Chapter 9

FORENSIC ASPECTS OF FETAL AND NEONATAL SKELETONS

DAVID S. WEAVER

INTRODUCTION

Unfortunately, most osteology and forensic osteology training does not do a very good job of teaching students about fetal and neonatal remains, often because of a lack of suitable teaching specimens, or because of instructor unfamiliarity with fetal and neonatal remains. Although a good deal of recent work exists, the forensic identification of fetal and neonatal human skeletal remains lags far behind that concerning adult and subadult remains. Many reviews of forensic techniques (Kerley, 1978a; Bass, 1969, 1987; Stewart, 1979; Steele & Bramblett, 1988; White, 1991; but see Bang, 1989; Iscan, 1989; Kosa, 1989; Ubelaker, 1989a; 1989b:52–53; Rhine, 1995) give little consideration to fetal and neonatal remains. In part, this may be because of a conviction that there will be little profit in studies of fetal and neonatal material (Schultz, 1923; Ubelaker, 1978; Stewart, 1979; *J. Hum. Evol.*, 1980). While that conviction has a rational basis in that it is unlikely that most identification criteria developed for use on older material will be directly applicable to the youngest material, there are reasons to expect that forensic identification of fetal and neonatal material has greater promise than is often allowed. Sexual differentiation begins at least as early as the tenth fetal week and may be of comparable relative magnitude to the more well-known differentiation that takes place at puberty. There are known sexual differences in rates of skeletal and dental maturation in children and adolescents. A few studies have suggested sexual differences in fetuses and neonates in the innominates, the cranial base, and the postcranial skeleton. As in all forensic analysis, there may be large variability in the emergence and development of the various analytic characteristics. Inasmuch as many of the studies that are used are based in small original samples without consideration of race, sex, or the other factors that introduce uncertainty into analysis, any conclusions for forensic work should be tempered with appropriate caution.

Aging criteria for fetal and neonatal skeletal remains are much better developed than are the criteria for sexing. Standards of skeletal ossification, long bone diaphyseal development, and dental development are in common use and will be outlined in this chapter. This chapter will focus on the identification of fetuses and neonates of less than one month postpartum chronological age.

The paucity of forensic identification criteria for application to fetal and neonatal remains is particularly problematic, in that there will typically be no other means of identifying the remains. Fetuses and neonates seldom are accompanied by identification of any type.

Fetal and neonatal skeletal material is even more subject to the vagaries of recognition and recovery than that of more mature individuals. At a given age the fetal skeleton is represented by hundreds of separate bones, with many of the epiphyses and bone segments presenting shapes and forms that could prove nearly unrecognizable to an observer who had been trained using only adult skeletal material. In general, the field work techniques and approaches of Skinner and Lazenby (1983) or Morse et al. (1983) will be useful guides to field recovery techniques. Also, Krogman and Iscan recommend using a series of screens to ensure recovery of the small bones, ending with a 1/8-inch mesh (1986:18). The only intact fetal bones that might then escape detection and recovery would be the smallest of the sesamoids, which are of unknown, probably minimal forensic significance. Fetal human bones can be confused, sometimes even by experienced investigators, with those of other animals, even when the skeleton is well represented. In archeological projects, the long bones of turtles, puppies, other mammals and even birds may be confused with human fetal bones. The presence of a cranium will usually prevent that confusion, of course. Add to this situation the reduced likelihood of adequate preservation, due to the fragility of the fetal and neonatal bones, and it becomes clear that exceptional care is required to discover, recover and analyze the skeletons. As a summary of field recovery techniques, Rhine's (1995) excellent discussion on recovery of fetal remains is an important resource for forensic practitioners. Finally, the data collection protocol and procedures provided in Buikstra and Ubelaker (1994) are highly recommended (with available companion computer data base software) as a standard for skeletal data collection, and the comments of Galloway et al. (1990) concerning case handling, analysis and reporting should be kept in mind.

THE MATURATION OF THE FETUS AND THE NEONATE

The skeletal maturation of the fetus and the neonate proceeds from the formation of cartilage models through the ossification of bony centers, to the completion of the bone itself. The ossification of the skeleton begins by the sixth fetal week (Birkbeck, 1976; Valdes-Dapena, 1979). Sexual differentiation begins at least by the eighth fetal week, with the onset of appreciable levels of testosterone in the male (Challis et al., 1976). By full term, testosterone levels in males drop from a high at about the fifteenth fetal week to minimal concentrations, paralleling estrogen levels in female fetuses (Grumbach & Kaplan, 1974). Ossification of each skeletal element proceeds at a bone specific, usually regular, rate, in keeping with the regular linear growth rates observed in fetal body weight and gross linear dimensions.

An argument can be made that, except for some slight deceleration in growth near term, neonates should be thought of as representing the end of the fetal growth pattern (Krogman 1972). The neonate has not, at birth, yet been required to respond to extrauterine forces to any great degree. Shortly after birth, infants embark on a somewhat slowed growth progression, characterized by a lessened slope of incremental growth (Falkner, 1977).

It is nearly certain that nutrition and disease have effects on fetal skeletal and, to a lesser extent, dental development, although few careful, controlled studies are available quantifying these growth effects (see Johnston, 1978, 1980; Angel, 1982).

AGING CRITERIA

Skeletal aging criteria at these early chronological ages depend on the observation of highly linear growth rates (Falkner, 1977). Dental aging depends on a similar set of linear assumptions, complicated by the observation of distinct rates of development for each deciduous and permanent tooth type (see Brand & Isselhard, 1990). Most of the aging criteria have been developed using radiographic data, usually from survey populations (Roche, 1978). Many of the radiographic observations have been converted for use on dry bone and may, therefore, be useful for forensic skeletal work. Corrections for radiographic scale differences and distortions tend to be specific to the methods used, but the need to convert radiographic observations before using them to evaluate dry bone remains a problem. Several investigators have created measurement series that are applicable to fetal and neonatal remains, including Schultz (1923, 1929), Fazekas and Kosa (1978) and Kosa (1989). Shrinkage of dry bones is not a severe difficulty when measuring such small bones as are found in fetal and neonatal individuals (Fazekas & Kosa, 1978:42).

A number of observations published concerning the maturation of the cranium have forensic applications. The size and closure of the various cranial fontanelles provides a rough estimate of skeletal age. The closure of any of the fontanelles is presumptive evidence of an infant or child, rather than a fetus or a neonate (Stewart, 1979). Likewise, the closure of the metopic suture of the frontal bone may distinguish a neonate from a fetus, but closure of any of the other cranial sutures indicates an older skeleton than those under consideration in this chapter. The size and thickness of the frontal, parietal, occipital, and temporal bones, when compared to crown rump length, led Ohtsuki (1977) to generate a series of plots that could be used, with caution, to estimate skeletal age. Crown rump length is well correlated with fetal chronological age (Stewart, 1979), and the logarithmic plots of bone thickness, vertical arc, and transverse arc can be read for crown rump length and thereby for chronological age. In a later paper, Ohtsuki (1980) digitized the area of the parietal bone and created highly significant linear plots of bone area for fetal age and for crown rump length. Redfield (1970) demonstrated a sequence for the maturation of the occipital bone that could be applied to fetal and neonatal skeletal remains. Unfortunately, as is often the case, the ages of most of the subjects in Redfield's study had to be estimated using other skeletal and dental criteria, introducing additional uncertainty. The small series of known-age individuals Redfield used to corroborate his attribution of fetal age to his larger sample shows the same sort of linear growth pattern as other studies of fetal growth, suggesting that his data may be reliable.

The ossification of the fetal skull has been well described (Mauser et al., 1975; Israel, 1978). The nasal, lacrimal, frontal, vomer, palatine, maxilla, premaxilla, zygoma, parietal, and mandibular bones all develop from intramembranous models between the sixth and ninth fetal weeks. The ethmoid and inferior conchae ossify with endochondral centers during the sixteenth to eighteenth fetal weeks. The temporal, sphenoid, and occipital bones are substantially more complex, ossifying from both intramembranous and endochondral centers at varying times. The occipital ossifies from both the intramembranous and endochondral centers during the sixth to eighth fetal weeks. The greater wing and pterygoid plate of the sphenoid ossify from membranous centers during the eighth week, while the presphenoid, basisphenoid, and the lesser wing ossify endochondrally during the ninth, twelfth or later, and twelfth weeks, respectively.

The temporal bone follows a complex ossification sequence. The petromastoid and the styloid process appear at twenty-two weeks and birth, respectively. The squama and the tympanic ring appear during the eighth and ninth fetal week. The tympanic ring fuses to the petromastoid portion by birth, and closure of the ring to form the tympanic plate proceeds throughout infancy and early childhood (Anderson, 1960; Weaver, 1979; Curran & Weaver, 1982).

Dental aging standards are more useful for infants and children than for fetal and neonatal individuals, in that the dentition is typically not erupted at birth. There is a long history of studies of dental development and maturation, however; though the studies usually involved relatively small samples, limiting our understanding of variability in calcification and development of the deciduous dentition. The pioneering studies of Kronfeld (1935), Schour and Massler (1941), and Meredith (1946) are among the many studies that attempted to establish the sequence and timing of the deciduous dentition. A few generalizations from that extensive early research stand to this day. First, it remains extremely rare to find an infant under six months of age with erupted dentition, and the first teeth to emerge are the deciduous medial incisors. Second, the permanent dentition has almost never begun calcification before birth, although the first molars have sometimes barely formed by birth. Third, all the deciduous teeth have begun calcification by the end of the sixth fetal month, although the eruption of those teeth always is a postnatal event. Thus, age estimation using dentition during the fetal and neonatal period must be based on the degree of calcification of the deciduous dentition, not on the dental eruption standards that are often most familiar to forensic specialists. The charts of Schour and Massler (1941), recently modified by Ubelaker (1978), are useful standards for prenatal and neonatal dental age estimation. Demirjian's discussion of the development of the dentition is an especially useful summary (1978; Reichs & Demirjian, Chapter 12, this volume) and Bang's (1989) chapter is a very useful treatise on subadult dental development.

Postcranial aging standards have traditionally been of two types: ossification standards and length-for-age standards. Garn and coworkers have contributed numerous useful observations concerning the appearance and development of various skeletal elements (e.g., 1969, 1974). Maresh and coworkers (Maresh & Deming, 1939), following the early work of Scammon (1930) and others, published some of the first studies of diaphyseal long bone length as aging standards using large known-age samples.

There are a multitude of papers illustrating the development of the centers of ossification of the hand and foot (see Krogman & Iscan, 1986). The papers are based on radiographic survey data, rather than dry bone, however, and the development standards are often extremely difficult to use in forensic work. If an individual were completely represented, or not skeletonized, the standards might well be useful, but Stewart (1979) is essentially correct that there is very seldom a case when aging depends on the evaluation of the ossification of the hands and feet. In the event those criteria can be used, Krogman and Iscan's chapter should suffice, though the studies cited generally suffer from the usual difficulties in generalizing from a study sample to the forensic case.

Long bone length-for-age standards are an outgrowth of the early radiographic studies performed longitudinally at various centers. The work published by Maresh and coworkers is exemplary (Maresh & Deming, 1939; Maresh, 1955). Radiographic studies examining intrauterine long bone lengths are understandably rare. Longitudinal radiographic studies have been less common in recent years, although work on intrauterine size has begun at various institutions using various ultrasonic methods. Corrections are necessary to allow the use of the radiographic data in the estimation of skeletal age, due to parallax errors and varying tissue thicknesses, but those corrections are generally made easier by the use of standard radiographic techniques. Hoffman (1979) notes correction factors of −2 to −3 percent in the Denver Child Research Council study, and most studies require corrections of less than 5 percent.

Many forensic specialists use the long bone length-for-age standards first published by Johnston (1962) for the prehistoric Indian Knoll skeletal sample. There are several problems with using those (and other) archaeologically derived standards for modern forensic material. First, the age intervals usually are quite broad for forensic purposes, being reported in six-month to one-year intervals, often listing prenatal material simply as fetal and using a comparatively large interval (usually six months or more) to represent the neonatal period. Second, the Indian Knoll standards were not, of course, of known skeletal or chronological age but were aged by "dental and osseous criteria." Third, there is no assurance that rates of maturation in an Archaic Period Native American skeletal sample should coincide with those of any specific group of modern fetuses and neonates. While none of those problems is important to the original purposes of Johnston's work, the unwitting use of archaeologically derived data as though they were generated on an appropriate sample could be misleading. There are studies available that have used macerated or dissected specimens in comparison to crown rump length and/or chronological age, and those data should be used in preference to either the radiographic or archeological data whenever possible. Mehta and Singh (1972) found a strong linear relationship between both humeral and femoral diaphyseal length and crown rump length. Fazekas and Kosa (1978) have produced extensive data, including the total body length and diaphyseal lengths of all six long bones, at half-month intervals for a cross-sectional sample of 138 fetuses. Kosa (1989) is a widely available source for age estimation using bone dimensions.

Pfau and Sciulli (1994) have introduced a promising method for age estimation using multiple criteria. With further work enhancing the data base and therefore the precision of age estimates, it is likely that using multiple criteria, as is recommended for adults (Krogman & Iscan, 1986; Lovejoy et al., 1985; and many others), will become an important method for studying fetal and neonatal skeletal material.

Several of the small bones of the fetal and neonatal skeleton have been studied as aging criteria. The vertebral column ossifies and fuses in sequence and can be used to distinguish younger remains from those of children

(Anderson, 1962; Fazekas & Kosa, 1978). The ossicles of the ear may prove useful in aging fetuses and are present within the temporal bone more often than might be imagined (Fazekas & Kosa, 1978). Discussing postcranial epiphyses, Krogman and Iscan state: "At birth only six epiphyseal centers are present: head of humerus, condyles of the femur and tibia, talus, calcaneus, and cuboid of the ankle" (1986:51). The humeral, femoral, and tibial epiphyses, in particular, are large and dense enough to survive burial and may be used to estimate a broad range of ages by comparison to radiographic standards.

There are suggestions of sex differences in fetal diaphyseal long bone lengths (Choi & Trotter, 1970) and there may be differences according to race, as well (Trotter & Peterson, 1969). It is also possible that chronic maternal nutritional deficiencies or poor maternal health, or other factors affecting the intrauterine environment, might bias skeletal age estimates based on either dental or skeletal development. There is a glaring lack of controlled studies examining any of the above propositions. Given the small overall size of fetal and neonatal individuals, it does not seem likely that any profound effects will be documented except in the most extreme cases. The precision of the available forensic age estimates is not so great as to be much affected by subtle differences in maturation rates, in any event.

SEXING CRITERIA

There are good reasons to expect that there will be observable sex differences among fetuses and neonates, though many treatises used by forensic specialists continue to suggest otherwise (Stewart, 1979; El-Najjar & McWilliams, 1978; Skinner & Lazenby, 1983; but see Rhine, 1995). As noted earlier, sexual differentiation begins very early in fetal life. Also, male fetuses and neonates are generally heavier and longer than females of the same chronological age (Crelin, 1973). Garn et al. (1975) have shown that the hand skeleton attains adult proportions by the thirteenth fetal week, lending credence to the possibility that similar correspondences may be found in other skeletal structures. Further, Garn et al. (1974) have shown that sex differences in hand proportions exist early in skeletal development. It is true that the small size of the skeletons, while insulating the forensic specialist from serious error in age estimation, may make it more difficult to establish classically accepted levels of confidence between the sexes. However, the primary obstacle to confident sexing of fetal and neonatal remains probably is the lack of studies of large samples of documented remains.

Choi and Trotter (1970), in a pioneering study, developed a discriminant function model using selected bone lengths and dry, fat-free bone weights that allowed 72 percent correct classification for sex of fetuses ranging from 16 to 44 fetal weeks. Since it is likely such equations are sample specific, similar studies should be undertaken with other documented samples as they become available.

The emergence of the deciduous and permanent dentition has been examined for use in sex determination (Black, 1978), but those standards have no likely application to fetal and neonatal skeletal material. Although male fetuses are generally larger than females at a given chronological age, it is not likely sexing by that size differential will prove useful, since the true chronological age of the unknown fetal case will not be available, and estimates of fetal size, which must be the basis of fetal age estimates, could only be tautologically applied to the issue of sex determination.

A relatively extensive literature has been created examining potential sex differences in fetal and neonatal os coxae (see Fazekas & Kosa, 1978; Weaver, 1980; Hunt, 1990; Mittler & Sheridan, 1992; Schutkowski, 1993; Holcomb & Konigsburg, 1995). As in the case of aging studies, studies on skeletal sex differences have been either radiographic or by direct measurement of dry bone. Differences have been expected in sciatic notch proportions, iliac proportions, general pelvic dimensions, and other details of pelvic form. In general, the expected and observed differences have paralleled those known for adults, although Hunt (1990), using an archaeologically derived sample of inferred sex and estimated age, did not find significant sex differences in his sample. Holcomb and Konigsburg (1995) found statistically significant sex differences in their analyses, but correctly stated that the degree of correct determination of sex using their techniques was not sufficient for most forensic applications.

The various radiographic studies of sex differences of the infant pelvic bones all present difficulties in positioning and measurement. Still, several of the studies have demonstrated sex differences (e.g., Reynolds, 1945). The demonstrated differences parallel those observed in adults, including a broader sciatic notch, wider pelvic inlet and outlet diameters, bi-ischial breadth, and longer pubic length among female neonates.

The recent developments in molecular biological techniques hold great promise for sex determination of skeletal remains. Those techniques are undergoing rapid development (Naito et al., 1994, for example) and soon may be capable of accurate and dependable sex determination from human bone from forensic (and other) contexts. However, because postmortem degradation and contamination effects may occur, even after the various molecular techniques mature and are in widespread use there will still be cases for which skeletal identification criteria will be needed.

The studies of macerated or dissected skeletal material also present sex differences that parallel those known for adults. Significant differences have been reported for the greater sciatic notch (Thomson, 1899; Boucher, 1957; Fazekas & Kosa, 1978), which has universally been reported as wider in females. The auricular table of the ilium has been proposed as diagnostic of sex in fetal and neonatal skeletons, with varying reliability (Weaver, 1980). In sum, it is probable that further studies of documented skeletal samples will provide more support for the proposition that sex determination of fetal and neonatal skeletons can be made reliable.

BIOLOGICAL AFFINITY

The ongoing debate over the validity, utility and relevance of forensic attempts to infer biological affinity, usually couched as "race," using skeletal remains promises to continue (Gill & Rhine, 1990; Goodman, 1995; Marks, 1995; Gill, Chapter 14, this volume, for example). The debate is not likely to be resolved, inasmuch as scientific, political, ethical and personal components of the various proponents' positions are inextricably intertwined. The fact remains, however, that if the skeletal material could provide any information concerning the likely biological affinity, that information would be of use in identification. Hope has been expressed that at least some of the traits used to infer biological affinity in adult material might be applicable to fetal and neonatal material (Rhine, 1995), but to date very little controlled study of the matter has been done. There are no widely accepted criteria to use to infer biological affinity for fetal or neonatal material. Cranial metric (Gill & Rhine, 1990; Krogman & Iscan, 1986) and non-metric traits (El-Najjar & McWilliams, 1978; Krogman & Iscan, 1986; Gill & Rhine, 1990; Gill, Chapter 14, this volume), and post-cranial metric and non-metric traits (Stewart, 1979; Krogman & Iscan, 1986; Gill & Rhine, 1990) may have some value for inferring biological affinity in fetal and neonatal material. That value will be tempered by several factors, however, and so adult traits should be used only after appropriate study and with appropriate caution. Many metric and non-metric traits are affected by developmental age or stage and by elements of a person's life history. For example, many of the cranial non-metric traits that are used to infer biological affinity simply would not yet have developed in fetuses and neonates. And, it is not always clear how differences in nutrition, disease, physical activity, trauma and other events that occur during growth and development may condition metric and non-metric traits.

Dental traits do hold some promise for inferences concerning biological affinity. It may be, for example, that shovel-shaped incisors will have similar value in suggesting Asian or Native American ancestry as those incisors have for adults (Hinkes, 1990). Whether the many other dental indicators of biological affinity found in adults (Scott & Turner, 1988; Kelley & Larsen, 1991, for example) will be of substantial use for fetal and neonatal materials awaits further study.