Mature Height	49	16.59	0.86	23	17.87	0.87	1.28*
<i>Skeletal Age</i>							
Adolescent – Start	52	10.51	0.84	45	12.28	0.80	1.77*
– Peak	55	11.79	0.81	43	14.43	2.93	2.64*
– End	46	13.55	2.64	38	15.40	0.58	1.85*

* significant difference

Peak of Adolescent Spurt (P.A.S.)

The peak of the adolescent spurt in females showed a mean chronological age of 11.67 years and a skeletal age of 11.79 years compared with the mean ages for males of 13.91 and 14.43 years respectively. The first girl to achieve the peak of the spurt had a chronological age of 9.5 years and skeletal age of 10.4 years, the last girl reached her peak at a chronological age of 13.62 years and a skeletal age of 12.9 years. The earliest maturing male recorded his peak adolescent growth rate at a chronological age of 11.6 years and the last maturing male had his peak at a chronological age of 15.6 years and a skeletal age of 15.2 years.

End of Adolescent Spurt (E.A.S.)

Females finished their adolescent statural growth spurt at the mean chronological age of 12.88 years and skeletal age of 13.55 years, whilst the mean ages for males were 15.42 and 15.40 years respectively. The earliest maturing female completed her adolescent spurt of statural growth at a chronological age of 11.45 years and a skeletal age of 11.5 years and the early maturing male's ages were 13.43 and 13.10 years respectively. The latest maturing female completed her adolescent spurt at a chronological age of 14.5 years and a skeletal age of 13.7 years, whilst the last maturing male achieved the same stage at 17.6 and 17.5 years respectively.

The attainment of mature height in females was at a mean chronological age of 16.59 years and for males 17.87 years. The first female and male to achieve mature height did so at chronological ages of 14.48 years and 16.03 years respectively whilst the last female and male to achieve mature height did so at chronological ages of 20.0 years and 19.81 years respectively.

There are significant differences between males and females in the start of the adolescent spurt (2.04 years), in the peak of the spurt (2.63 years) and in the end of the spurt (2.74 years). This sexual dimorphism is not reduced markedly when the respective differences in adolescent stages are computed by skeletal age (1.77, 2.64 and 1.85 respectively) which are also significantly different. Whilst the skeletal age calculations reduce the standard deviations of the mean differences for the effective spread of these adolescent stages, this reduction is not marked and illustrates that individuals do not attain these specific growth stages at identical skeletal ages, and that skeletal maturation is not absolutely identical with skeletal growth.

The Timing, Appearance and Sequence of Epiphysial-Diaphysial Growth Stages.

Skeletal age assessments of the hand-wrist area subjectively quantify the maturation sequence of the transformation of cartilage to bone in the carpals, in the primary and secondary epiphysial ossification sites of the long bones (phalanges, metacarpals, radius and ulnar) and the final transformation of these carpals and epiphyses into their adult shapes.

(i) Timing

Figure 4 and Table 3 show that 28 out of 31 ossification centres constantly appearing in the hand-wrist area, tend to appear on the average up to 5.5 years in females and 7 years in males. Only the pisiform (29) and the adductor (30) and flexor (31) sesamoids appear generally after 7 years of age and thus after this age only the appearances of these ossification sites and the changes in carpal and epiphysial fusion shapes are usually available for comparison with adolescent growth stages. The trapezoid (26), scaphoid (27) and distal ulnar (28) tend to appear from 5 to 7 years and therefore their initial appearance, together with various epiphysial growth stages, have been correlated with the mid-growth or juvenile spurt and are the basis of a separate report (Bowden, 1976).

(ii) Appearance

The epiphysial-diaphysial growth stages in the hand-wrist area occur in a relatively fixed sequential pattern and this is in contrast to the apparently haphazard appearance of the earlier primary and secondary ossification centres. Whilst the epiphysial-

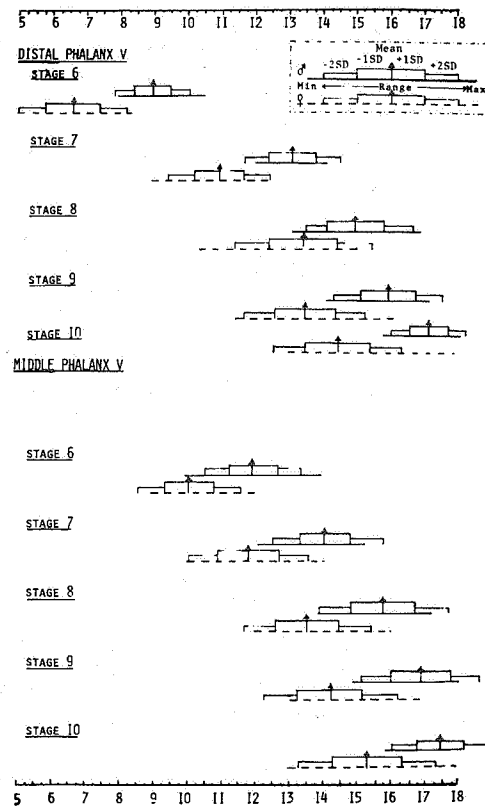


Fig. 4: Ages of appearance (years) of epiphysial stages in distal phalanx V and middle phalanx V expressed in terms of the mean age plus or minus one and two standard deviations for both males and females.

TABLE 3. Bones in the hand-wrist area and average ages (years) of ossification for males and females.

BONES IN HAND-WRIST AREA	OSSIFICATION (Years)	
	Males	Females
1. Capitate *	.25	.25
2. Hamate	.25	.25
3. Distal Radius	.75	1.2
4. Proximal Phalanx 3	1.0	1.5
5. Proximal Phalanx 2	1.0	1.5
6. Proximal Phalanx 4	1.0	1.5
7. Metacarpal II	1.0	1.5
8. Distal Phalanx I	1.0	1.5
9. Metacarpal III	1.0	1.8
10. Metacarpal IV	1.25	2.0
11. Proximal Phalanx 5	1.25	1.5
12. Middle Phalanx 3	1.25	2.0
13. Middle Phalanx 4	1.25	2.0
14. Metacarpal V	1.25	2.0
15. Middle Phalanx 2	1.25	2.0
16. Triquetral *	1.75	2.5
17. Distal Phalanx 3	1.75	2.1
18. Distal Phalanx 4	1.75	2.1
19. Metacarpal I	1.75	2.8
20. Proximal Phalanx 1	1.75	2.8
21. Distal Phalanx 5	2.0	3.0
22. Distal Phalanx 2	2.0	3.0
23. Middle Phalanx 5	2.0	3.25
24. Trapezium *	2.0	3.0
25. Lunate *	2.5	3.5
26. Trapezoid *	4.0	5.5
27. Scaphoid *	4.0	5.5
28. Distal Ulna	5.5	7.0
29. Pisiform *	9.0	10.0
30. Adductor Sesamoid #	11.0	13.0
31. Flexor Sesamoid #	13.0	15.0

* Carpal Bones

Sesamoids

diaphysial growth stages vary in minor details (Greulich and Pyle, 1959) for the different phalanges, metacarpals, ulnar and radius, the various epiphysial stages generally are very similar. (Figures 1 and 2). The stage sequences are first the initial appearance of the epiphysis, then slowly the epiphysis enlarges until it equals the shaft in size, and then the stages of fusion follow, i.e. epiphysial appearance, enlargement and fusion.

(iii) Sequence

The sequence of these maturational changes of the epiphysial-diaphysial areas for the hand-wrist area is specific, although the precise changes in timing for the individual centres varies with genetic, racial, nutritional, and socio-economic conditions. The mean ages of appearance, the ranges and standard deviations of the stages 6-10 for all bones have been calculated and those for distal, proximal and middle phalanx digit V are illustrated for males and females in Table 4 and summarised in Figure 5. This shows both the polymorphism in the spread of the range of ages and the sexual dimorphism of the occurrence of these stages with chronological age. Similar illustrations of the stages for all the investigated changes show very similar characteristics. A summary of these changes shows that in general, the sequence of the appearance of the specific stages occurs as follows:

1. Phalanges of Digits I, II, III, IV, V

Each epiphysial-diaphysial stage tends to occur first in the distal, then in the proximal and finally in the middle phalanges. Most frequently, even in biannual radiographs, the proximal and middle phalanges go through their stages together. They are observed first in the distal phalanx of the thumb and then in the distal phalanges of digits II, III, IV and V in that order and only rarely does digit V precede digit IV. The sequence is such that whilst a specific epiphysial-diaphysial growth stage is occurring in one phalanx, another phalanx may be a stage preceding or succeeding it. For example, when digit V distal phalanx attains stage G & P 6 (equals shaft) the middle phalanx digit V frequently has attained stage G & P 5 ($\frac{3}{4}$ width of shaft) and so on.

2. Metacarpals of I, II, III, IV, V

3. Tibia (proximal)

4. Femur (distal)

5. Ulna (distal)

6. Radius (distal)

Table 5 documents the time intervals between the appearance of the various epiphysial stages together with the significant differences which existed between the sexes. Figure 5 illustrates the intervals between the appearance of these various epiphysial stages and the tendency for a gradual decrease in time as these fusion stages progress, from approximately 4 years for the stages 6 to 7 in the distal phalanges, to approximately 3 years for the proximal phalanges and 2 years for the middle phalanges. Figure 5 also illustrates the gradual decrease in the time intervals as the fusion stages proceed from 6 to 7, from 7 to 8, from 8 to 9 and from 9 to 10, and this decrease is shown through all of the phalanges. There is not only a decrease in the mean time, but also in the ranges, and the standard deviations are particularly low in stages 8 to 9 and 9 to 10. This tendency was present in all epiphysial-diaphysial growth areas but is particularly marked in the distal, proximal and middle phalanges illustrated here. It is stressed that the radiographic stages can only be assessed from annual radiographs and the results should be interpreted against the evidence of Novak

TABLE 4. Ages of appearance (years) of epiphysial stages (all phalanges) for males and females.

Stage		Mean	S.D.	Range	Number	Difference
DISTAL						
Stage 6	M	8.96	0.57	7.96–10.47	55	2.32 *
	F	6.64	0.81	4.99– 8.39	53	
7	M	13.04	0.68	11.96–14.13	42	2.15 *
	F	10.89	0.74	8.98–12.28	60	
8	M	14.90	0.84	13.04–16.87	43	2.25 *
	F	12.65	1.02	10.32–14.98	53	
9	M	15.83	0.83	14.04–17.11	33	2.41 *
	F	13.42	0.88	10.97–15.92		
10	M	17.02	0.65	15.87–18.00	31	2.62 *
	F	14.40	0.95	12.95–16.91	42	
PROXIMAL						
Stage 6	M	11.02	0.77	8.98–12.07	53	2.72 *
	F	8.30	0.86	6.96–10.19	60	
7	M	13.83	0.72	12.01–15.04	50	2.46 *
	F	11.37	0.71	9.98–13.09	59	
8	M	15.67	0.98	13.89–17.11	33	2.27 *
	F	13.40	1.05	10.97–15.92	50	
9	M	16.74	0.88	14.89–18.00	29	2.43 *
	F	14.31	0.98	11.96–16.91	43	
10	M	17.41	0.71	15.87–18.15	20	2.03*
	F	15.38	1.07	12.96–17.97	38	
MIDDLE						
Stage 6	M	11.94	0.69	10.06–13.93	55	1.82 *
	F	10.12	0.75	8.93–11.99	61	
7	M	14.03	0.74	12.17–15.21	50	2.17 *
	F	11.86	0.88	10.00–13.98	58	
8	M	15.76	0.93	13.89–17.11	32	2.26 *
	F	13.50	0.94	11.96–15.92	47	
9	M	16.82	0.87	14.89–18.00	28	2.51 *
	F	14.31	0.98	12.94–16.91	43	
10	M	17.47	0.71	15.87–18.15	20	2.09 *
	F	15.38	1.07	12.96–17.97	38	

M = Male
F = Female

* Significant differences between males and females.

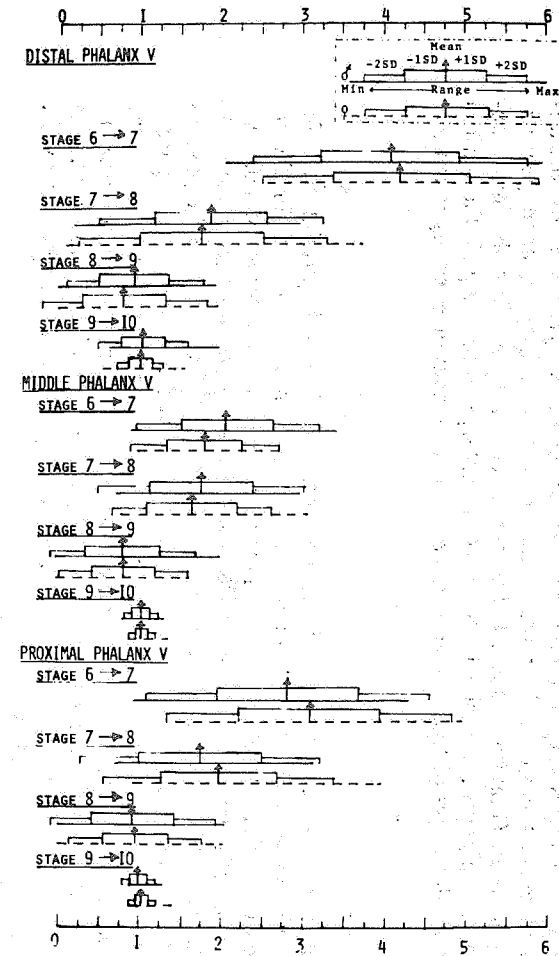


Fig. 5: Intervals (years) between the appearances of various epiphysial stages in the phalanges expressed in terms of the mean interval plus or minus one and two standard deviations for males and females.

TABLE 5. Intervals (years) between the appearance of various epiphysial stages for males and females.

Stage		Mean	S.D.	Range	Number	Difference
DISTAL						
Stages 6-7	M	4.10	.78	2.02-5.94	40	
	F	4.20	.76	2.60-5.88	47	-.10 *
7-8	M	1.87	.62	0.21-2.98	36	
	F	1.75	.70	0.17-3.74	49	.08
8-9	M	0.91	.30	0.0 -1.89	30	
	F	0.77	.42	0.0 -1.95	45	.14
9-10	M	1.06	.27	0.64-1.99	25	
	F	1.02	.14	0.57-1.59	36	.04
PROXIMAL						
Stages 6-7	M	2.77	.81	0.94-4.27	46	
	F	3.13	.81	1.43-4.98	53	-.36 *
7-8	M	1.75	.68	0.72-3.13	31	
	F	2.00	.64	0.90-3.95	45	-.25
8-9	M	0.92	.40	0.0 -2.03	23	
	F	0.98	.28	0.0 -1.96	34	-.06
9-10	M	1.00	.10	0.87-1.28	17	
	F	1.02	.08	0.88-1.37	35	-.02
MIDDLE						
Stages 6-7	M	2.03	.48	0.93-3.39	48	
	F	1.78	.35	1.00-2.74	51	.25 *
7-8	M	1.60	.55	0.72-2.98	31	
	F	1.62	.46	0.84-3.04	44	.02
8-9	M	0.87	.34	0.0 -1.99	22	
	F	0.85	.27	0.0 -1.59	33	-.02
9-10	M	1.01	.10	0.81-1.28	17	
	F	1.02	.08	0.88-1.37	35	.01

M = Male

F = Female

* Significant differences between males and females.

et al (1958) indicating that similar fusion stages particularly were very rapid, varying from 2-28 months with a tendency for the fast and slow fusion rates to be specific for individuals.

The intervals for these stages, proceeding from one stage to the next, show significant differences between the sexes only where indicated, i.e., for proximal and middle phalanges, stages 6 - 7. This relative decrease in sexual dimorphism could be viewed as illustrating a difference only in times taken for the onset of the fusion process, but not for the intervals once the fusion process has started.

The Distribution of the Adolescent Spurt Stages with Specific Epiphysial/Diaphysial Growth Changes

(i) Start of Adolescent Spurt

Figure 6 illustrates the frequency distributions, for males and females, of the time

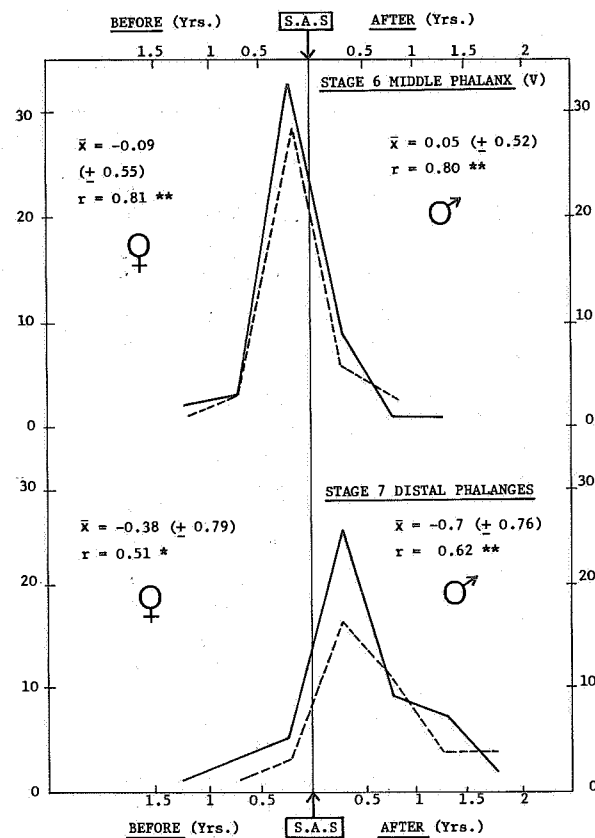


Fig. 6: Frequency distributions of the time intervals between the start of the adolescent spurt (S.A.S.) and stage 6 of the middle phalanx V and stage 7 of all distal phalanges.

TABLE 6. Time interval (years) between the ages of occurrence of the three stages of the adolescent growth spurt and various stages of epiphyseal development of the phalanges shown.

STAGES OF AOLESCENT SPURT		Female			Male		
		Mean	s.d.	n	Mean	s.d.	n
<i>Start</i>	minus						
(1)	Middle Phalanges Stage 6	0.30	0.65	51	0.28	0.73	43
(2)	Digit V Middle Phalanx Stage 6	-0.09	0.55	51	0.05	0.52	43
(3)	Distal Phalanges Stage 7	-0.38	0.70	52	-0.70	0.76	38
<i>Peak</i>	minus						
(1)	Middle Phalanges Stage 7	0.11	0.65	51	0.32	0.87	42
(2)	Distal Phalanges Stage 8	-0.64	0.67	47	-0.53	0.57	38
(3)	Ulnar Sesamoid Appearance	0.64	0.85	53	0.95	0.99	42
<i>End</i>	minus						
(1)	Middle Phalanges Stage 8	-0.27	0.55	40	-0.14	0.52	28
(2)	Proximal Phalanges Stage 8	-0.19	0.65	41	-0.07	0.52	28
(3)	Distal Phalanges Stage 9	-0.25	0.66	40	-0.16	0.65	27

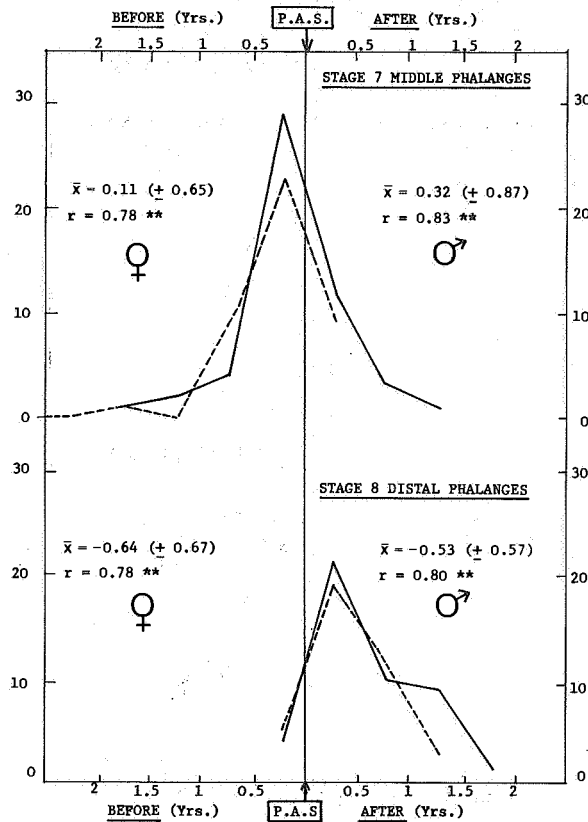


Fig. 7: Frequency distributions of the time intervals between the peak adolescent spurt (P.A.S.) and stage 7 of the middle phalanges and stage 8 of the distal phalanges.

intervals between the attainment of specific radiological shapes (Greulich and Pyle, stages 6 and 7) and the start of the adolescent statural growth spurt. All the middle phalanges (Table 6) reached stage G & P 6 (equals) on an average of 0.3 years for females and 0.28 years for males before the start of the adolescent spurt. The middle phalanx digit V (Figure 6) reaches stage G & P 6 (equals) on an average 0.05 years before in males and 0.09 years after in females the start of the adolescent spurt ($r = 0.80$ and 0.81 respectively).

The distal phalanges (Figure 6, Table 6) reach stage G & P 7 (capping) 0.70 years in males and 0.38 years in females after the start of the adolescent spurt ($r = 0.62$ and 0.51). Figure 6 also illustrates the increased efficiency of the prediction for the start of the adolescent spurt when more variables or when more epiphysial-diaphysial growth stages of distal and middle phalanges are utilised. In the majority of both males and females, middle phalanx digit V attains stage G & P 6 (equals) within plus or minus six months of the start of the adolescent spurt. However the efficiency of predicting the start of the spurt is increased if a check is made of the sequence to see that the middle phalanges of all digits I to V have attained stages G & P 6 (equals). If the middle phalanges of digits I, II, III have attained stage G & P 6 and IV and V have not, then

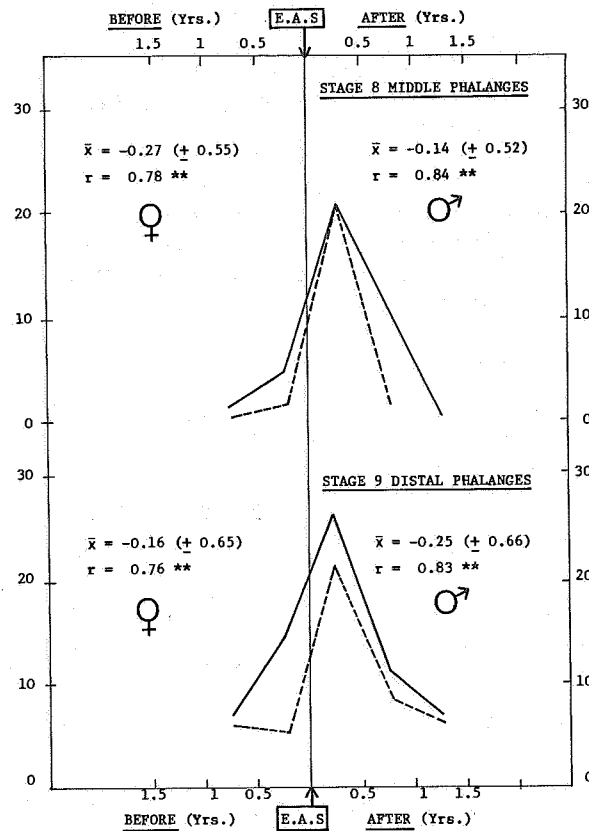


Fig. 8: Frequency distributions of the time intervals between the end of the adolescent spurt (E.A.S.) and stage 8 of the middle phalanges and stage 9 of the distal phalanges.

the start of adolescent statural spurt may be imminent but in isolated individuals may be up to two years away (Figure 6). Similarly increased efficiency of prediction is achieved if the radiograph shows that middle phalanges of all digits have attained stage G & P 6 (equals) and yet there is no sign of the stage G & P 7 (capping) of the distal phalanges. The accuracy of prediction is improved by waiting until stage G & P 7 (capping) has commenced in the distal phalanges, particularly in digits I, II and III as the epiphysal growth tends to spread from I-V.

(ii) Peak of the Adolescent Spurt

Figure 7 and Table 6 show that the middle phalanges reach stage G & P 7 (capping) on an average of 0.32 years in males and 0.11 years in females prior to the peak of the adolescent spurt ($r = 0.83$ and 0.78 respectively). The distal phalanges reach stage G & P 8 (fusion begins) 0.53 years in males and 0.64 years in females after the peak of the adolescent spurt ($r = 0.80, 0.78$). Figure 7 also illustrates that although most middle phalanges reach stage G & P 7 within a $\frac{1}{2}$ year period either side of the peak of the adolescent spurt, the range in males is from 2.5 years before to 0.5 years after and in females from 2.0 years before to 1.5 years after. Similarly, the bottom graph in Figure

7 shows that most of the distal phalanges reach stage G & P 8 (fusion begins) after the peak of adolescent growth has passed, and the range for males is from 0.5 years before to 2.0 years after and for females from 0.5 years before to 1.5 years after.

Clinically it appears that the co-ordination of the two stages in all of the phalanges, but particularly in digit V, is important. When all the middle phalanges have reached stage G & P 7, indications are that the peak adolescent velocity is imminent and a confirmatory check should show that all of the distal phalanges should be almost reaching stage G & P 8. If the latter has occurred then the indications are that the peak of the adolescent spurt has just passed.

(iii) End of Adolescent Spurt

Table 6 and Figure 8 indicate that most of the middle phalanges reach stage G & P 8 (fusion begins) after the end of the adolescent spurt on average 0.14 years and 0.27 years after in males and females respectively. The ranges are from 1.0 years before to 1.5 years after in both males and females ($r = 0.84$ and 0.78 respectively). The proximal phalanges reach stage G & P 8 (fusion begins) 0.07 years and 0.19 years after the end of the spurt for males and females respectively. The range for males is from 1.5 years before to 1.0 years after and for females from 2.0 years before to 1.5 years after. Similarly the distal phalanges reach stage G & P 9 (fusion complete) from 1.0 years before to 1.5 years after for males and females, the average values being 0.16 years after in males and 0.25 years after in females ($r = 0.83$ and 0.76 respectively).

The combined results for the middle, proximal and distal phalanges indicates that for increased efficiency and accuracy in the individual assessment of the end of the adolescent spurt, the three phalanges should be taken into consideration together. Where the middle and proximal phalanges have reached stage G & P 8 and the distal phalanges stage G & P 9, the end of the adolescent growth spurt has almost certainly occurred. Only three individuals achieved all middle phalanges stage G & P 8 and distal phalanges stage G & P 9 before the end of the adolescent growth spurt. When all the phalanges, i.e. middle phalanges stage G & P 8, proximal phalanges stage G & P 8 and distal phalanges stage G & P 9, were considered, then every individual had passed the end of the adolescent growth spurt.

It is stressed again that the results shown are taken from annual radiographs and the documented evidence from Noback et al (1958) would suggest these fusion stages occur very quickly and probably the drop off in rate of statural growth may be even more sharp than our biannual statural records indicate.

Summary and Conclusions

Although the evidence presented in this report correlates specific epiphysial-diaphysial stages with statural growth, its direct clinical application in orthodontics with its dependence on facial growth, probably is valid but this should not be interpreted as absolute. Whilst there is general evidence (Nanda, 1955; Grave, 1971; Helm et al, 1971) that there is direct relationship between statural and facial growth, specific areas within the facial skeleton vary in the degree of their relationships (Hunter, 1966; Grave, 1971) and the changing patterns of facial growth make direct comparisons hazardous (Bjork and Skieller, 1972). Investigations within this Unit certainly show that variations in the types of growth (e.g. predominantly horizontal, anterior rotation or vertical, backward rotation) are dependent not only on morphological types but also upon maturational stage.

It would not be unrealistic to anticipate that those changes in facial growth which were generally mediated from the cartilaginous based cranial base structures would show a direct relationship to the adolescent statural growth (Roche et al, 1970). However those facial changes not so directly related to cartilage-bone maturation, may not show the same very close relationship. For example, bone development related to dental or occlusal development e.g. molar height, (the distance from palatal and mandibular planes to the occlusal surfaces of 6 year old molars) may not bear such a close relationship to statural growth, and these molar heights appear to be the areas involved in the extrusion processes inherent within certain forms of mechano-therapy (Schudy, 1964; Creekmore, 1967; Merrifield and Cross, 1970). Similarly there is evidence that facial growth changes continue after final statural growth has ceased (Tallgren, 1974; Bjork and Skieller, 1974). This applies particularly to the development of the mandible and probably even its relationship changes in various morphological types, such as the skeletal III which shows a tendency for mandibular growth to continue after general statural growth has been completed.

Conclusions

A survey of the literature shows that all maturational phenomena are influenced in individuals by a combination of genetic, racial, climatic, seasonal, nutritional and socio-economic factors.

Ossification sequences and maturational phenomena within the hand-wrist area show polymorphism and sexual dimorphism and this should be realised in the clinical use of any of these criteria as predictives of adolescent stages.

The adolescent growth stages (start, peak and end) showed polymorphism and sexual dimorphism not only in relation to chronological, but also to skeletal age, thereby limiting skeletal age as a predictor of adolescent stages.

Descriptions of the timing, appearance and sequence of epiphysial changes, show a tendency for most of the epiphysial stages to occur in a strict sequence throughout the hand-wrist area.

Whilst polymorphism and sexual dimorphism existed in the ages of appearance, the intervals between the fusion stages did not show these features.

Stage G & P 6 (equals) in the middle phalanges occurs on the average just prior to, and stage G & P 7 (caps) in the distal phalanges occurs on the average just after the start of the adolescent spurt.

Stage G & P 7 (caps) in the middle phalanges occurs on the average just prior to, and stage G & P 8 (fusion begins) in the distal phalanges occurs on the average just after the peak of the adolescent spurt.

Stage G & P 8 (fusion begins) in the middle phalanges occurs on the average just before, and stage G & P 9 (fusion complete) in both proximal and distal phalanges occurs on the average just after the end of the adolescent spurt.

Because of the sequential nature of the epiphysial stages to occur from digit I-V, the efficiency of prediction of adolescent stages increases if more stages in more digits are included. Particularly does this apply to the severely advanced or retarded individuals where chances of mistiming are high if only single maturity criteria are used.

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