TECHNICAL NOTE

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Analysis of Shrinkage in Human Fetal Diaphyseal Lengths from Fresh to Dry Bone Using Petersohn and Köhler's Data

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ABSTRACT: Calculation of gestational age from forensic fetal remains may be problematic. If soft-tissue indicators are not available, then diaphyseal lengths obtained through sonograms on living fetuses *in utero* or radiographs of long bones can be compared to known European standards, such as Fazekas and Kósa (1978) and Olivier and Pineau (1958, 1960). Radiographic comparison to these European standards, however, requires a correction factor for diaphyseal shrinkage from fresh to dry states. Percent shrinkage is calculated for six diaphyses (humerus, ulna, radius, femur, tibia and fibula) from Petersohn and Köhler's data published in Fazekas and Kósa (1978:362–369). Average shrinkage, standard deviation, minimum and maximum values are calculated for each diaphysis and for all diaphyses during 4–10 lunar months (LM) and newborns. Corresponding average and standard deviation values are as follows: 4 LM-10.09% ± 2.67%; 5 LM-5.74% ± 0.84%; 6 LM-3.48% ± 0.49%; 7 LM-2.32% ± 0.16%; 8 LM-2.18% ± 0.51%; 9 LM-1.76% ± 0.14%; 10 LM-1.90% ± 0.59%; and newborns-1.28% ± 0.55%. Analysis of these values suggests that percent shrinkage steadily declines as the fetus ages. This pattern presumably reflects calcification of bone during growth and development *in utero*. These findings demonstrate a significant shrinkage in the diaphysis early in development, which may alter accurate age estimation in the earliest fetal age groups.

KEYWORDS: forensic science, forensic fetal osteology, diaphyseal lengths, diaphyseal shrinkage, Petersohn and Köhler, ossification, forensic anthropology

Forensic specialists are sometimes required to determine gestational age from complete or partial fetal remains, thus dictating analytical procedures. In some instances, remains may be submitted to the medical examiner's office in less than perfect condition, such as in macerated, decomposed, mummified or skeletonized states. While the diaphyses from these cases can be directly compared to more traditional sources, such as Fazekas and Kósa (1) and Olivier and Pineau (2,3), they cannot be directly compared to modern sonographic data available in the medical literature (4–6), since postmortem shrinkage of hard and soft tissues may alter accurate gestational age determination.

This purpose of this study is to account for postmortem shrinkage that occurs during desiccation of organic matrix of bone. Petersohn and Köhler (7) measured diaphyseal lengths from fresh to dry, carbonized and calcined states for 490 fetal and newborn bones. Their data, as presented in tabular form in Fazekas and Kósa's Forensic Fetal Osteology (1), are analyzed by one month lunar age groups for fetuses ranging from 4–10 lunar months and newborns for six diaphyses—the humerus, radius, ulna, femur, tibia and fibula—from fresh to dry states.

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Materials and Methods

The article by Petersohn and Köhler (7) is not readily available and Fazekas and Kósa (1) do not address the methodology employed by these researchers. It is presumed, therefore, that these fetuses were of European ancestry, and the number of fetuses may or may not be indicated by the number of diaphyses present. Since Petersohn and Köhler apparently analyzed diaphyses from both right and left sides of the body, it is unclear whether bones from a single side or from both sides were listed in the data. Moreover, according to these same tables (1), Petersohn and Köhler presumably used fetal remains that were incomplete or partial in nature. For instance, a variable number of diaphyses were used, ranging from 49 fibulae to 99 humeri.

These data were entered into Foxpro for Windows, Microsoft Corporation, Version 2.6, 1985–1994, and shrinkage rates, for each bone, were calculated by means of the following formula: For each fetal bone the value for dry bone length (D) is subtracted from the corresponding value for fresh bone length (F) to account for overall shrinkage. The value obtained for overall shrinkage is divided by the fresh bone length (F) and multiplied by 100 to derive percent shrinkage (F-D/F × 100 = percent shrinkage). Then, for each lunar age group, the mean percent shrinkage, standard deviation, minimum and maximum percent shrinkage for each diaphysis is calculated (Tables 1–6).

Results

An analysis of Petersohn and Köhler's data suggests that percent shrinkage varies by skeletal element and by age cell. These values are calculated for each of the six diaphyses during the course of fetal development *in utero* and in newborns. Analysis of these data demonstrates that average values generally decline with age for each bone, while minimum and maximum values fluctuate greatly by associated sample size, lunar age and diaphysis (Tables 1–6).

A comparison of average percent shrinkage with associated sample size (n) by skeletal element and lunar age group is presented

TABLE 1—*Humeral shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	6	9.13	2.18	5.91	11.65
5 LM	47	5.39	2.85	1.68	15.91
6 LM	14	3.37	1.00	2.21	5.13
7 LM	8	2.24	0.51	1.41	3.03
8 LM	4	1.45	1.36	0.02	2.62
9 LM	6	1.68	0.40	1.23	2.16
10 LM	12	1.75	0.65	0.49	2.43
Newborn	2	2.03	0.94	1.36	2.69

TABLE 2—*Ulnar shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	3	9.23	0.52	8.80	9.81
5 LM	31	5.65	2.28	2.35	11.26
6 LM	9	3.46	1.14	2.08	6.58
7 LM	7	2.25	0.57	1.43	3.12
8 LM	4	2.21	0.48	1.59	2.70
9 LM	5	1.82	0.37	1.24	2.28
10 LM	11	3.09	4.48	0.51	2.20
Newborn	2	1.06	0.01	1.05	1.64

TABLE 3—*Radial shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	3	9.73	2.76	10.08	12.30
5 LM	37	5.79	2.36	1.76	9.96
6 LM	14	4.30	1.46	1.95	7.17
7 LM	6	2.40	0.75	1.46	3.24
8 LM	4	2.41	0.13	2.31	2.59
9 LM	6	1.90	0.81	1.26	3.40
10 LM	12	1.70	0.48	1.04	2.28
Newborn	2	0.39	0.11	0.31	0.46

TABLE 4—*Femoral shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	6	13.85	4.33	6.33	18.30
5 LM	44	4.59	2.48	0.30	10.96
6 LM	14	3.56	1.06	2.13	5.19
7 LM	8	2.46	0.71	1.26	3.43
8 LM	4	2.28	0.55	1.79	2.66
9 LM	6	1.67	1.23	0.85	1.71
10 LM	10	1.72	0.55	0.53	2.40
Newborn	1	1.48	0.00	1.48	1.48

TABLE 5—*Tibial shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	3	12.35	2.60	9.45	14.46
5 LM	44	5.82	2.41	2.56	12.57
6 LM	14	3.44	1.53	1.50	6.72
7 LM	8	2.51	0.80	1.48	4.20
8 LM	4	2.93	0.80	2.07	3.63
9 LM	6	1.94	0.78	1.04	3.15
10 LM	12	1.69	0.75	0.68	2.24
Newborn	2	1.19	0.06	1.15	1.23

TABLE 6—*Fibular shrinkage rates for fetuses between 4–10 lunar months and newborns.*

	Sample Size	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	1	6.27	0.00	6.27	6.27
5 LM	16	7.18	2.21	2.91	10.11
6 LM	7	2.77	1.73	0.76	5.64
7 LM	3	2.07	0.37	1.71	2.44
8 LM	4	1.82	0.77	1.29	2.96
9 LM	6	1.59	0.56	1.04	2.66
10 LM	10	1.46	0.36	0.71	1.92
Newborn	2	1.52	0.23	1.35	1.68

in Table 7. These results demonstrate that percent shrinkage varies between 6.27%–13.85% for all six diaphyses during the fourth fetal lunar month and steadily decreases to 0.39%–2.03% in the newborn age cells. These changes are represented graphically by Fig. 1, where lunar age corresponds to the x-axis (newborn diaphyseal lengths are graphed at 10.5 lunar months) and percent shrinkage corresponds to the y-axis.

The average values recorded in Table 7 for all six diaphyses are averaged to obtain a percent shrinkage for all diaphyses in all lunar age groups (see Table 8). In the fourth fetal month, shrinkage rates average 10.09% ± 2.67%, with a range from 6.27% in the fibula to 13.85% in the femur. By the fifth fetal month, the average percent shrinkage is nearly half that of the fourth, 5.74% ± 0.84%, and the range is not as variable, 4.59% to 7.18%. Similar decreases are noted in the sixth fetal month, with the average nearly half that of the previous month, 3.48% ± 0.49%, and the range more confined, 2.77% to 4.30%. The seventh and eighth fetal months are similar to each other, 2.32% and 2.18%, and the ranges remain limited, 1.45% and 2.93%. Average shrinkage during the ninth and tenth lunar months is also similar, 1.76% and 1.90%, with more limited ranges of 1.46% and 3.09%, respectively. Finally, minimal shrinkage is noted in newborns, whose diaphyses shrank an average 1.28% ± 0.55% and range from 0.39% to 2.03% (see Table 8).

Discussion

The diaphyseal shrinkage rates discussed above are a direct reflection of the loss of water and organic matrix, such as hyaline connective tissue, through desiccation. Shrinkage, therefore, is related to the process of ossification *in utero*. Formation of the bony collar marks the initiation of endochondral ossification from

TABLE 7—*Comparison of shrinkage rates by skeletal element for fetuses ranging between 4–10 lunar months (LM) and newborns.*

	4 LM	5 LM	6 LM	7 LM	8 LM	9 LM	10 LM	Newborn
Humerus	9.13% (6)	5.39% (47)	3.37% (14)	2.24% (8)	1.45% (4)	1.68% (6)	1.75% (12)	2.03% (2)
Radius	9.73% (3)	5.79% (37)	4.30% (14)	2.40% (6)	2.41% (4)	1.90% (6)	1.70% (12)	0.39% (2)
Ulna	9.23% (3)	5.65% (31)	3.46% (9)	2.25% (7)	2.21% (4)	1.82% (5)	3.09% (11)	1.06% (2)
Femur	13.85% (6)	4.59% (44)	3.56% (14)	2.46% (8)	2.28% (4)	1.67% (6)	1.72% (10)	1.48% (1)
Tibia	12.35% (3)	5.82% (44)	3.44% (14)	2.51% (8)	2.93% (4)	1.94% (6)	1.69% (12)	1.19% (2)
Fibula	6.27% (1)	7.18% (16)	2.77% (7)	2.07% (3)	1.82% (4)	1.59% (6)	1.46% (10)	1.52% (2)

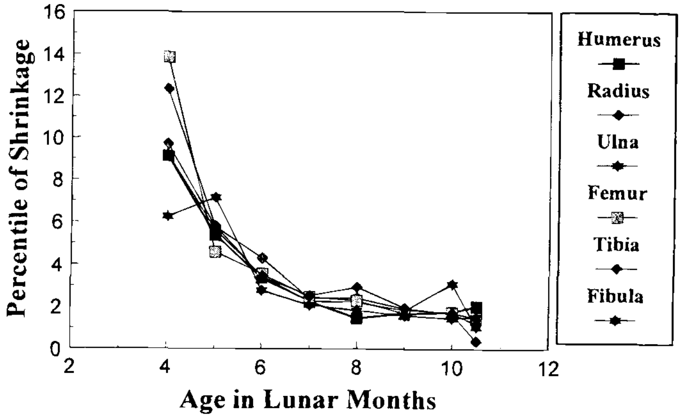

FIG. 1—*Comparison of diaphyseal shrinkage rates.*

the cartilaginous precursor. According to Mall (8), ossification occurs as early as 42 days in the humeri and femora, as late as 55 days in the fibulae. Once the diaphyses have formed, deposition of hydroxyapatite crystals and other calcium salts occurs in the zone of calcified cartilage within the metaphysis. With increasing gestational age, a decreasing ratio of organic to inorganic matrix occurs. This exchange of organic matrix for inorganic matrix was demonstrated by Felts (9), who stated that decreased growth is best represented by a hyperbola. In this regression formulae ($y = 2.080X^{-.395} \pm 8.17$), x represents the length of the ossified shaft and y is the combined length of cartilage as a proportion to the total length of the shaft. Even with this type of growth pattern, the shrinkage rates are not constant by length and diameter or by lunar age group, but rather more variable in slope.

According to Fazekas and Kósa (1), Petersohn and Köhler noted two general principles in their analysis: decrease in length of the diaphysis is inversely proportional to increase in lunar age of the fetus; and decrease in length may differ in homologous bone from the same fetus. The first principle is confirmed in this study, but the second principle cannot be corroborated since Fazekas and Kósa did not publish the tabular data by side of the body, and analysis of shrinkage within a given fetus is not possible at this time. In many respects, but especially in regard to shrinkage rates, Fazekas and Kósa's interpretation of Petersohn and Köhler's data does not match those in this paper. These differences were not accounted for since the original German source has only recently become available (Courtesy of Dr. Kosa).

TABLE 8—*Combined diaphyseal shrinkage rates by 4–10 lunar months and newborns.*

	Diaphyseal Samples	Average Shrinkage, %	Standard Deviation, %	Minimum Value, %	Maximum Value, %
4 LM	1–6	10.09	2.67	6.27	13.85
5 LM	16–47	5.74	0.84	4.59	7.18
6 LM	7–14	3.48	0.49	2.77	4.30
7 LM	3–8	2.32	0.16	2.07	2.51
8 LM	4	2.18	0.51	1.45	2.93
9 LM	5–6	1.76	0.14	1.59	1.94
10 LM	10–12	1.90	0.59	1.46	3.09
Newborn	1–2	1.28	0.55	0.39	2.03

Conclusion

The analysis of Petersohn and Köhler's data on diaphyseal shrinkage from fresh to dry bone published in Fazekas and Kósa (1) is useful to forensic specialists who must deal with shrinkage in fetal remains submitted in less than pristine conditions. While a brief analysis of the original findings are published in Fazekas and Kósa, it is not systematic in coverage by skeletal element and age group. Furthermore, the original published article is not easily accessible in the United States and remains generally unavailable to Western scholars.

Two techniques are generally used to calculate gestational age from forensic fetal remains: comparison to dry bone length using traditional sources, such as Fazekas and Kósa (1) and Olivier and Pineau (2,3); and comparison to sonography data from the medical literature (4–6). With the first technique, the loss of organic matrix from fresh to dry bone causes shrinkage in the overall length and diameter of the diaphysis, the extent of which varies by the lunar age of the fetus and the diaphysis in question. Correction for shrinkage is especially necessary in the earlier lunar age groups, where rates can vary between 6.27%–13.85%; it becomes less of an issue in older lunar age groups, where rates range between 0.39%–2.03%. With the second technique, if the fetal remains are in poor condition, then adjustments for shrinkage also need to be made before comparison to sonography data.

Acknowledgments

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ERRATUM

A typesetting error in a regression formula appeared on page 425 of: Huxley AK. Analysis of shrinkage in human fetal diaphyseal lengths from fresh to dry bone using Petersohn and Köhler's data. J Forensic Sci 1998 Mar; 43(2): 423–426. The error appears at line 10, left column, page 425.

''In this regression formulae ($y = 2.080\times^{-}$✂$^{395} \pm 8.17$), x represents the length of the ossified shaft ....'' should be corrected to read

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