ABERDEEN GROWTH STUDY

I. THE PREDICTION OF ADULT BODY MEASUREMENTS FROM MEASUREMENTS TAKEN EACH YEAR FROM BIRTH TO 5 YEARS

BY

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Between 1923 and 1927 the late Professor Alexander Low measured a series of newborn babies, and in the subsequent years he succeeded in measuring 65 of the boys and 59 of the girls at each birthday up to and including 5 years. Twenty-one physical measurements were made on each child (always by Professor Low himself) and a record was kept of the number of erupted teeth, the time of closure of the anterior fontanelle, the age and parity of the mother, the age of the father and whether the baby was breast or bottle fed. The complete raw data of this growth study were published posthumously a few years ago (Low, 1952).

There is very little information available on the relation between growth in the first five years and adult size and shape, and it occurred to us that the value of this growth study, which was the first longitudinal one made in Great Britain, would be greatly increased if we could find and remeasure some of the subjects now that they were grown up. Accordingly a search for them was instituted, and all except six were successfully traced. Not all, however, were available for measurement, and of those that were, a few could not be persuaded to make what, in many cases, was an arduous journey from their homes to Aberdeen or to London. In all we managed to measure, photograph and somatotype exactly 65% of the original group of both men and women. Thus our records, made between 20 and 25 years after the subjects' last attendances with Professor Low, concern 42 men and 38 women.

The details of the follow-up are given in Table 1. A quite surprising number of subjects had died, all except one from natural causes. One of the men was crippled with rheumatoid arthritis, and another was a leucotomized schizophrenic. None of the women were ill, but two were more than six months pregnant, and so were excluded. Six of the 38 women measured were also pregnant, but their pregnancies had lasted less than six months and they have been included in the statistics below without any alteration in their records; their weight and probably their fat measurements are slightly elevated, but their skeletal ones should be unchanged. (All the various statistics given in the section on results below have been also calculated for weight with these six women excluded, and none of them differed sensibly from the figures given here for the total 38.)

TABLE 1
FOLLOW-UP OF ABERDEEN GROWTH STUDY SUBJECTS AFTER 20 TO 25 YEARS

	Men	Women
Remeasured	42 (65%)	38 (65%)
Died	6	5
Emigrated	8	3
Sick or > 6 months pregnant	2	2
Untraced	3	3
Refused attendance ..	4	8
Total .. .	65	59

The great majority of the adult measurements were done at Aberdeen in January, 1953, the remainder in London during the subsequent three months. All subjects had the original measurements repeated, using the same technique as Professor Low, and in addition had subcutaneous fat and bicondylar measurements taken, together with standardized nude photographs for photogrammetric anthropometry and somatotyping (Tanner, 1955, appendix). In this first paper we are concerned with the prediction of adult measurements from childhood ones, and to this end give the means and standard deviations at each age of supine length, weight, head length and breadth, shoulder and hip widths, and length of lower arm and foot. These dimensions were chosen so that most of the various factors described in adult physique and reflecting differential growth were represented (see Tanner, 1953).

The inter-correlations between measurements at each year are given for each dimension, and also the cumulative percentages of the adult variance explained by multiple regressions using all measurements up to 0, 1, 2, 3, 4 and 5 years respectively.

In subsequent papers we expect to discuss (*a*) the fitting of equations to the individual growth curves and the relations between distance, velocity and acceleration in individuals; (*b*) the relations between the various dimensions at various ages, that is, change of shape with age; (*c*) the assessment of developmental maturity from growth curves; and (*d*) the relation of adult somatotype to the pattern of growth.

Results

Before the statistics given below were calculated the childhood data were carefully examined for errors of measurement and recording, such as are known to occur in even the best regulated studies (Healy, 1952). Graduating curves of the form $y = a + bt + c \log (t + \frac{3}{4})$, where y is the measurement recorded at t years, were fitted to each individual's data for each measurement and the residuals (recorded figure minus predicted figure) at each age examined. In this way some clearly erroneous recorded figures were discovered and altered (usually by 10 units) to the presumed proper value. A list of these alterations is given in the Appendix; suffice it here to say that we have altered a figure only when we were quite satisfied that an error had occurred. The total number of alterations were: weight, nil; head length, 1; head breadth, 1; stature, 14; biacromial width, 4; bitrochanteric width, 10; foot length, 3; cubit (forearm plus hand length), 9. The total corrections are 42 out of 3,360 linear measurements, that is 1·2%, which is not unreasonable in the light of other workers' experience in this field (Healy, 1952). The uneven distribution of these alterations between different measurements is partly due to the fact that some measurements are less prone to gross errors of reading the instruments than others, and partly to the genuine measuring errors in certain measurements, e.g., shoulder width, being sufficiently large to make the detection of gross errors somewhat uncertain; undoubtedly in this latter class of measurements, and in weight, a few undetected gross errors remain.

The means and standard deviations for each measurement at each year are given in Table 2.

TABLE 2

MEANS AND STANDARD DEVIATIONS AT EACH AGE FOR 42 MALES AND 38 FEMALES

		Age in Years						
		0	1	2	3	4	5	(Adult) 25-30
Supine length*†	male ..	495·4	733·3	839·4	920·8	991·8	1,048·1	1,719·2
		15·83	30·41	38·40	41·20	40·94	43·77	64·90
	female ..	497·3	725·9	838·1	921·8	997·8	1,058·8	1,611·7
		18·27	28·84	36·63	34·44	41·12	45·04	56·84
Cubit	male ..	136·5	188·0	216·2	236·2	254·5	268·7	460·3
		4·71	11·58	12·01	11·47	13·15	13·99	18·04
	female ..	136·7	185·6	213·4	234·7	252·9	268·3	418·5
		4·40	9·01	10·34	11·43	14·34	14·25	16·48
Foot length	male ..	79·2	110·6	125·7	137·1	148·0	155·3	251·7
		4·23	6·68	7·40	8·19	9·59	9·28	11·42
	female ..	78·8	108·6	123·8	136·0	147·1	156·2	229·9
		4·31	6·55	6·80	7·83	8·74	8·31	10·49
Biacromial	male ..	121·8	173·9	194·1	207·4	220·3	231·9	399·1
		4·50	11·80	12·54	11·26	11·58	13·83	15·69
	female ..	122·0	174·1	192·8	208·1	219·5	231·9	360·3
		5·02	10·23	9·49	10·82	11·96	11·10	13·60
Bitrochanteric	male ..	96·7	142·7	160·6	172·6	177·7	181·8	316·7
		3·96	7·86	8·12	6·46	6·63	7·00	14·09
	female ..	96·6	141·4	159·7	169·6	176·1	182·2	314·6
		4·46	7·81	7·53	6·39	6·78	6·93	16·66
Weight (lb.)	male ..	6·89	20·49	25·11	28·66	32·85	36·42	139·06
		0·97	2·52	2·23	2·37	3·39	3·40	14·46
	female ..	7·05	19·89	24·32	28·85	32·42	36·09	123·94
		1·01	2·21	2·00	3·19	4·09	4·13	19·57
Head length	male ..	119·4	160·1	168·9	172·4	175·0	177·0	192·3
		3·88	5·08	4·77	4·92	4·79	5·11	5·58
	female ..	120·0	158·0	165·4	170·5	172·4	174·4	184·1
		3·86	6·50	5·20	5·74	5·33	5·53	5·75
Head breadth	male ..	94·4	127·3	133·1	136·4	138·4	139·9	150·4
		4·19	3·91	4·69	4·46	4·17	4·48	5·54
	female ..	94·7	126·7	131·9	135·4	137·4	138·6	144·8
		2·53	4·11	3·82	3·99	3·96	3·89	4·21

* See text. † All measurements except weight in mm.

The data constitute a pure longitudinal series (Tanner, 1951), every child having been present at every age. Supine length in the table and throughout this paper refers to total body length taken with the child lying on its back: from age 0 to 3 length was measured this way, while at 4 and 5 and adulthood it was measured with the subject standing. The standing figures have been converted to supine ones by means of Palmer's (1932) table. A reliable conversion to standing height could not be made from these tables at the younger ages.

The mean values in Table 2 will be examined more fully in a subsequent paper, and call for little comment here. Up to and including age 5 there is very little if any sex difference in size; the adult sex difference comes about through the greater adolescent spurt of the male (Tanner, 1955). With regard to the standard deviations, it is especially noticeable that the figures at birth are much lower than subsequent ones. This is particularly true for biacromial and bitrochanteric diameters, and least marked for foot length and the head measurements. This low variability at birth is not a feature of any of the other published series of data covering this age range, in which the birth or shortly-after-birth standard deviations are usually only slightly less than the 1-year-old figures. It cannot be accounted for by the selection of children with unduly similar measurements since the standard deviations in the present series agree well with those for the much larger series of 900 children from which the individuals repeatedly measured were drawn (Low, 1950). This larger series seems to have been drawn from hospital cases without selection, except for the rejection of babies weighing less than 5½ lb. at birth. The possibility has to be entertained, therefore, that there was a tendency for the measurer to get over-similar answers from one child to another when measuring 3-day-olds. Apart from this, the standard deviations in general increase slightly as the means increase, a familiar tendency in growth data. The high standard deviations at age 2 and 3 for bitrochanteric diameter may perhaps reflect the greater amount of fat over the hips at these ages.

In Tables 3A-H the correlations between measurements at different ages are presented. These tables are most simply examined in two parts: the correlations at ages 1-5, and those involving the adult measurements.

We will consider first the 1-5 block. There are several tendencies which might be expected *a priori*. First, correlations between years close to each other would be expected to be greater than correlations between years further apart. In other words, we

TABLE 3A

CORRELATIONS OF MEASUREMENTS AT SUCCESSIVE AGES

	0	1	2	3	4	5
Supine length, male						
0						
1	0·64					
2	0·48	0·85				
3	0·52	0·81	0·93			
4	0·46	0·78	0·88	0·93		
5	0·43	0·74	0·83	0·87	0·95	
Adult	0·25	0·65	0·79	0·80	0·81	0·77
Supine length, female						
0						
1	0·39					
2	0·41	0·76				
3	0·36	0·78	0·81			
4	0·40	0·78	0·82	0·90		
5	0·34	0·76	0·82	0·88	0·95	
Adult	0·29	0·70	0·74	0·78	0·82	0·81

TABLE 3B

	0	1	2	3	4	5
Cubit, male						
0						
1	0·35					
2	0·25	0·85				
3	0·37	0·78	0·87			
4	0·32	0·71	0·81	0·91		
5	0·33	0·72	0·82	0·88	0·92	
Adult	0·26	0·43	0·54	0·62	0·58	0·58
Cubit, female						
0						
1	0·15					
2	0·14	0·75				
3	0·14	0·65	0·86			
4	0·12	0·75	0·87	0·93		
5	0·11	0·69	0·80	0·90	0·92	
Adult	0·23	0·55	0·73	0·78	0·80	0·76

TABLE 3C

	0	1	2	3	4	5
Foot length, male						
0						
1	0·54					
2	0·50	0·83				
3	0·58	0·77	0·83			
4	0·49	0·64	0·72	0·87		
5	0·45	0·55	0·63	0·77	0·91	
Adult	0·37	0·54	0·60	0·65	0·54	0·46
Foot length, female						
0						
1	0·22					
2	0·28	0·81				
3	0·21	0·72	0·84			
4	0·13	0·59	0·68	0·85		
5	0·12	0·55	0·55	0·75	0·87	
Adult	0·48	0·68	0·59	0·64	0·60	0·54

TABLE 3D

	0	1	2	3	4	5
Biacromial, male						
0						
1	0·27					
2	0·30	0·74				
3	0·31	0·58	0·68			
4	0·28	0·35	0·41	0·75		
5	0·23	0·14	0·22	0·51	0·87	
Adult	0·12	0·43	0·33	0·37	0·13	0·00
Biacromial, female						
0						
1	−0·24					
2	−0·01	0·48				
3	0·19	0·10	0·44			
4	0·23	0·12	0·35	0·81		
5	0·12	0·09	0·41	0·59	0·84	
Adult	0·24	0·28	0·39	0·30	0·36	0·37

TABLE 3E

	0	1	2	3	4	5
Bitrochanteric, male						
0						
1	0·31					
2	0·46	0·62				
3	0·44	0·52	0·71			
4	0·30	0·31	0·46	0·82		
5	0·23	0·25	0·37	0·69	0·95	
Adult	0·28	0·25	0·49	0·45	0·36	0·36
Bitrochanteric, female						
0						
1	−0·09					
2	−0·06	0·61				
3	0·08	0·42	0·61			
4	0·06	0·39	0·50	0·77		
5	0·07	0·33	0·35	0·54	0·91	
Adult	0·17	0·52	0·52	0·43	0·40	0·32

TABLE 3F

	0	1	2	3	4	5
Weight, male						
0						
1	0·48					
2	0·43	0·83				
3	0·49	0·64	0·86			
4	0·51	0·66	0·72	0·84		
5	0·37	0·65	0·76	0·81	0·92	
Adult	0·38	0·57	0·51	0·57	0·55	0·59
Weight, female						
0						
1	0·03					
2	0·16	0·79				
3	0·17	0·70	0·64			
4	0·22	0·76	0·71	0·86		
5	0·16	0·76	0·72	0·85	0·94	
Adult	0·42	0·29	0·43	0·34	0·46	0·46

TABLE 3G

	0	1	2	3	4	5
Head breadth, male						
0						
1	0·35					
2	0·20	0·85				
3	0·31	0·85	0·91			
4	0·34	0·76	0·82	0·88		
5	0·38	0·77	0·80	0·88	0·97	
Adult	0·36	0·61	0·61	0·73	0·85	0·85
Head breadth, female						
0						
1	0·23					
2	0·09	0·85				
3	0·16	0·83	0·92			
4	0·26	0·82	0·88	0·92		
5	0·17	0·78	0·87	0·90	0·96	
Adult	0·14	0·66	0·77	0·75	0·81	0·79

TABLE 3H

	0	1	2	3	4	5
Head length, male						
0						
1	0·29					
2	0·20	0·79				
3	0·24	0·73	0·92			
4	0·29	0·80	0·86	0·88		
5	0·27	0·76	0·85	0·87	0·96	
Adult	0·10	0·62	0·59	0·56	0·71	0·75
Head length, female						
0						
1	0·32					
2	0·36	0·77				
3	0·35	0·69	0·81			
4	0·35	0·74	0·84	0·93		
5	0·40	0·72	0·79	0·93	0·96	
Adult	0·37	0·68	0·62	0·79	0·82	0·82

expect that in each column of the tables the coefficients will get less as the eye follows the column downwards, and in each row of the tables the coefficients will get more as we read from left to right; the highest figure in each column or row should be the one next to the diagonal line. In general this expectation is borne out. There are a few individual exceptions, probably due to the combined effects of measuring errors and genuine vagaries in the individual growth curves on account of illness or other causes. One thing, however, is very noticeable; all the birth correlations are at a considerably lower level than later figures, and they are also less regular. Thus, for the cubit measurements, for example (Table 3B), birth correlations are of the order 0·10 to 0·35, whereas all 1-year-old and subsequent correlations are over 0·65.

It is further to be expected that the correlations between adjacent pairs of years will get larger as the children get older and the growth rate slows down. This happens, as can be seen by following down the figures next to the diagonal line. The 1-2 year correlations average 0·76, the 2-3 year average 0·79, the 3-4 year 0·87, and the 4-5 year 0·93. The birth-1 year correlations, however, are all much lower, and average 0·27. Evidently birth measurements are very much less of a guide to future developments than are measurements taken at 1 year of age. Possible reasons for this are discussed below.

Examining now the adult correlations in Tables 3A-H, that is the lowest rows of figures, we see the same sort of effect. The pattern of these correlations can be most easily seen from Fig. 1 where the data for supine length, head breadth, cubit, foot length, weight, biacromial and bitrochanteric diameters are graphed, with male and female correlations averaged. Consider first supine length, the top line: there is a steep rise in adult correlation from birth to 1 year and a lesser but distinct rise from 1 to 2. After this the rise becomes quite small and the adult/5-year correlation is actually slightly below the adult/4-year correlation. All measurements except body weight show this steep rise in adult predictability from birth to 2 years. Weight does show a rise, but it is only from 0·40 to 0·53. This simply confirms what we have already noticed; that measurements at birth are a singularly worse guide to future development than measurements taken a few years later.

The other striking feature of Fig. 1, however, is certainly less expected. Instead of the curves continuing their parabolic upward course to age 5, all except weight and the two head measurements show a stationary or downward trend after age 3. In other words, we can better predict most adult dimensions from measurements taken at age 3 than from measurements taken at age 5. This is particularly true of the two body breadth measurements where the adult/5-year correlations are very small indeed. There is further discussion of this below.

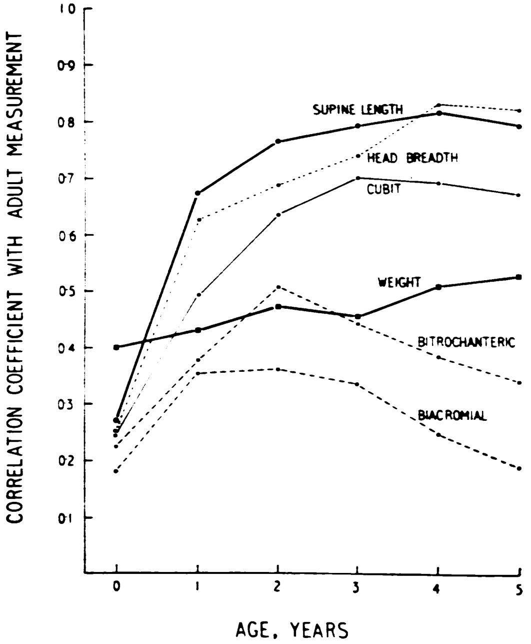

FIG. 1.

TABLE 4

PERCENTAGE OF ADULT VARIANCE ACCOUNTED FOR BY MEASUREMENTS AT PREVIOUS AGES

Measurements available at ages		0	0, 1	0, 1, 2	0, 1, 2, 3	0, 1, 2, 3, 4	0, 1, 2, 3, 4, 5
Supine length	male	4	43	62	67	68	67
	female	6	46	56	61	65	64
Cubit	male	4	16	26	34	32	30
	female	3	31	51	59	63	62
Foot length	male	12	26	32	37	35	34
	female	21	55	54	59	60	59
Biacromial	male	0	15	12	13	14	12
	female	3	13	18	16	17	15
Bitrochanteric	male	6	8	22	23	22	25
	female	0	27	32	31	30	27
Weight	male	12	30	29	37	35	42
	female	15	21	25	23	26	25
Head length	male	0	36	37	36	48	56
	female	11	46	46	65	70	69
Head breadth	male	11	37	40	53	72	72
	female	0	40	57	56	64	63

The question arises whether the prediction of the adult dimension would be much better if in addition to the record at age 5, say, we also had available all the previous information about the child's growth, that is the records at 0, 1, 2, 3 and 4 years. In Table 4 this question is answered for the present data. The figures given are the percentages of the adult variance of each measurement accounted for by regression on the measurement at birth, then birth and 1 year combined, then 0, 1 and 2 years, and so on up to the last column of the table, where the percentage of adult variance explained by all the information we have available is given. (The 'percentage variance explained' will be recognized as analogous to the square of the multiple correlation coefficient, but is preferable to the latter because, unlike R^2, it allows for the effect of decreasing degrees of freedom in the estimate of error as the number of independent variates gets larger. Thus it is possible for the percentage variance explained actually to decrease slightly as additional variates are added in, if they contribute little or nothing to the prediction.)

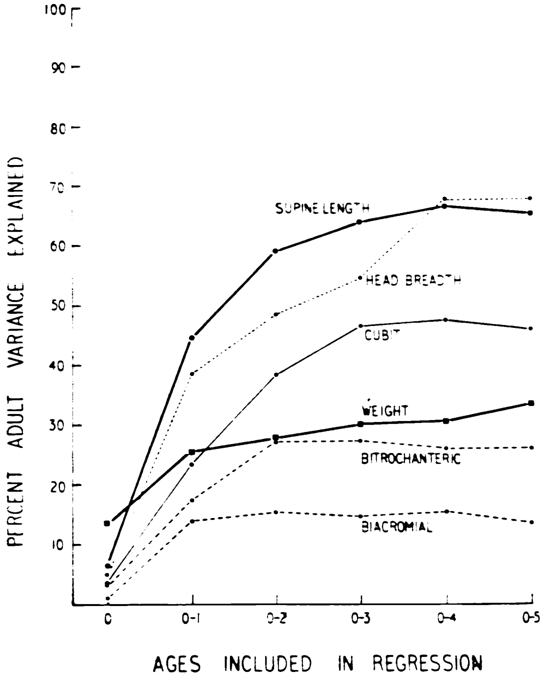

FIG. 2.

The general pattern of the figures in Table 4 can be seen plotted in Fig. 2, where the male and female figures have been averaged. The curves resemble closely those of the ordinary adult correlations given in Fig. 1, except, of course, that the drop after 3 years in the simple correlations is flattened into approximately a horizontal line in the multiples. The same conclusions appear, however. Predictability of adult dimensions is practically nil at birth, increases fairly sharply for most dimensions to 2 years, slightly more to 3, and thereafter fails to improve. The straight correlations showed that knowing the 4- or 5-year measurement is no better, and in some cases is worse, for prediction than knowing the 2- or 3-year-old measurement. These further multiple regression figures demonstrate in addition that if one does know the 3-year-old measurement practically no further information is obtained by taking measurements at 4 and 5 years of age. In other words, the rate of growth between ages 3 and 5 is apparently without predictive value for adult dimensions. Actually the rate of growth as such is of very little predictive value throughout, because the multiple regressions at age 3 (which embody rate of growth from 0 to 3 as well as actual size at age 3) are very little better at predicting adult size than is the simple regression on size at 3 years. In supine length, for example, the percentage of adult variance explained by the measurements at 0, 1, 2 and 3 combined is (Table 4) 67 % for males and 61 % for females, whereas the percentage adult variance explained by supine length at age 3 alone (from Table 3A) is 64 % for males and 61 % for females. This point will be elaborated in a later paper.

Discussion

Low Birth Correlations. Amongst the possible causes of the low birth correlations are the following:

LARGER MEASURING ERRORS AT BIRTH THAN SUBSEQUENTLY. This is possible but unlikely; the experience of most anthropometrists is that the difficult age for measuring children is not at birth but between 1½ and 2 years when the child is old enough to protest but not mature enough to cooperate. In any case no reasonable amount of unreliability of measurement could have lowered the correlations to the extent found.

MATERNAL MALNUTRITION DURING PREGNANCY. The mothers were mostly drawn from a working class group in the days before antenatal care services were well developed. It is likely that some ate a good deal less than the optimal diet during pregnancy, and the effect of this could be to throw some of the foetuses off their (presumably) genetically-determined curves. There is one fact which stands out clearly against this explanation, however: in the Brush Foundation study (Simmons, 1944) at Western Reserve, Cleveland, the same tendency of the birth correlations is seen. The correlations between birth weight and weight at 1 year were 0·32 and 0·49 (boys and girls), whereas subsequent adjacent-year correlations are 0·85 for 1-2 years and over 0·90 thereafter. For height the birth-1 year correlations were 0·40 and 0·30; 3 months-1 year correlations were 0·68 and 0·75, and 1-2 year correlations 0·88 and 0·84. These mothers and children were all drawn from the highest economic groups of American life and their diet must have been very nearly optimal. Again, the study of Bayley and Davis (1935) on Californian children shows the same depression of the 1-month-old correlations for the several measurements that they report from 1 month to 3 years. This group, too, is at least a well-nourished one, and their correlations are very similar to ours. For example, the 1-month correlations for hip width (sexes combined) with 1, 2 and 3 years are 0·37, 0·32 and 0·23, whereas the 1 year-2 year correlation is 0·80. For weight the 1 month-2 year correlation is 0·45, the 1 year-2 year correlation 0·91.

MATERNAL ENVIRONMENT, GENERAL AND LOCAL. This would seem to be the most acceptable explanation. Both in animals and man the birth weight is to a considerable extent dependent on the prenatal environment. Thus, in man the inborn growth rate of the foetus is modified during the last two months or so of pregnancy by maternal factors which are quite distinct from the maternal genes influencing the child's ultimate size. These factors affect not only the rate of prenatal growth, but also the gestation time. They appear to be both systemic and uterine, and they serve to hold back in growth, and also to expel early, the genetically large child who happens to be developing in a small-sized mother (McKeown and Record, 1952, 1953). The mother's environment and nutrition play a part in these prenatal influences, but apparently not a more important one than her heredity (Robson, 1955), which presumably acts through hormonal constitution and uterine and placental size. The effect of this prenatal influence does not, however, persist. Cawley, McKeown and Record (1954), for example, have shown that, although the correlations between gestation time and birth weight and birth length are about 0·35 and 0·31 (even when heights of father and mother, maternal age and birth rank are allowed for), the correlations between gestation time and 1-year-old weight and length are practically zero. Unfortunately we have no data on the gestation time of our Aberdeen subjects. Conversely, the correlation with average parental weight in the Oxford Child Health Survey children was only 0·22 at birth, but rose to 0·42 by age 1 (Hewitt and Stewart, 1952).

We are thus presented with a picture of, presumably, a genetically determined growth curve which in favourable environmental circumstances the child may follow at first in the uterus and later outside it. But towards the end of his uterine existence he may be deflected very considerably from this curve by the characteristics (both genetical and environmental) of his mother, and after birth he takes a little time to get back on to it, somewhat after the manner of a growing animal who has passed through a period of not too severe malnutrition (see Tanner, 1955, p. 85). There is, indeed, a negative correlation between birth weight and weight gain during the first six months (Thomson, 1955) and, to a much smaller extent, during the second six months (Norval, Kennedy and Berkson, 1951) which probably reflects this catching-up mechanism. The same applies to birth length and length increment (Simmons and Todd, 1938). This is probably still an over-simplified picture. We cannot be sure that the vagaries of intra-uterine life may not sometimes produce a permanent effect, though comparison of identical and non-identical twins makes this appear rather unlikely. In any case it looks as though prediction of a child's ultimate adult size from his size at birth is at present a losing game; by 1 year one has at least something to go on, and by 3 years quite a good deal. This does not necessarily mean that adult shape cannot be predicted from shape at birth or that it can be predicted from shape at, say, 3 years; the problem of 'guessing the somatotype' remains entirely open. We are now in process of examining the constancy during growth of various combinations of measurements, and hope to report on this later.

It is interesting that the largest correlation between an adult measurement and a birth measurement is that for weight. This extends the data of Illingworth and others (Illingworth, Harvey and Gin, 1949) who showed that heavier babies on the whole turned into heavier children. The prediction equations of weight at age 25-30 from birth weight in the present data are

Adult weight (lb.) = 5·62 birth weight (lb.) + 100·3 (men)
Adult weight (lb.) = 8·06 birth weight (lb.) − 67·2 (women)

with the large standard errors of prediction of ±13·4 lb. for men and ±17·8 lb. for women. For the prediction of adult weight from 5-year-old weight the regression coefficients are 2·50 and 2·16 for men and women respectively, with standard errors of prediction of 11·7 lb. and 17·4 lb.

Diminution of Correlations at Ages 4 and 5. The diminution of adult correlations after about age 3 for all measurements except weight and head length and breadth (see Fig. 1 and Table 4) seems to admit of two possible explanations.

PERIODS OF ACCELERATION. Some sort of acceleration may be occurring on the curves from 3 onwards, with its beginning falling at different ages in different individuals. This happens, as is well known, at adolescence and it has precisely the effect of lowering the correlations with adult measurements during the years of the spurt, so that, for example, one can predict the adult height better from height at age 12 than at age 14 (see Tanner, 1951, 1955, p. 65). But there is no other evidence known to us that any period of acceleration does occur at the 3-5 years of age period. This matter needs further examination.

EFFECT OF MALNUTRITION. The children reached this age at near the height of the 1928-30 depression and it is probable that some suffered real privation. Nevertheless, if differential degrees of malnutrition have lowered adult prediction for shoulder and hip width, it is hard to see why they have not done so for weight.

Neither of these explanations seems to us very satisfactory and more research needs to be done, with children followed during their whole course of growth. In the literature there are a few records of correlations of near-adult height and weight with previous measurements from age 7 onwards (summarized in Fig. 1 of Tanner, 1951) and it looks as if the stature correlation curve given in Fig. 1 can be continued slowly upwards to reach about 0·84 at ages 10-12, after which it falls again till after adolescence. The weight curve probably also rises continuously to somewhere around 0·7 before adolescence, though this is less certain.

Sex and Measurement Differences. There are some sex differences apparent in the figures of Tables 3 and 4, and also and much more strikingly some differences between body measurements. None of the sex differences is very large, but perhaps the consistently lower predictability of cubit, foot length and head length in the male calls for some comment. A reason why *all* male predictions should be lower than female ones comes readily to mind. The adolescent spurt is of greater magnitude and almost certainly of greater variability in the male. (Thus the standard deviations of height, for example, are practically the same for boys and girls before puberty, but some 8% greater for boys after puberty.) If the magnitude of the spurt is relatively independent of the course of growth before adolescence, which on present evidence seems likely, then the predictability of adult male values should be lower. The curious thing, however, is that for supine length the predictabilities of male and female are almost identical. So, although this explanation may be true, more work needs to be done before the situation becomes clear. In particular, it would be very interesting to know how closely the immediately pre-adolescent dimensions of boys and girls could be predicted from earlier measurements. It is a great pity that our measurements do not continue till age 11 or 12.

There are considerable differences in predictability between different body measurements. Supine length has the highest predictability of those we have studied, which is a fortunate practical accident, as this is what people most usually want predicted. The regressions of adult supine length on length at age 3 are

$$\text{Adult length (mm.)} = 1\cdot27\ (\text{length at age 3, mm.}) - 549\ (\text{men})$$

$$\text{Adult length (mm.)} = 1\cdot29\ (\text{length at age 3, mm.}) - 423\ (\text{women})$$

with standard errors of estimate of 39 and 36 mm. (For conversion to adult standing height subtract about 15 mm.) However, the reader should be warned that because of the secular trend to a greater amount of growth completed at a given chronological age (see Tanner, 1955, p. 88) these figures will probably give too high predictions if applied to present-day children. It is interesting that Bayley and Pinneau (1952) give the percentage of adult stature achieved at age 3·0 as 53·5% for boys and 57·2% for girls: these figures are for Californian children studied about five years later than the Aberdeen ones. For the Aberdeen children the figures are almost identical: 53·6% and 57·2%.

Next to supine length in predictability came the head measurements, which are the only ones which show a substantial betterment in prediction from 3 to 5. It is astonishing that despite the relatively small amount of growth still to occur after age 5 the prediction of adult head size is relatively less accurate than that for supine length.

Body breadths have much the lowest predictability, for reasons that are not at present clear. Biacromial diameter is admittedly very difficult to measure in young children, and the correlations may be lowered by a good deal of measuring error. Bitrochanteric diameter, however, is fairly straightforward, though affected to some extent by fat. However, neither explanation seems sufficient to account for the very low values obtained and the question must be raised (though we certainly cannot answer it) as to whether these breadth dimensions are more affected by environmental circumstances than are the lengths. It is very necessary that this material be checked with the other growth data available in a few places in the United States and gradually becoming available in the United Kingdom.

Weight stands in between the lengths and breadths. The correlation between adult and birth figures is greater for weight than for any other dimension, but at later ages it rises rather less than for most others. (The true birth weight correlations might well be slightly higher than those given here, because these are for weight at 3 days post-partum, which unfortunately is at the peak of the post-partum weight loss. As different babies reach their maximum loss on different days (Meredith and Brown, 1939) a small extra source of variability affects these figures.) As in the case of the other measurements, the predictability of adult weight from weight reached at 5 years can be scarcely at all improved by knowledge of the course of the weight gain from birth to five.

Summary

During the years 1925-32 the late Professor Alexander Low measured a series of 65 boys and 59 girls at birth and at subsequent birthdays up to and including age 5. Twenty-one physical measurements were taken and the raw measurements on each individual were published recently (Low, 1952).

We have traced, remeasured, and somatotyped as adults aged 25-30, 65% of those individuals, that is, 42 men and 38 women.

The means and standard deviations at each age, including adulthood, are given for measurements of supine body length, weight, head length and breadth, shoulder and hip breadths and length of lower arm and foot.

We have examined the constancy of growth pattern during the first five years and the relation of growth and physique at this time to adult physique. Part of our results are reported here, and part will appear in later papers. In this paper are given the matrix of correlation coefficients for ages 0, 1, 2, 3, 4, 5 and adult for each of the measurements mentioned, and also the percentage of adult variance of each measurement accounted for by multiple regression on the childhood measurements. Thus the percentage variance of adult body length accounted for by length at birth is 5%, by a combination of length at birth and 1 year 45%; by combination of 0, 1 and 2 years 59%; 0, 1, 2 and 3 years 64%; 0, 1, 2, 3 and 4 years 66%; and 0, 1, 2, 3, 4 and 5 years 66%.

The chief results are as follows:

(*a*) Correlations of all birth measurements with later measurements are much lower than the intercorrelations of later measurements between themselves. Thus for lower arm length all the birth correlations are in the range 0·10-0·35, whereas all 1-year and subsequent correlations are over 0·65. It is evident that the size of the newborn baby is only very slightly related to the size of the adult, or even to the size of the 2-year-old. The evidence of other studies agrees with this and supports the conclusion that prenatal environment during the last two months of pregnancy is the major determinant of newborn size, this prenatal environment depending to a considerable extent on the hereditary characteristics (such as uterine size) of the mother. The inherent growth characteristics of the child assert themselves after birth, however, and the correlations of childhood measurements with adult measurements rise sharply; for example, for supine length from 0·27 at birth to 0·67 at 1 year, 0·75 at 2 years and 0·79 at 3 years. The correlations for most measurements rise relatively little from 2 to 3 years and from 3 to 5 years not at all, on average. It seems that prediction of adult size can be made just as well from age 3 as from age 4 or 5. These results imply nothing as to the predictability of adult shape, a subject we are now examining.

The largest of the birth-adult correlations is for body weight, but this is only 0·40; the correlation with adult weight rises less than those of other measurements with increasing age and is 0·53 at age 5. The amount of male adult variance in weight accounted for by all the previous measurements from 0 to 5 is 42% compared with 67% for supine length.

(*b*) The cumulative multiple regression figures (percentage of adult variance accounted for at increasing ages) support these conclusions and add the information that the rate of growth from birth to 5 years has only a very small effect on adult measurements. Rate and size seem practically independent.

(*c*) Some sex differences in the measurements appear to be present and are described.

We must emphasize that these data, like those of all longitudinal studies, have their own peculiar characteristics, particularly in regard to subject selection and to environment during growth. Conclusions drawn from them may at least in detail be inapplicable to other samples. There is a great need for similar studies to be undertaken on other groups, to discover how far the generalizations given in this paper hold true for all growing children.

Much of this work was done while one of us (J.M.T.) was Ernest Hart Memorial Scholar of the British Medical Association. We wish to thank the B.M.A. for this support, without which this research would not have been possible.

Miss A. M. Clark, Professor Low's secretary, had a remarkable knowledge of the families concerned, and it is largely due to her enthusiasm that so many persons were traced after a lapse of nearly 25 years. We wish to record our grateful thanks for her staunch cooperation.

We wish also to thank Professor A. A. Moncrieff and Dr. F. Yates, F.R.S., for their critical encouragement; and, finally, to put on record our use of the Elliott Mark I electronic computer, without which we literally could not have made more than a fraction of the calculations these data call for.

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APPENDIX

List of Corrections Made in Aberdeen Records

Details of criteria for correcting are given in the text. Only head length, head breadth, height (or supine length), biacromial and bitrochanteric widths, foot length, cubit and body weight have been examined. The corrected measurement reads as follows:

Dimension	Sex	Case Number	Age	Corrected Measurement
Head length	M	6	1	171
Head breadth	M	6	1	135
Height	M	2	3	986
	M	4	1	767
	M	6	4	1,030
	M	7	2	906
	M	11	5	1,038
	M	13	4	1,020
	M	35	3	887
	M	38	5	980
	M	43	3	905
	M	54	1	755
	M	65	4	850
	F	6	3	990
	F	9	2	820
	F	10	2	830
Biacromial	M	2	5	250
	M	16	1	172
	M	32	1	170
	M	50	3	228
Bitrochanteric	M	4	1	146
	M	9	1	147
	M	24	5	181
	M	38	3	175
	M	50	1	145
	M	64	1	126
	F	4	1	150
	F	10	5	180
	F	23	5	188
	F	54	5	197
Foot length	M	42	4	147
	M	54	5	153
	F	53	3	136
Cubit	M	8	4	270
	M	56	1	185
	M	64	3	215
	F	3	2	225
	F	4	4	280
	F	6	1	194
	F	18	1	186
	F	23	4	256
	F	40	1	176