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Radiographic Determination of Developmental Age in Fetuses and Stillborns

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ABSTRACT: The gestational age and/or viability of a fetus can become an important forensic issue. Several investigators have produced linear regression formulas based on crown-heel length (CHL), crown-rump length, or body diameters to determine gestational age. This study re-examines the relationship between fetal long bone length and CHL and tests a method of estimating CHL, and therefore gestational age, from radiographic measurements of the major long bone diaphyses. The results are compared with data based on dry bone measurements.

Data from 252 cases confirm a strong correlation between all long bone lengths and CHL ($\geq r = .9063$; $p < 0.01$). Long bone length means for each CHL group are presented, as well as regression formulas for estimating CHL from radiographic measurements of the long bone diaphyses. The findings correspond closely with results based on a European sample, thereby validating that reference population as a normative sample for fetal analysis in the United States. The radiographic method can be used in instances where skeletal preparation is impossible or undesirable.

KEYWORDS: forensic science, forensic anthropology, William R. Maples, fetal osteology, growth and development, radiography

Skeletal growth is used to assess vitality in both individuals and populations. Several studies provide standards of “normal” percentiles of growth for a given age (1,2). Similarly, assessment of skeletal development provides an indication of level of maturity. Standards based on appearance of ossification centers and/or bone morphology are used to assess “skeletal age” (3–6). Both types of developmental standards are used by physicians and other clinicians for growth assessment. They are also utilized by anthropologists in comparative studies and forensic work (7–11).

Estimation of developmental age of fetuses is used to predict the birth date, diagnose pathological conditions that affect growth, and provide data crucial to the timing of interventional healthcare decisions. In studies of skeletal populations, differentiation between infants and fetuses is an important factor in demographic reconstructions, providing clues about abortion rates, maternal deaths during childbirth, and early childhood disease (8–16).

Earlier studies utilizing radiography were abandoned because of the risk of radiation to the mother and fetus. Current methods of determining gestational age in living fetuses are based on sonographic imaging to determine head size, long bone length, or femoral cartilage diameter (17–19). Olivier and Pinneau (21,22) derived linear regression formulas based on CHL to estimate gestational age. These studies are currently used to determine the developmental age of intact, fleshed fetuses (17–19,21,22).

In the prenatal period, growth in length of long bones is almost linear and several standards have been established for both clinical and non-clinical applications (1,23–29). Most studies of fetal growth are conducted on fetuses aborted during the first 26 weeks of pregnancy (30,31). Greater sample size is possible because of an increased frequency of spontaneous and elective abortions during the first trimester of pregnancy.

The close correlation between fetal length (crown-heel length or crown-rump length) and long bone length to period of growth has been used to determine developmental age in both clinical and anthropological contexts. Most studies utilize crown-heel length (CHL) because that measurement has been found to contain less interobserver error than crown-rump length (32).

Despite extensive literature on growth of the fetus, we have yet to establish the extent of populational variation (33). We continue to use standards developed primarily from white, healthy populations in the United States and Europe. Clinical radiography and associated medical data present an opportunity to gather comparative data for a variety of populations.

The landmark study for calculating developmental age in bioarcheological and forensic contexts requires the measurement of dry bone (23). However, this sample represents a relatively homogenous eastern European population which may be inappropriate for use in determining developmental age for individuals belonging to the more genetically diverse population of contemporary America. Furthermore, the measurement of dry bone requires skeletal preparation and, in some cases, may be unnecessarily invasive. Huxley (34) recently addressed the problem of dry bone shrinkage, which may add an additional source of error.

This study establishes the correlation between radiographic lengths of the major long limb bones with CHL and explores the possibilities and pitfalls of determining developmental age from linear growth measurements. Results are compared with those of Fazekas and Kósa (23).

Materials and Methods

This study uses measurements of the long bones of the extremities taken from postmortem radiographs of spontaneously and therapeutically aborted fetuses delivered at Shands Medical Center, a tertiary-care center located on the University of Florida campus in Gainesville, Florida. The radiographs were initially used to aid in the determination of cause of death. Additional data were derived from medical records.

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Most of the cases were delivered in Gainesville, however, a small number of the autopsies were referrals from hospitals and clinics in the smaller communities surrounding the Gainesville area. It may be assumed, for purposes of comparative analysis, that all cases were delivered (and the vast majority of cases, underwent development) between sea-level and 50 m altitude. No socio-economic data were recorded in the autopsy records.

The total sample of fetuses ($n = 398$) was identified by sex. Males comprised 57.6% of the sample ($n = 227$), and females comprised 42.4% ($n = 167$). Four cases omitted the sex of the fetus, either because sex was ambiguous due to developmental anomalies, or the autopsy record had conflicting information and the actual sex of the specimen could not be determined by the investigator.

In each case, the "race" of the child was based on the "race" of the mother. It is customary for this data to be self-reported when admission records are completed by the mother or her representative. However, in some cases, it has been the personal observation of the author that "race" is often clinician-reported based on perceived phenotype. "Race" was recorded for 387 cases: The category "white" comprised 57.8% ($n = 230$); "black" was 40.7% ($n = 162$); and "other" was recorded 1.3% ($n = 5$).

Data were taken from cases meeting the following criteria: (1) both an autopsy record and radiograph exist; (2) at least one measurable long bone diaphysis is present; (3) no congenital skeletal abnormalities are detected by the author; and (4) the CHL was measured soon after death by the attending pathologist.

The radiographs were taken in a cabinet-type Hewlett-Packard Faxitron using unscreened Kodak EM-1 diagnostic mammography film. The film produces sharp images when used in unscreened cassettes (Fig. 1). X-ray intensity and exposure times were adjusted for maximum image quality. Examination of the radiographs under magnification demonstrates clear, distinct margins.

Each radiograph was assessed for proper positioning of the fetus. The fetuses were placed in a supine position with the extremities in anatomical position. Long bones positioned parallel to the film plane were measured with a transparent metric scale to within 0.5 mm to obtain maximum length. When possible, measurements were taken from both sides. When the measurements were unequal, the longest measurement was recorded. The radiographs were not marked to indicate the left and right side of the specimen.

The cases were arbitrarily clustered into 12 groups of CHL, and thus similar stage of development. The groups roughly correspond to gestational ages from 4 lunar months to post-term. Summary descriptive statistics are provided for the total sample and each CHL group. Bivariate regressions are via the least squares method.

Results and Discussion

Three-hundred and ninety-eight cases have both autopsy records and measurable radiographs. Of these, 252 cases have a recorded CHL and at least one measurable long bone diaphysis. These cases are subdivided into twelve CHL groups. The first ($<$210 mm) and last ($>$520 mm) CHL groups are excluded from this analysis because they contain an insufficient number of cases.

Mean long bone lengths are progressively greater with each successive CHL group, with the exception of the 420–449 and 450–489 groups. This discrepancy is caused by a sampling error for the femur, tibia, and fibula (Table 1). Relative lengths for the other bones are affected as well. The error is most likely the result of a single case in which the CHL recorded in the autopsy protocol was significantly shorter than the actual CHL measurement.

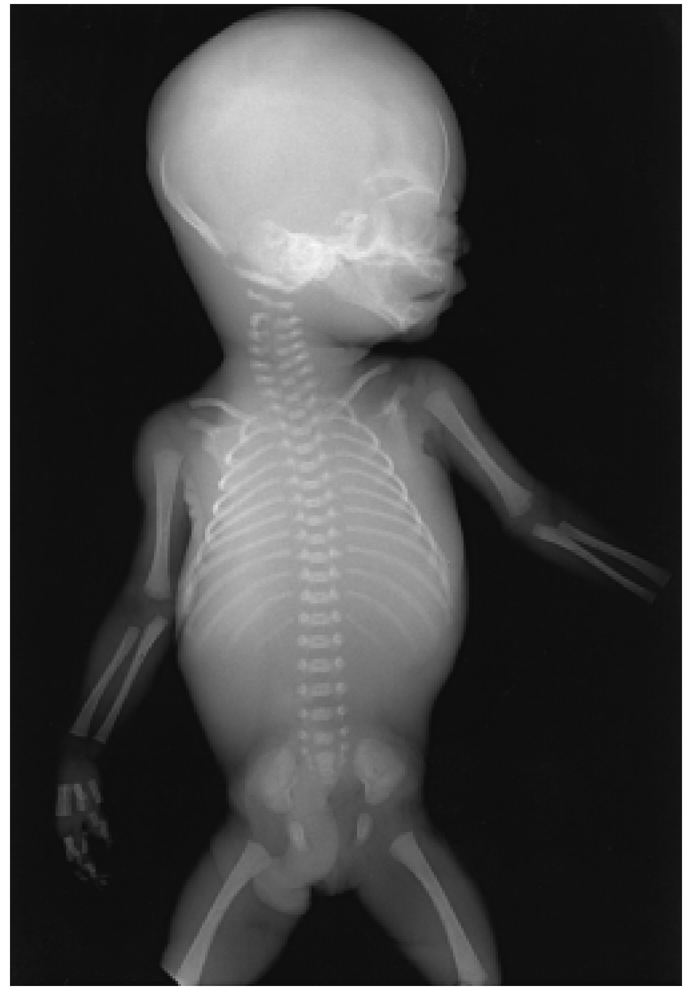

FIG. 1—*A typical fetal radiograph.*

Long bone diaphyseal lengths are found to correlate significantly with CHL ($r^2 \geq 0.8375$; $p < 0.01$). This correlation is consistent with that found between adult long bone length and stature (35,36). Least-squares linear regression produces the following formulas for predicting CHL from radiographic bone lengths:

$$\text{CHL} = 45.571 + (\text{humerus})6.839 \pm 7.704$$
$$\text{CHL} = 47.886 + (\text{radius})8.196 \pm 8.696$$
$$\text{CHL} = 51.642 + (\text{ulna})7.193 \pm 8.097$$
$$\text{CHL} = 90.835 + (\text{femur})5.188 \pm 7.866$$
$$\text{CHL} = 82.858 + (\text{tibia})6.308 \pm 8.351$$
$$\text{CHL} = 79.677 + (\text{fibula})6.896 \pm 9.948$$

Techniques for determining the gestational age of fetal or perinatal remains are designed to calculate the time since conception. However, in most cases, the time of conception cannot be known with certainty. Many studies calculate gestational age based on the mother's last normal menstrual period (LNMP) with the assumption that ovulation and conception occur during a specific time in the menstrual cycle, usually cited as either within one week of the last menstrual period, or at the mid-point of the cycle. This assumption may lead to an error of as much as two weeks (38). Additionally, errors in reporting occur, such as when implantation bleeding is mistaken for the last menstrual period. Even in cases of

TABLE 1—*Long bone diaphyseal lengths (mm): Mean length and standard deviations from the mean (S.D.).*

	Humerus		Radius		Ulna		Femur		Tibia		Fibula	
CHL Group	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
210–239	27.85	2.46	23.50	2.05	26.00	2.15	28.60	2.66	24.80	2.66	24.38	2.55
240–269	33.18	4.90	26.93	3.92	30.14	4.58	35.38	5.65	29.08	3.09	28.08	2.75
270–299	36.50	2.78	30.52	3.02	33.78	2.67	39.00	3.59	33.09	2.96	31.48	2.92
300–329	39.11	3.40	32.29	2.92	36.33	3.21	42.71	4.61	35.23	3.43	33.17	3.52
330–359	43.21	3.09	35.50	2.47	40.15	2.74	47.40	3.90	40.28	3.24	38.02	3.19
360–389	46.87	2.73	39.00	2.60	43.75	2.47	51.42	2.99	44.05	2.48	41.72	2.33
390–419	53.36	5.35	44.56	4.85	50.38	5.92	61.19	6.92	54.22	4.86	51.21	4.40
420–449	56.14	2.92	45.82	2.69	51.50	2.55	65.33	6.22	54.33	5.69	51.00	4.44
450–479	58.28	5.81	47.62	5.74	54.04	6.43	64.67	8.26	53.00	7.57	49.75	7.37
480–520	64.02	5.07	52.24	2.68	59.37	2.84	74.20	7.56	62.60	5.59	58.38	5.79

isolated coitus, fertilization may not take place immediately and one must rely on the history provided by the mother (39,40).

The possibility of miscalculating gestational age presents a problem for growth and development studies. Several methods have been used to omit infants that are older than their calculated gestational age. Authors have excluded outliers in bimodal curves and scattergrams (41,42), used maternal examinations and histories (24,43), or considered clinical tests of a neonate's maturity (24,41–43) in order to establish the validity of gestational ages based on LNMP. Exclusion of fetuses and infants that are younger than their calculated gestational age is more problematic. Isolated cases may be growth retarded but present no other signs of pathology. Manipulation of data in order to arrive at "valid" gestational ages is a circular process and data are excluded that would broaden the variability of normal fetal growth.

Numerous studies (21–22,44–47) confirm the correlation between the duration of pregnancy and the development of the fetus. The preponderance of data using estimated time of conception based on different criteria suggest that there is a close correlation between linear length and gestational age. Fazekas and Kósa (23) group their fetal sample on the basis of body length, not "period of pregnancy," because of their inability to determine the exact time of conception. They use Haase's Rule, which they believe has been shown to be accurate (45,46,48) when compared with gestational age based on LNMP. By means of Haase's Rule, the age of the fetus can be determined from its body length. Fetal body length in centimeters can be closely estimated until the 5th lunar month by squaring the number of the months of pregnancy, and after this time by multiplying the months by 5 (23,47).

Brock (47) published data on how values of the body length of fetuses of "known" gestational age correspond to those obtained by Haase's rule. For comparison, Brock used the data of Dietrich (45), and Scammon and Calkins (46). Table 2 shows how closely the actual data and the values obtained by Haase's calculation correspond (23).

Fazekas and Kósa (23) divide their data into groups as follows: Fetuses 40 cm long are included in the age group of 8 lunar months. In the same group are fetuses 39 and 41 cm long, whereas those with a body length of 42 and 43 cm (born at the beginning of the 9th lunar month) are included in the age group of 8.5 lunar months. So, lunar months are classified by the fetal lengths listed in Table 3.

I compare relative long bone lengths with those of Fazekas and Kósa (37) by assuming the validity of the relationship between fetal length and gestational age. Table 4 lists mean humeral lengths by gestational age, as derived from the respective regression for-

TABLE 2—*Fazekas and Kósa's (1978; Table 8, p. 31): Growth in crown-heel length in cm with respect to fetal age (in lunar months).*

Period of Pregnancy in Lunar Months	(Dietrich, 1925)	(Scammon & Calkins, 1929)	Haase's Rule
2	3.0	. . .	4
3	9.8	7.0	9
4	18.0	15.5	16
5	25.0	22.7	25
6	31.5	29.2	30
7	37.1	35.0	35
8	42.5	40.4	40
9	47.0	45.4	45
10	50.0	50.2	50

TABLE 3—*Months of gestation and equivalent CHL (based on Fazekas and Kósa, 1978).*

Months of Gestation	Equivalent CHL Length
5 lunar months	24–26 cm
5½ lunar months	27–28 cm
6 lunar months	29–31 cm
6½ lunar months	32–33 cm
7 lunar months	34–36 cm
7½ lunar months	37–38 cm
8 lunar months	39–41 cm
8½ lunar months	42–43 cm
9 lunar months	44–46 cm
9½ lunar months	47–48 cm
10 lunar months	49–51 cm

TABLE 4—*Mean humerus lengths for approximate gestational age in weeks as reported by Warren (current study) and Fazekas and Kósa (1978).*

Weeks Gestation	Warren (Current study)	Fazekas and Kósa
28–30	46.87	45.00
30–34	53.36	50.40
34–36	56.14	54.30
36–38	58.28	58.40
38–40	64.02	63.10

TABLE 5—*Long bone diaphyseal lengths (mm) for Fazeka and Kosa (1978): Mean length and standard deviations from the mean (S.D.).*

	Humerus		Radius		Ulna		Femur		Tibia		Fibula	
CHL Group	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
210–239	25.91	1.43	21.51	1.21	23.91	1.59	26.48	1.55	23.37	1.91	22.54	1.83
240–269	32.08	1.70	26.50	1.61	29.86	1.89	32.86	1.99	28.86	2.16	28.14	2.28
270–299	34.31	1.38	28.61	1.92	31.46	1.39	35.55	2.22	32.33	3.13	30.74	2.36
300–329	38.33	2.81	32.20	2.05	35.61	2.45	40.98	2.99	36.39	2.87	34.93	2.81
330–359	42.19	2.57	34.59	1.91	38.95	1.96	44.43	3.17	39.96	2.10	38.31	2.29
360–389	45.59	2.34	37.60	1.72	42.32	2.20	48.60	2.32	43.73	1.89	42.28	2.22
390–419	50.56	1.84	41.09	1.88	47.06	2.55	55.78	1.92	49.03	2.42	47.21	2.73
420–449	53.59	1.97	43.33	1.29	49.49	1.65	60.09	2.92	53.16	2.30	50.66	1.88
450–479	55.52	2.58	45.80	2.14	51.28	2.55	62.52	2.95	54.70	2.96	51.62	2.77
480–520	61.91	3.07	49.84	1.99	57.23	2.10	71.60	4.06	62.27	3.29	59.46	2.75

mulas of both studies. On visual inspection, the relative length of the long bones in individuals of the Fazekas and Kósa (23) sample correspond closely with the current data. Only data for the humerus are shown, however, the formulae produce similar results for the other long bones.

The data from the current study is better compared with that of Fazekas and Kósa (23,37) by converting their raw data into CHL groups. Table 5 lists mean long bone lengths by CHL group for the Fazekas and Kósa sample. A Student's *t*-test performed on a random sub-sample of the data, matching cases with equal CHL, shows that there are no significant differences in proportions between the 2 populations, with the exception of the femur, which is significant at the $p = 0.05$ level ($p = 0.0433$). The similarity of the 2 populations in proportionality is somewhat surprising given the genetic diversity of the American sample. The overall slightly longer limb lengths of the current sample for corresponding CHL groups is most likely a product of slight radiographic magnification error, dry bone shrinkage in the Fazekas and Kósa (23) sample, or both.

Both methods of comparison show that Fazekas and Kósa's eastern European data are valid for determining the CHL of fetal skeletal remains in the United States. Gestational age may then be determined by using prior studies to calculate gestational age based on CHL. Results obtained by the radiographic method correspond with the dry bone measurements of Fazekas and Kósa and, therefore, the method can be used in instances where skeletal preparation is undesirable or impossible.

Conclusions and Summary

Measurements of the six major long bones of the extremities are taken from a series of fetal radiographs. Additional data are collected from associated autopsy records. I divide the sample arbitrarily into groups of similar CHL, and thus, similar developmental age, in order to assess the relative growth and proportionality of the limb bones.

All long bones correlate significantly with CHL ($r^2 \geq 0.8375$; $p < 0.05$). This relationship is consistent with the relationship of adult long bones to stature (35,36). I provide least-squares linear regression formulas for predicting CHL from radiographic bone lengths. Gestational age may then be determined using one of several studies relating CHL to period of pregnancy. The data correspond closely with that of Fazekas and Kósa (23). This shows that relative linear growth and proportionality is similar between the two samples. The radiographic method of long bone measurement may be used when skeletal preparation is impossible or undesirable.

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