

# Evidence for X-Linkage of Tibial Length and Body Length

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**ABSTRACT** Sister-sister, brother-brother and sister-brother similarities in both tibial length and stature from one month through 10 years are in accord with the hypothesis of partial X-linkage, they reject the hypothesis of selective inactivation of an X chromosome, and they indicate that the complex that is body length is suited to simplistic analysis.

In a series of previous studies, we have provided growing evidence for least partial involvement of the X chromosome in a wide variety of developmental and dimensional events. The parameters include tooth size, both mesiodistal and buccolingual, tooth formation (i.e. calcification, root elongation and movement) and post-natal ossification timing, as shown by both parent-child and sibling intergenerational and intragenerational correlations (Garn and Rohmann, '62a, '62b, '66; Garn, Rohmann and Davis, '63; Garn, Kerewsky and Lewis, '66; Garn, Lewis and Kerewsky, '65a, '65b, '67; Garn and McCreery, '69; Garn, Rohmann and Hertzog, '69). These results have been confirmed in part by Lewis and Grainger ('67) and Goose ('67) for crown size in Canadian and British children, and they have been discussed, in part, by Acheson ('66) and Hunt ('66), among others.

In the present study we have extended the data design to include a single-bone measurement, that is the length of the tibial metaphysis, testing the assumption that genetic and chromosomal effects are more likely to be elucidated in single bones than in complexes involving bones of different types. Therefore, like-sexed and cross-sexed sibling comparisons are also included for the more conventional measurement of body length both as a comparison and to extend our studies on the possible involvement of the X chromosome in multiple size factors.

## MATERIALS AND METHODS

This study is based upon serial, longitudinal radiogrammetric and anthropometric measurements of like-sexed and unlike-sexed sibling pairs from one month of age (0.08 years) through 10.0 years. Comparisons are therefore entirely within family lines and at identical ages, throughout. Tibial length measurements were made as the maximum calcified length of the metaphysis, to the nearest 0.1 mm, on a Gerber Analog Data Reduction System (GADRS) with simultaneous card-punching and typewriter output. Bone length was measured as derived from the output and then computer-corrected for increasing radiographic enlargement due to enlargement of the lower leg in the course of growth. Body length, in turn, was measured as recumbent length through the seventh year and as standing height thereafter (cf. Garn and Shamir, '58).

Sister-sister, brother-brother and brother-sister correlations were then made by computer, using the IBM 1620 electronic calculator. Raw scores rather than normalized T-scores were employed throughout the correlational procedure since the distributions of both stature and tibial length were shown to be satisfactorily free from skewness and both approximated classical Gaussian distributions.

It should be observed that the serial, longitudinal approach employing like-sexed and cross-sexed siblings effectively elim-

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inates the ubiquitous problem of sampling possibly divergent gene pools. At the same time, it introduces an indeterminate sampling bias which is then repeated in each age-interval considered. Hence the age-for-age data are not independent events, and in the statistical analysis that follows, this potentiality is clearly recognized.

### Findings

As shown in the first table, sibling correlations for the length of the tibial metaphysis are systematically positive throughout and follow a consistent pattern. At all ages, from 0.08 years on, 23 sister-sister correlations exceed the comparable sister-brother correlations and in 21 out of 23 comparisons exceed brother-brother correlations as well. While these differences in tibial similarity are statistically significant by the stochastic Chi-squared test at any reasonable level of confidence, the data are best summarized as the mean value of  $r$  from the mean  $z$  transform of  $r$ . Here, the best estimate of the true magnitude of

sister-sister correlations is 0.71, the comparable pooled value of  $r$  for brother-brother correlations is 0.48 and that for sister-brother correlations is 0.42. Accordingly, sisters show systematically greater similarity in postnatal tibial development than either like-sexed brother-sister or cross-sexed brother-sister pairs.

Exactly the same correlational trend obtains for body length, i.e. recumbent length through 7 years and standing height thereafter. Without exception, sister-sister correlations exceed all 23 sister-brother correlations and, with but three exceptions, body length in sisters is more alike than body length in brothers. Here, mean values of  $r$  are 0.66 for sister-sister correlations, 0.52 for brother-brother correlations, and 0.47 for cross-sexed brother-sister sibling correlations. Overall, the mean values of  $r$ , obtained from the mean  $z$  transform of  $r$ , show exactly the same trends both for the single-bone roentgenogrammetric measurement and for the conventional anthropometric measurement. The comparable

TABLE 1  
*Extent of prepuberal sibling similarities and sex linkage in tibial length and body length*

Age	Tibial length						Body length					
	Sister-sister		Brother-brother		Sister-brother		Sister-sister		Brother-brother		Sister-brother	
(years)	N	$\bar{r}$	N	$\bar{r}$	N	$\bar{r}$	N	$\bar{r}$	N	$\bar{r}$	N	$\bar{r}$
0.08	19	0.399	49	0.435	76	0.135	62	0.463	73	0.447	141	0.274
0.25	19	0.404	42	0.202	64	0.229	65	0.562	72	0.464	152	0.376
0.50	28	0.563	60	0.493	94	0.437	75	0.519	73	0.436	156	0.351
0.75	25	0.553	40	0.553	67	0.253	68	0.477	68	0.519	145	0.357
1.0	31	0.616	53	0.522	92	0.347	74	0.538	74	0.494	154	0.393
1.5	21	0.490	38	0.459	55	0.282	72	0.489	67	0.512	146	0.369
2.0	28	0.661	43	0.537	80	0.375	66	0.622	70	0.504	147	0.391
2.5	23	0.606	27	0.500	50	0.438	68	0.582	66	0.493	136	0.472
3.0	28	0.671	54	0.559	80	0.477	63	0.622	70	0.680	137	0.467
3.5	19	0.695	32	0.562	52	0.407	58	0.653	66	0.583	126	0.532
4.0	31	0.694	51	0.553	79	0.481	61	0.673	63	0.613	123	0.503
4.5	16	0.585	29	0.526	44	0.406	55	0.719	70	0.598	117	0.569
5.0	30	0.594	53	0.535	78	0.431	53	0.730	68	0.573	116	0.539
5.5	15	0.748	28	0.501	38	0.587	50	0.737	70	0.517	111	0.565
6.0	34	0.766	60	0.388	82	0.534	51	0.765	70	0.571	123	0.556
6.5	30	0.783	43	0.405	65	0.500	49	0.744	66	0.534	113	0.524
7.0	34	0.826	50	0.516	76	0.469	52	0.697	67	0.508	114	0.463
7.5	31	0.828	43	0.458	66	0.471	51	0.755	63	0.535	109	0.503
8.0	30	0.783	54	0.488	70	0.321	47	0.739	62	0.501	102	0.526
8.5	29	0.879	32	0.510	55	0.453	41	0.724	64	0.517	100	0.514
9.0	28	0.896	42	0.399	57	0.518	43	0.723	62	0.495	102	0.494
9.5	20	0.868	26	0.328	43	0.483	42	0.710	60	0.458	93	0.449
10.0	24	0.807	48	0.433	56	0.506	40	0.714	60	0.452	90	0.466
Mean $r^1$		0.711		0.476		0.420		0.660		0.522		0.467

<sup>1</sup> From the mean  $z$  transform of  $r$ .

mean values of  $r$  are within  $\pm 0.05$ , throughout, and not systematically different in direction.

Accordingly, the totality of 138 age-specific, measurement-specific and pairing-specific length correlations, covering the period of 0.08 through 10 years, clearly indicates greater similarity of sisters as compared to brothers or brother-sister pairings, a finding that is consistent with the hypothesis of at least partial mediation of the X chromosome.

#### DISCUSSION

The findings in this particular study are particularly interesting in that they resolve an ancient debate. They show that, contrary to expectation, sister-sister, brother-brother and sister-brother similarities in tibial length and body length are rather similar. The tibial correlations and the stature correlations differ from each other by less than 0.05 on the average, and in no consistent direction. Thus, while the tibia is a single tubular bone and body length is a complex of 5 kinds of bones plus two fat pads (cf. Garn, '66) the two types of length measurements yield essentially similar results. Such a conclusion was also evident in our perinatal radiogrammetric comparisons of a decade ago (Garn, Greaney and Young, '56) and both give new confidence to intrapopulation comparisons using body length alone.

The findings also indicate that, from the first month on, sister-sister similarities exceed brother-brother similarities and these in turn exceed sister-brother similarities both for tibial length and for body length. Overall, these data are consistent with the hypothesis of partial X-mediation, a finding consistent with many other findings on both crown-size dimensions, tooth calcification, tooth movement, postnatal ossification timing, length of individual metacarpals and phalanges, metacarpal cortical thickness, and other developmental parameters. The 138 sex and age-specific correlations in the present study, add to nearly 1000 other correlations involving both sibling pairs and parent-child pairs, together tend to confirm the hypothesis of (partial) X-chromosomal mediation of developmental events. Either we have an

incredible "run" in the exact gambler's sense, or numerous parameters of size and development all attest to a major role of the X chromosome as shown by both sibling comparisons and parent-child similarities.

The fact that sister-sister similarities exceed brother-brother similarities in both tibial length and body length from one month through 10 years of age is similarly incompatible with the hypothesis of selective inactivation of the paternal X chromosome; if it were, sisters would not be dimensionally more similar than brothers. Selective inactivation of the maternal X in turn can not be rejected outright from these data (through it would tend to attenuate fraternal similarities), but such a likelihood is contraindicated by the greater relative variability of postnatal ossification timing in girls (cf. Garn and McCreery, '69).

Now the mechanism of X-linkage holds at least one micro-evolutionary potential in that intergenerational differences between males are then completely subject to random gene fluctuations. More explicitly, fathers and their sons are totally unrelated insofar as the genetic complement of their X chromosome is concerned. Under these circumstances, chance events could bring about relatively large intergenerational differences in males, as we have previously indicated for crown size (Garn, Lewis and Walenga, '68). Given the present evidence for at least partial involvement of the X chromosome in tibial length and stature, one might anticipate greater intergenerational differences in stature between fathers and sons than between mothers and their daughters. Furthermore, the effects of hybridization would then be greater for males in the first filial generation than for females in the first filial generation, a suggestion that is easily subject to test. Indeed, for dimensional traits that are largely or exclusively X-linked the effects of hybridization would, initially, be totally different for sons and daughters respectively.

Putting all of our data together, both dental and skeletal, dimensional and developmental, plus English and Canadian data on crown size, pairing siblings and

parents and their children, the classical assumption of at least partial mediation of the X chromosome appears to hold. This may be a function of the genes involved, thus allowing the possibility of either selective or random inactivation of other genes on the X chromosome. This may be a total-chromosome effect, of which we have some evidence in our intra-sibship similarities in the magnitude of sexual dimorphism. This could even be population-specific, allowing for the possibility of either random or selective inactivation of one or the other X chromosome in populations other than the one described here. The parsimonious explanation, however, is that of (partial) X-mediation of tibial lengths and body length as well as other diameters of bones and teeth and postnatal timing of dental development and of the bony nuclei of round bones, epiphyses of tubular bones and (even) of some primary centers.

#### ACKNOWLEDGMENTS

The authors acknowledge the invaluable assistance of Patricia S. Gindhart in setting up and executing the GADRS program for automated roentgenogrammetry and the assistance of Guido Wernicke and the Fels computer facility in completing the data analysis. This study was begun under Grant AM 03816 from the National Institutes of Health and completed under Grant AM 13378 to the Center for Human Growth and Development. Shirley M. Garrett assisted in the manuscript preparation.

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