Chapter 9
Evidence of Neglect from Immature Human Skeletal Remains: An Auxological Approach from Bones and Teeth

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Abstract  Child neglect is the most common form of child maltreatment and failure to thrive is one of its most common manifestations. Although growth failure has many etiologies, recognizing it is very important in aiding the identification of neglect in living children and in fatality cases, particularly in the detection of severe malnutrition. Although the forensic anthropologist may deal with a fatal case of child neglect, the assessment of growth failure from osteological observations is considerably limited. The expert relies on the assessment of dental and skeletal growth and development for the estimation of age and the assessment of growth failure. Although dental development is susceptible to environmental insults, such as malnutrition, it is more stable than skeletal growth and maturation, which is more susceptible. This chapter cautions the use of dental development for age estimation in suspected cases of child neglect and offers two general approaches for the detection of growth failure from observations in bone and teeth. One approach relies on comparing height estimates and long bone lengths to sex and age-specific references of height and long bone length, while the other relies on assessing the discrepancy between dental and skeletal age. A sample of identified Portuguese human immature skeletons is used to illustrate the consistency of results between the two approaches. Although an auxological approach to the study of bones and teeth can provide important insights into the growth status of individuals represented by their hard tissues, it cannot be definite about the diagnosis of malnutrition and, particularly, neglect as the cause of the child’s death.

9.1 Introduction

Immature human skeletal remains can be found in a variety of forensic contexts, although actual forensic anthropology cases involving children are rare. In non-conflict areas, perhaps the most common circumstances are those of homicide and maltreatment. Several studies are devoted to the development and testing of
techniques employed in the identification of child remains by the forensic anthropologist, and the literature provides numerous examples of methods for determining age, sex, height, and ancestry from immature skeletal remains [1, 2]. However, few advances have been published in recognizing the circumstances surrounding the child’s death. Children are by definition immature and, as such, are particularly susceptible to various forms of maltreatment, and physical and nonphysical violence. Neglect is the most common form of child maltreatment, but has received much less attention than child physical or sexual abuse [3]. Up until recently, forensic anthropologists rarely have had the opportunity to examine cases of child abuse [4], and in various circumstances, they are now frequently called upon for an assessment of bone trauma in suspected cases of abuse. This is in contrast with child abuse identified in an archeological context [5, 6], where most cases go unidentified for a variety of reasons [2], including the fact that few child skeletons may survive in the burial record. This is also true for cases of neglect, with the possible exception of abandonment and infanticide in an archeological context [7, 8], but the reasons why these cases remain unidentified are different.

In general terms, child neglect results from acts of omission from the caretaker who fails to provide basic necessities to the child [3]. In cases of neglect the child is exposed to a variety of invisible insults, such as malnutrition, recurrent infection, and injury, which may not be detected from human skeletal remains. The most common problem resulting from physical and emotional neglect during infancy is growth failure [9, 10], but since growth disruption has many etiologies, neglect may remain “hidden” and be difficult to distinguish from other causes. In a forensic context, an auxological approach to the study of immature skeletal remains may provide important clues in the detection of growth deficit from bones and teeth. Subsequently, this can aid the expert in the identification of physical and/or emotional abuse. This chapter deals with forms of neglect that will lead to growth failure. It will provide a brief overview of the clinical literature on child neglect and on failure to thrive as a common manifestation of neglect and abuse. This is followed by a brief review of fatal cases of neglect, as well as by a discussion of the diagnostic criteria for growth failure when a fatality is involved. The conditions under which growth failure can be detected from immature skeletal remains and the implications of nutritional neglect on age estimation are mentioned. Specifically, two general approaches for the detection of growth failure from immature human skeletal remains are proposed and a discussion of their limitations is presented.

9.2 Child Neglect and Failure to Thrive in a Clinical Setting

Neglect is the most common form of child maltreatment. For example, using 2008 data on cases of child maltreatment known to Child Protection Services agencies in the United States, of the approximately 760,000 children found to be victims of child maltreatment, more than half (71%) suffered from neglect [11]. In cases of neglect,
boys and girls are equally likely to be physically neglected, and the incidence is higher among children between 0 and 11 years old [12]. There are marked differences in the rates of physical neglect for family income, with the highest rates in low-income families [12].

Legal definitions of child neglect vary [3], but most agree on nine components of neglect: inadequate food, inadequate clothing, inadequate shelter, inadequate supervision, inadequate medical care, inadequate emotional care, inadequate education, exploitation, and exposure to unwholesome circumstances. The basic principle underlying each component is that neglect occurs when a child’s basic needs are not met by the caregiver, regardless of the circumstances leading to the inadequacy of care [3, 13, 14]. Therefore, neglect refers to regular acts of omission, and it is not included in physical abuse classifications. Situations of neglect require a detailed analysis of the context in which they occur, since not all negligence is intentional and criminally prosecuted, but instead may represent simpler cases of social and health risk.

Since child neglect usually results from a heterogeneous collection of situations, some professionals have categorized it into several types, on the basis of its different components, frequently as medical, physical, safety, educational, and emotional neglect [3, 13, 15]. In educational neglect, the caregiver fails to fulfill the child’s educational needs and include endorsed or tolerated school absenteeism, families never enroll their child in school despite the child reaching the mandatory age, and families fail to take the necessary steps to assess and meet the needs of children with disabilities. Inattention to child’s needs of attention, affection, and emotional support, as well as exposure to domestic violence, is among the most common type of emotional neglect. Medical neglect is usually distinct from physical neglect because it involves the expertise of the healthcare providers in detecting this type of neglect. It is usually manifested in disregard for routine health care, delay in seeking healthcare assistance, and refusal of appropriate medical care for treatable diseases. Physical neglect results from unacceptable parenting, usually a lack of reasonable supervision or little attention to creating and maintaining a safe environment. It can be identified as single or multiple circumstances where there is an obvious disregard toward the child’s hygiene, health, or nutritional status. Abandonment of a child is generally considered safety neglect, as well as leaving the child in places where they are put at a significant risk. Since individual cases usually involve more than one type of neglect, it is, perhaps, more useful in the assessment to conceptualize it in terms of the basic needs that are not met when neglect exists, rather than in terms of the type of neglect.

Screening for neglect by the healthcare professional involves the assessment of the child and adult caregiver to identify signs and symptoms related to neglect [16]. Failure to thrive is a common manifestation of various types of neglect and of physical abuse. For example, according to a 2004 report by the Massachusetts Department of Public Health covering 6 years of statewide experience, 1700 children were referred for failure to thrive, and most of these children would fulfill at least one of the criteria for neglect [17]. Failure to thrive has been defined as a significantly prolonged cessation or deceleration of growth compared to age-
and sex-specific references for normal children [10, 14, 17] and is often considered another separate type of neglect or is included in physical neglect as a nutrition-related form of neglect [14, 15]. However, failure to thrive or the inadequate growth of infants and children is more of a sign or consequence, rather than a diagnosis, and is also not synonymous to neglect. In addition, child neglect represent a wide range of care-giving deficits, and not all will manifest in growth failure. Some of the most common signs include poor hygiene and grooming, irregular feeding habits, recurrent infections, and injuries; some of the most common symptoms include delay in social skill acquisition and learning, appetite and sleeping disturbances, antisocial behavior, and reduced peer interaction [18].

In nutritional neglect cases, failure to thrive usually occurs when the child’s basic nutritional needs are not met, namely when the child is not offered sufficient nutrients. The main factor behind abusive malnutrition is then protein-energy deprivation. However, most cases of failure to thrive actually result from emotional abuse and psychosocial stress, usually concomitant with nutritional deprivation [9, 14]. For example, the care givers may be uninformed about proper nutritional requirements, they may be psychologically or mentally impaired, or there is a history of domestic violence and physical abuse in the family. In these circumstances, the child will develop psychosomatic pathologies and digestive dysfunctions, which will lead to digestion of inadequate amounts of offered nutrients, low retention of ingested nutrients, or increased metabolic demands that exceed ingested nutrients. Endocrine factors are thought to be at play when retarded growth results from emotional abuse or stress rather than from nutritional deprivation. Emotionally abused or neglected children usually show depressed growth hormone levels, whose production by the pituitary may be affected by the amygdala and limbic cortex when subjected to emotional stress [19]. Consequently, one of the clinical manifestations of the “battered child syndrome” is also malnutrition [20] and, consequently, growth failure. The nutritional and psychosocial causes of failure to thrive are also demonstrable by growth recovery by long-term physically neglected and emotionally abused children when placed in foster care [21]. The pervasiveness of growth failure in cases of child neglect and abuse may likely result from the fact that infants and toddlers are more exposed to basic needs such as nutrition and preventable diseases, as acts of omission from the caretaker. They have great nutritional demands due to growth, have immature immune systems and are totally dependent on adults for feeding, care and attention.

The differential diagnosis of failure to thrive is vast, but the primary etiology of many cases of growth failure is malnutrition and infection, with insufficient nutrients to meet metabolic requirements [10, 22]. Growth reflects the balance between caloric intake and metabolic expenditure, and in physical neglect, malnutrition determines a low protein-energy intake sufficient for maintenance, fighting disease, activity, and growth. Thus, the economy of nutrients (protein and energy), which are being allocated to maintenance and fighting disease, is being diverted from physical activity (which decreases) and growth (which is delayed or retarded). In addition, malnutrition, by virtue of diminishing the available energy allocated to fight disease, exposes the child to more disease. In turn, in a diseased environment, nutrition intake
is lowered, thus contributing to the escalade of this infection-nutrition synergistic cycle, which affects growth [22, 23]. Eventually, the nutrition-infection synergy will further contribute to growth retardation. Although almost every serious illness of childhood and infancy are included in the differential diagnosis of failure to thrive, major medical diagnoses such as cystic fibrosis, cerebral palsy, congenital heart disease, HIV infection or AIDS, cancer, as well as metabolic and several other chronic conditions are among the most important etiologies of growth failure [10, 17, 24]. In addition, more subtle causes of growth failure must be considered as well. These include oral motor deficiencies, breast-feeding difficulties, errors in baby formula preparation, poor diet selection, or improper feeding technique [10, 17, 24]. One important aspect in the differential diagnosis of failure to thrive is the prenatal history to distinguish in utero exposures to neglect from congenital infections and malformations. Alcohol and drug abuse during pregnancy are important causes of growth failure and must be considered [14]. Women who were physically abused during pregnancy also show a greater risk of preterm delivery [25], which may concur with postnatal neglect situations.

Since malnutrition is the main factor behind growth failure, depending on the duration and quality of the protein and energy deficiency, two main types of malnutrition can be recognized from growth: stunting and wasting. The first clinical sign of malnutrition is acute and refers to weight loss or wasting. In the face of malnutrition, after weight gain has ceased, linear growth continues for a while. If conditions of malnutrition persist and become chronic, a reduction in height occurs and the child is said to be stunted. Clinicians usually diagnose failure to thrive in children whose physical development falls persistently below the third or fifth percentile in height for no known medical reason [10]. Velocity of growth is frequently a better measure of growth deficiency than height or weight at a specific point in time, because it is obtained from a long-term follow-up history of the child [17, 26]. A fall downward over 2 or more percentile lines is sufficient for a diagnosis. However, a clinical evaluation for failure to thrive involves a comprehensive family history, physical examination, feeding observation, and a home visit by an appropriate healthcare professional.

There are three groups of risk factors associated with failure to thrive as a form of neglect: social, family, and individual factors [10, 13–15, 17]. Social factors include the wider social, cultural, and economic context of the family and neglected child. Poverty is the greatest single risk factor for failure to thrive worldwide and in the United States. Other social risk factors include lack of available extended family to help with child rearing, social isolation of the family, employment instability, and housing conditions. The family comprises the immediate environment of the child and their family characteristics, at the level of both parent and parent-child interaction. Risk factors at this level include parent attributes such as single parenthood, adolescent parents, and family violence. Infant-caregiver attachment issues are an example of parent-child interaction risk factor. The last group of risk factors includes individual factors at the level of the caregiver, such as substance abuse by the caregiver or a history of abuse of the parent as a child. At the level of the victim
or child, individual risk factors include age and whether the infant was born preterm or with low birth weight.

9.3 Fatal Child Neglect and the Forensic Anthropologist

The death of a child is the most extreme outcome of child neglect or abuse. Omissions in child care can be so severely dangerous that death can occur. Over half of the child fatalities attributed to child maltreatment results from neglect [27]. Of the approximately 1600 deaths in 2008 known to have occurred from child maltreatment, 32% where associated with neglect alone and 40% resulted from a combination of physical abuse and neglect [11]. The majority of victims of fatal neglect are under 3 years [28, 29], and about one-third are younger than 1 year and two-thirds are males [28]. Although less severe forms of neglect can be generally handled by child protection services agencies, without police or prosecutor involvement, more serious cases of neglect, and particularly fatal cases, involve the criminal justice system.

Early reports on fatal child neglect examined cases where children died from “passive” neglect because they were abandoned, or when children died as an extreme consequence of deprivation, such as malnutrition, or when parents failed to provide adequate health care [28]. In its extreme form, failure to thrive secondary to neglect may be fatal [17]. The definition of fatal neglect has now broadened to include common injury deaths, and the role of parental supervision in these preventable injury deaths is now amply recognized [30]. In fact, most fatal cases of neglect appear not to involve chronic or severe malnutrition, but instead are associated with a single life-threatening incident [28, 30]. Although growth failure cannot be the cause of death (usually is starvation), diagnosing or detecting failure to thrive is, nonetheless, a strong indication of continuous child neglect in life [31].

The literature on fatal child neglect is relatively scarce, compared with that of fatal physical abuse. There are several cases of child neglect fatalities described in the literature [28, 29, 31–37], and most report circumstances of severe malnutrition or starvation, with documented growth failure. Although most reports also describe physical safety or medical neglect involving a fatal injury, none of these report on the growth status of the children involved. In these cases of fatal nutritional neglect, the most affected children are those under 1 year of age, and rarely are there children over 3 years involved. The exception is usually older children with special needs [31].

Failure to thrive is a clinical diagnosis made in a living child who is not growing or gaining weight as expected, but if a child dies as a result of nutritional neglect, the pathologic findings relate to the presence of severe malnutrition [29, 31]. In addition, even if the child dies as a result of a fatal injury, pathological changes associated with malnutrition may be present as well, as a consequence of concurring neglect. In fatal cases of malnutrition, weight loss and height retardation are so extreme that they are usually below weight and height percentiles. Consequently,
other anthropometric criteria are needed to measure the amount of growth failure. Several classification systems have been developed to estimate protein-energy malnutrition in developing countries and these have proved useful in a forensic setting, because they allow an estimate of the degree of malnutrition [38]. The more simple classifications like the Gomez classification of protein-energy malnutrition [39] use the expected weight for the respective age group as standard, but these cannot distinguish acute malnutrition from chronic one. Taking into account not only weight but also height and the expected weight for the actual height is what the Waterlow classification of protein-energy proposes [40]. In addition, the Waterlow classification provides a grading to classify acute and chronic protein-energy malnutrition, according to the actual weight in percentage of normal weight of respective age group and the actual height in percentage of normal height of respective age group, respectively. In the most severe grade of malnutrition, actual height is below 80% of normal height for age [40]. Combining height and weight data can provide an indication of the persistence in neglect [38]. In acute malnutrition there may be a severe loss of body weight, while the reduction in body height may be only very slight. Conversely, impaired growth in height is a sequel of a chronic condition.

In fatal cases, the autopsy also provides additional diagnostic criteria for severe malnutrition. The most common autopsy findings are extreme emaciation, sunken eyes, and low body weight and organ weight, with the frequent exception of the brain, loss of subcutaneous and mesenteric fat, and atrophy of muscles of organs, in particular endocrine and reproductive glands [29, 34, 36, 37]. In addition to starvation as the cause of death and growth failure, in cases of lethal child abuse where a single or multiple injury incidents are the cause of death, emotional and psychosocial stress can also lead to growth failure in these children [9]. In these circumstances of fatal abuse, detecting growth failure can be important as a sign of abuse, in the final diagnosis.

In a forensic context, the anthropologist will deal with fatal cases of child neglect. In particular, the forensic anthropologist may be called upon when the child’s body is decomposed and reduced to hard tissue to assess whether the child may have been neglected or abused. There are several cases in which forensic anthropologists have examined the skeletons of children, who were physically abused in life [4, 41]. In the archaeological record there are few reports, namely that by Blondiaux and co-workers [5], who describe a 2-year-old child skeleton, from fourth-century Normandy, suspected of having suffered child abuse, and that by Wheeler and co-workers [6], who examined another potential case of abuse in a 2–3-year-old child from fourth-century Egypt. Comparatively, the detection of neglect, namely severe malnutrition, has not been so successful in the forensic and archaeological context. Although growth failure is a common manifestation of neglect and abuse, its etiology may not result from intentional acts of neglect, and, consequently, it becomes “invisible” to the eyes of the expert. This is particularly true in the archaeological record, where the anthropologist has little contextual information and stunting was pervasive in past. Nonetheless, Walker and co-workers [4] describe a forensic case that revealed many Harris lines in the long bones suggesting
episodes of malnutrition and infection. In the archaeological study by Blondiaux and co-workers [5], the child’s skeleton also showed evidence of rickets, which is suggestive of nutritional deficiencies and of neglect as well. None of the forensic or archaeological reports explored further the growth status of the skeletons under analysis, namely the possible divergence between dental and skeletal age estimates.

In much the same way as diagnosing growth failure can provide useful insights into the detection of a child neglect case, the identification of skeletal growth failure is one of the most powerful tools to detect neglect from immature skeletal remains. Wasting cannot be detected from osteological findings because weight cannot be accurately estimated from the skeleton. Autopsy findings associated with cases of lethal starvation are also useless in the identification of growth failure and severe malnutrition from skeletal remains, because they rely on soft tissue changes. Consequently, only reduced bone size and delayed skeletal maturation as a result of chronic malnourishment can be identified. This means that, in practice, if height, linear growth, or maturation is unaffected, malnourishment cannot be recognized in children’s skeletons.

Studies of human skeletal growth in the past have become increasingly popular, and there is a wealth of literature dealing with this topic [42–47]. The term “paleo-ology” has been proposed to group together growth and development studies of past populations from bone and teeth [48]. The study of growth patterns reconstructed from skeletal remains in bioarchaeological studies usually involve the construction of a skeletal growth profile to examine the cross-sectional age-progressive trend in growth in sex-pooled samples [49]. In skeletal growth profiles, a proxy for stature growth such as a long bone measurement, usually femur length, is plotted against a measure of chronological age, such as dental age. Under stressed environmental conditions, such as malnutrition or infection, a large number of individuals will show a bone growth deficit relative to dental age, and this relative difference indicates a delay in skeletal growth as a consequence of stress. Therefore, determining whether a child is stunted from skeletal remains involves the comparison of a measure of skeletal growth with a measure of dental age, which may not necessarily involve the construction of a growth profile. For instance, the use of skeletal maturation indicators, such as changes in size and shape of ossification centers, can be used as an alternative to long bone diaphyseal length. This alternative is particularly useful in cases where the skeleton is incomplete or badly preserved, lacking the long bones, and provides the opportunity to simply compare skeletal and dental age.

Although skeletal growth profiles from sex-pooled samples are commonly used in assessments of growth in archaeological populations, their use in a forensic context will allow the detection of differences in growth or maturation attained between the child case and the reference sample. The use of linear skeletal growth and skeletal maturation as measures of growth delay or deficit relies on the assumption that growth and maturation of the skeleton are more affected by external factors such as malnutrition and infection, whereas dental development is more buffered. For this reason, skeletal growth measures are normally employed to identify physiological
stress in an individual, whereas dental development is used to estimate his/her chronological age.

9.4 An Auxological Framework for Aiding the Identification of Neglect from Immature Human Skeletal Remains

From an auxological perspective, the detection of neglect from immature skeletal remains is, ultimately, about identifying the effects of malnutrition and infection on growth and development of the skeleton and dentition. Since the cause of malnutrition and infection can be other than neglect, a human growth perspective can only aid the expert, while pursuing other lines of evidence that support a diagnosis of neglect. A diagnosis of growth failure or of severe malnutrition from osteological findings will not be able to establish the cause of death. Instead, the diagnosis of growth failure may contribute to the identification of a case of neglect, since failure to thrive is a common manifestation of neglect and abuse, and as such the cause of death may not be nutritional.

The greater sensitivity of skeletal growth and development to external factors, such as malnutrition and infection, compared to the more buffered dental system, is at the core of growth assessments from the skeleton. Although different studies use different approaches to measure skeletal and dental development, the literature largely supports this assertion. The lower sensitivity of dental development is suggested by relative greater delays in skeletal maturation than in tooth formation in children with major abnormalities affecting growth, diseases and malnutrition. For example, Vallejo-Bolaños and España-López [50] examined the developmental delay in dental and skeletal maturation of Spanish children with a growth disorder (short familial stature) and found that skeletal maturation was more retarded with respect to chronological age than permanent tooth formation. Ozerovic [51] examined the relationship between chronological age, dental formation, and skeletal maturation in Yugoslavian children with cerebral palsy and reported that chronological and dental age differed on average by 1–7 months, while skeletal age differed from chronological age by an average of 4–11 months. In several cases of β-thalassemia major, the mean delay in skeletal maturation was 28% compared to a mean delay of 17% in dental formation [52]. Similarly, Garn and co-workers [53] reviewed a series of North American children with growth disorders of varying etiologies, including hypothyroidism, celiac disease, and anemia, and found that, in general, the degree of retardation in dental formation of this mixed group was approximately one-third the magnitude of the skeletal delay. Edler [54] arrived at very similar results in a sample of British patients with hypopituitarism, where average percentage delay in skeletal maturation was 27.9% in age groups between 7 and 12 years, while for tooth formation, the average delay was only 9.3%. Keller and co-workers [55] also found that, compared to skeletal development, the dental system is not noticeably affected by endocrine and metabolic diseases, except in pituitary insufficiency, hyperthyroidism, and delayed puberty. In a sample of children with sickle-cell anemia studied by Sears and co-workers
skeletal age was also found to be significantly behind chronological age by approximately 17 months, whereas dental age was not found to be significantly different from chronological age. Finally, Holderbaum and co-workers [57] found that HIV-positive children showed delayed dental age, but the delay in skeletal age was much greater (approximately half as much), particularly before the administration of antiretroviral drugs.

Not many studies have directly examined the effects of malnutrition on dental and skeletal development, but the greater impact of nutrition on skeletal development is suggested by greater advancement of skeletal maturation relative to tooth formation in obese children [58]. Another example of the impact of nutrition and of general improvement in living conditions is the study by Melsen and co-workers [59]. These authors examined a group of Asian children, with inexact chronological age adopted by Danish families within 1 month after their arrival in Denmark and re-examined them 1 year subsequent to the first examination. At the time of the second examination the children showed an increment in dental age in accordance with the time interval between the two examinations but an increase in skeletal age that exceeded the corresponding time span. The authors suggest that the greater recovery of skeletal development reflected its greater environmental sensitivity.

More recently Cardoso [60] and Conceição and Cardoso [61] were able to further document that skeletal growth and skeletal maturation are more affected by environmental circumstances than dental formation. In these studies, dental and skeletal ages were contrasted against chronological age in a sample of fully identified known sex and age Portuguese child skeletons, which were divided into two subsamples of differing socioeconomic status. The father’s occupation and the place of residence provided information about socioeconomic categorization of the sample that was meant to stratify the sample in two groups: one of individuals exposed to more negative environments (low socioeconomic status) and the other of individuals exposed to more positive environments (high socioeconomic status). This stratification assumes that children in a higher socioeconomic group have preferential access to fundamental resources, such as better nutrition, sanitary living conditions, and health care than do children in the lower socioeconomic group. Cardoso [60] found that, in addition to skeletal age showing a greater delay relative to chronological age when compared to dental age, the socioeconomic difference in skeletal age, obtained from diaphyseal femur length, was about 1 year, whereas the socioeconomic difference in dental age was only about 0.5 years. Conceição and Cardoso [61] found a similar socioeconomic difference in dental age, while the socioeconomic difference in skeletal age, obtained from skeletal maturation indicators at the knee, was about 1.2 years.

### 9.4.1 Age Estimation

As part of the identification process of the child, age estimation is crucial and is commonly obtained from dental and skeletal growth and development. Since growth failure is a common consequence of neglect, in a forensic anthropology situation,
dental and skeletal growth have the dual purpose of providing age estimates and of aiding in the detection of neglect. Dental development is less affected by environmental influences than skeletal growth and maturation, and is the preferred method for estimating age in immature skeletal remains. However, neglect can influence the rate of tooth formation through the effects of malnutrition. As a consequence, although age can be usually estimated with confidence by forensic anthropologists, in suspected cases of neglect this technique can be seriously hampered.

Once considered very stable and free from environmental influences, dental development is now thought to be less buffered. Dental development comprises the processes of tooth emergence and tooth formation, and the latter is traditionally considered the most accurate age-at-death estimator [62, 63]. The influence of nutrition on the emergence of the deciduous and permanent dentition has been suggested and demonstrated for some time [64–70], but nutritional effects on tooth formation have been more contentious. However, some studies have been able to show an indirect effect of nutrition on tooth formation. This includes most of the studies cited above that support the assertion of lower sensitivity of dental development, relative to skeletal development, to major abnormalities and diseases affecting growth. For example, indirect impacts of nutrition on dental formation include the report by Garn and co-workers [53], who have found a dental delay in patients with celiac disease (0.67 years). In patients with β-thalassemia studied by Laor and co-workers [52], dental age was also found to be significantly delayed by 12–24% of chronological age. The studies by Cardoso [60] and by Conceição and Cardoso [61] are other examples of the indirect influence of nutrition on tooth formation, where dental age was consistently behind chronological in low socioeconomic status children. More recently, Cardoso and co-workers [71], using samples of Portuguese children in the early and late twentieth century, were able to document the first consistent secular acceleration in dental formation, in response to improvements in social and economic conditions, which influenced the nutritional status of children over time.

Studies that have demonstrated a more direct effect of malnutrition on dental development are rare and include that by Murchison and co-workers [72], who carried out an experimental study with protein-deprived infant rhesus monkeys. In these monkeys, crown-root deciduous length in protein restricted monkeys was found to be significantly less than those of controls, although only for deciduous second molars. Hilgers and co-workers [73] also found a significant direct effect of nutrition on dental development, but in conditions of overnutrition. BMI status was determined in a sample of children between the ages of 8 and 15, where a mean dental age acceleration of 1.53 years was found for obese individuals, compared to 0.68 years for normal children. Finally, with respect to the third molar, Rai [74] using a sample of North Indian patients between the ages of 17 and 21 found that dental and chronological age did not differ in the group of well-nourished individuals, but dental age underestimated chronological age in the group of malnourished subjects. In this study, the patients were categorized according to the nutritional risk index, which incorporates information about the subject’s weight and plasma albumin level [74].
Evidence also suggests that the deciduous dentition is less affected by malnutrition than by permanent dentition [75–80] by contrasting the delay in deciduous and permanent eruption in different studies. Although a delay in both dentitions have been associated with childhood malnutrition, no comparative studies have been carried out. In addition, this nutritional effect seems to be documented for tooth emergence but not for tooth formation. Given that older children have a greater chance of accumulating environmental insults, it is perhaps reasonable to assume that the formation of the permanent teeth will also likely show a greater possibility of delay in maturation, when compared to that of the deciduous teeth.

A clearer picture has been emerging with respect to the consequences of malnutrition, and other external factors, in dental formation. Malnourished children may show delayed dental development compared to what is expected for their age. Consequently, age estimation from tooth formation should be performed critically. In a forensic context, this is particularly noteworthy in cases of suspected abuse or neglect.

9.4.2 Assessing Growth Failure from the Skeleton

Two general approaches are proposed here for the assessment of growth status from immature human skeletal remains. The two approaches differ in that one requires age to be known and the other is better used when true age cannot be ascertained with accuracy. Once the child is identified, his/her true age is usually known from comparison with the date of birth. However, in some situations, age or date of birth may not be determined, such as in cases of an unreported non-hospitalized delivery or cases of immigrant families. Due to the rapid body changes associated with growth, accurate age determination is essential for an accurate assessment of growth status. Both approaches also require sex to be known with certainty due to sex-specific differences in growth. In the first approach, growth failure is assessed by comparing an estimation of height or the length of the long bones with sex- and age-specific reference data for height and long bone length. Since height or length is being compared with a reference, age must not be estimated. The risk of delay in tooth formation in neglect cases may jeopardize the identification of growth failure, through underestimation of true age. In the second approach, growth failure is assessed by determining the discrepancy between two estimates of age: dental age, which is more stable, and skeletal, which is more susceptible to malnutrition and other nutrition-related factors. The larger the discrepancy between ages, the greater the growth deficit.

Since both approaches will only detect cumulative insult on skeletal growth and development, they will only be indicative of chronic and not acute malnutrition. For that reason, it is also less likely that a young infant will be identified as stunted or maturationally delayed, because not enough time may have elapsed for the insult to become chronic. This may be related to fact that skeletal growth faltering is usually only detectable at about 6 months of age in studies of living infants and children from developing countries [81].
9.4.2.1 Assessing Growth Failure from Height Estimates and Long Bone Length

One possibility of identifying failure to grow is to compare the height of the child, estimated from long bone lengths, with an age-specific reference of height. A pre-requisite of this approach is that age has to be known with accuracy, once the remains are identified. If age is estimated from dental development, the effects of malnutrition may be underestimated due to a delay in tooth formation, as the child will appear younger than he/she is. A few methods have been proposed for estimating the height of immature skeletal remains, but most have important limitations. Only methods that provide regression formulae based on actual bone lengths are referred to here, and these include the studies by Telkkä and co-workers [82], Feldesman [83], Smith [84], and Ruff [85]. In these studies, height is obtained from living subjects, and the lengths of all six long bones (humerus, radius, ulna, femur, tibia, fibula) are collected from radiographs.

This approach may be useful because it will allow the expert to assess whether the child’s height is below the 3rd or 1st percentiles of height for the age of the child. However, the initial problem is the choice of method for height estimation. Since the purpose is to compare the height estimate with a reference, the sample utilized by the height estimation method should match or be similar to the sample of reference children, against which the height estimate will be compared. In addition, due to issues of population mimicry in regression, the height estimated from a certain method will be the expected height for that bone size in the sample of children from which the regression formulae derive. If the sample utilized by the height estimation method is composed of shorter children than that of the reference sample, the case child will appear shorter than he/she is. Consequently, the choice of height estimation method will be dependent on the sample from which it is derived and the reference against which the height estimate will be compared.

The studies of Feldesman [83], Smith [84], and Ruff [85] are all based on the Child Research Council (Denver) data, but they differ in age range. While Ruff [85] has developed regression formulae for all six limb bones to estimate height from 1 to 17 years of age, Smith [84] has provided formulae only from 3 to 10 years. Feldesman’s [83] equations only apply to the femur of 8–18-year-old children. Differences between Smith’s and Ruff’s methods result from the fact that Smith utilized only standing height and eliminated the years where height is measured from recumbent length, as well as the post-pubertal individuals. Changes in growth from puberty alter the relationship between height and long bone length. It is important to note that Ruff has corrected recumbent length for standing height in infants, so that Ruff’s estimates cannot be used for comparison with reference data, since in this age group it is based on recumbent length. Finally, the study by Telkkä and co-workers [82] is based on Finnish data, which is not described in detailed. In a study by Cardoso [86] it was shown that in a sample of child skeletons of known height, children are tallest when height is estimated from Telkkä and co-workers’ [82] formulae. Although this is not a sufficient indication that this is the most suitable method, the fact that the Child Research Council children are significantly
shorter than the Fels Longitudinal Growth Study children (see also below), suggest that Telkkä and co-workers’ method may be the best choice for estimating height with the purpose of comparing it with a height reference. The reason for this is that the Fels data was utilized to construct the 1977 NCHS growth charts [87]. Although the Fels data includes long bone lengths from 1 month to 18 years, no regression formulae for height estimation were developed from these series.

One major problem with comparing a height estimate with a reference is that Cardoso [86] showed that the methods devised by Telkkä and co-workers [82], Feldesman [83], and Smith [84] tend to underestimate true height consistently in a sample of stunted children. This results from altered body proportions in the stunted child, who is not simply a smaller version of a taller child, but has instead proportionally shorter legs relative to trunk [88–92]. In fact, since a significant proportion of abused and neglected children are stunted, they also show disproportionally short legs [93]. Consequently, if the Waterlow classification (see above) is applied to the height estimates, the child will appear more stunted, as the estimated height in percentage of normal height of respective age group is smaller than the actual height (which is unknown).

One alternative to estimating the height of the child, which also requires the age to be known, is to use the long bone length directly to measure the growth deficit. However, reference data for long bone lengths is relatively scarce and is available only from radiographic sources. Maresh [94] provides mean long bone length for age between 1 month and 18 years and is based on the Child Research Council children. The Harvard School of Public Health Growth Study also includes long bone length reference information, which was published by Anderson and co-workers [95], for the tibia and femur between 1 and 18 years of age. Similarly, Ghantus [96] published reference values for the length of the radius and ulna from 3 to 24 months, based on the Brush Inquiry/Foundation Growth Study carried out at Western Reserve University (Cleveland). Since the Fels longitudinal growth data was utilized to construct the 1977 NCHS growth charts [87], the long bone data from this study may represent the best approximation of a reference for long bone length. Unfortunately, long bone length data for the Fels study is available only for the tibia and radius and for children from 1 month to 18 years of age, at 6-month intervals [97].

The Fels or Harvard data will most closely resemble a reference sample, in particular, because long bone lengths in the Denver sample are significantly shorter than those in the Fels and Harvard data. Since there are no percentiles for long bone lengths, the only option is to calculate a z-score from reference data. Actually, Maresh’s [94] long bone data tables include the 10th, 50th, and 90th percentiles, but they are of little use in the detection of severe malnutrition. z-scores are calculated by subtracting the median bone length for age from the actual bone length divided by the standard deviation [98]. The advantages of the z-score are that it allows more precision in describing growth status and distinguishes between a child at (whose z-score may be −2.5) or below the 1st percentile (whose z-score may be −3.5 or lower). Although there are no grading schemes for stunting based on z-scores of long bone length, according to Waterlow and co-workers [99], when the child’s
actual height is 85% of normal height for age – close to the most severe grade of malnutrition of 80% – this corresponds to a z-score between −3.6 and −4.2, depending on the age of the child (under 6 years). However, long bones of the lower limb, namely the femur but particularly the tibia [22, 94, 100, 101], being the fastest growing segments of the body will be more sensitive to nutritional insults and to the detection of severe stunting and severe malnutrition. In addition to the z-score, the calculation of tibia length in percentage of normal tibia length for age may provide an approximation to the Waterlow classification. However, relative tibia length (as percentage of height) increases throughout the growth period, and this complicates its interpretation. Another problem is that long bone length data published by Maresh [94] are not corrected for magnification, and its use can confound interpretations of growth patterns, whereas data provided by Gindhart [97] has been corrected.

9.4.2.2 Assessing Growth Failure from Discrepancies Between Skeletal and Dental Development

Considering that dental development is negatively affected by nutritional status (especially severe and chronic malnutrition), rather than attempting to predict chronological age from tooth formation and plotting dental age against long bone length or a stature estimate to detect growth failure, it may be more useful to compare the level of attainment in dental development to the level of attainment in skeletal growth and development. This can be accomplished by calculating the difference between the two ages in years. Discrepancies between dental and skeletal development are simple subtractions, where a positive score indicates that dental age is advanced relatively to skeletal age and the score increases as the skeletal age lags increasingly behind the dental age. The basic premise in using these discrepancies for detecting growth failure in immature skeletal remains is that dental development is more stable and skeletal development is more susceptible to environmental insults. Discrepancies between dental and skeletal age are indicative of cumulative insult, such that the greater/longer and the more severe the insult the greater the discrepancy and the lesser chance of catch up growth. One important aspect of these calculated skeletal and dental ages is that they are attained ages and not predicted ages. That is, they are informative of how far the child has gone in his/her development, but are not necessarily a good approximation of his/her chronological age.

Contrary to the previous approach, assessing growth from discrepancies between dental and skeletal development does not require knowing the age of the child with certainty. Since these discrepancies are relative measures of growth status, it is only necessary that the methods utilized to determine dental and skeletal age are based on the same sample or on similar samples of children with similar developmental statuses. Otherwise, differences between dental and skeletal ages may result from differences in the samples in which the methods were based, rather than from real differences. This similarity is not easy to accomplish given the diversity of methodologies available for estimating both dental and skeletal age. Several methods have been proposed for assessing dental age and the most common use stages of tooth
calcification obtained from radiographic data. Skeletal age is commonly assessed by measuring skeletal maturation or, less frequently, by examining growth in height (skeletal growth). Skeletal maturation is usually derived from radiographic data on the appearance and fusion of centers of ossification, such as those of the hand and wrist. Since skeletal maturation comprises changes in bone size and ossification of the growth plates, it implies the completion of skeletal growth and height [102]. Therefore, because these two developmental processes are closely related, linear skeletal growth can be used as a proxy for growth in height.

To the best of the authors’ knowledge, only the Fels Longitudinal Growth Study has been the source for both skeletal and dental development data, which can be used for physiological age assessments. The studies on the formation of the deciduous and permanent dentition, carried out by Moorrees, Fanning, and Hunt [103, 104], are largely based on the Fels data and are among the few that provide information across the entire age range of the developing dentition. The Fels material was the source of data for the deciduous dentition and for the permanent posterior teeth (C-M3). Data published by Gindhart [97] is also based on the Fels data and can be used for skeletal age estimation from skeletal linear growth using the sex- and age-specific long bone length data between 1 month and 18 years of age. Skeletal maturation can provide an alternative measure of skeletal age by using the score methods published by Roche and co-workers for the hand and wrist [105] or knee [106], which also derive from the Fels study. In these methods, specific indicators of growth are scored as noted on radiographs and are then used to compute a skeletal age.

Moorrees, Fanning, and Hunt [103, 104] also utilized dental data from the Harvard School of Public Health Growth Study in their studies, and, consequently, the long bone length data provided by Anderson and co-workers [95] can provide a possible alternative for the assessment of skeletal age, for comparison with dental age obtained from the Moorrees standards. One problem with the use of Gindhart [97], or other similar reference values for long bone length, is that their tables are divided up in very few age groups, particularly in younger children where age changes are more rapid. Consequently, the calculation of attainment age for infants, in the case of Gindhart’s data, is made with reference to only four expected ages. This may result in a frequent underestimation of the true skeletal age attained by these children.

Since there is a greater magnitude of growth deficit in older children, due to accumulated nutritional insult over time, there may be a tendency to standardize the differences by dental age. The purpose of the approach is to detect chronic cases of malnutrition, which will be obscured by standardized discrepancies. This is particularly true for the infants, whose relative small dental/skeletal age discrepancies may be amplified by their very young dental age with which the discrepancies are standardized. The use of long bone may also affect the accuracy with which dental/skeletal age discrepancies can detect cases of growth failure. Because the growth of the tibia will be more sensitive to insult, discrepancies between skeletal growth and dental development calculated from tibia data will tend to classify/identify more stunted individuals than when the discrepancies are calculated from femur or other long bone. However, the use of tibia and femur data as increasingly reflecting the conditions of malnutrition is consistent with the findings of Wales, who
demonstrated that a significant proportion of abused children are short and have shorter lower limb lengths.

Skeletal maturation can provide an important alternative to skeletal growth when estimating skeletal age, but its assessment is problematical from skeletal remains. Although hand-wrist bone maturation is routinely used to calculated skeletal age in the living, it is difficult, if not impossible, to apply in skeletal material due to problems of recovery, preservation, and identification of ossification centers. Therefore, developmental indicators of bone maturation in the knee have a great potential to be used with a skeletal sample because the epiphyses of the knee are significantly larger than those of the hand, they preserve well, are more easily recovered, can be easily identified, and are already present from birth [61]. This is where the Roche and co-workers’ method for determining skeletal age from maturational indicators at the knee proves most useful, particularly since it is based on the Fels data.

### 9.4.2.3 Illustrating the Two Approaches

In order to illustrate the similarities and/or differences between the approaches described above, as well as their usefulness and value, a sample of Portuguese documented child skeletons was selected from the Lisbon Collection housed at the National Museum of Natural History [107]. Individuals in the collection do not represent the contemporary population of Portugal, as they were mostly born and died in the first half of the twentieth century. In addition, they represent the middle to low socioeconomic strata of the Lisbon at this time period, as inferred from occupations of the male segment (mostly menial occupations) and from the origin of the remains (temporary graves at the local Lisbon cemeteries) [108]. This collection include over 100 fully identified skeletons of individuals under the age of 20 years, but only children under the age of 3 were selected, as this is the age group where neglect is more prevalent. Individuals in the collection can be described as representing populations experiencing lower levels of social and economic development, where the children may parallel those living under conditions of mild to moderate malnutrition and moderate to high infection.

In this sample of child skeletons, skeletal age was obtained as the age at which a certain long bone length was attained relative to the average long bone length measurements for each sex provided by Gindhart [97]. Dental age was calculated as the sex-specific mean age of attainment for the deciduous and permanent tooth stage of Moorrees, Fanning and Hunt [103, 104]. These studies were chosen because they are both based on the Fels Longitudinal Growth Study sample, making dental and skeletal age directly contrasted. In order for the results to be comparable with that of height, height was estimated from tibia length using Telkkä and co-workers method [82] and z-scores were obtained from the same reference data on the tibia [97]. Actual tibia length as percentage of expected tibia length for age was also calculated to assess its value as an alternative to the Waterlow classification for height. The z-score and tibia length as percentage of normal length should provide similar results to that of plotting height estimates against the WHO reference, when height is estimated from tibia length. Due to differential preservation, a total of
25 skeletons could have their physiological ages and height calculated from these methods.

Data from previous studies have shown that most children in this collection are stunted [60, 61, 86], so it is no surprise that the approaches described here confirm these previous findings. Of the 25 children analyzed, 19 (76%) are below the 15th percentile for height, 11 (44%) below the 3rd percentile, and 4 (16%) under the 1st percentile, compared to the WHO growth reference. z-Scores under –3.6 are all included below the 1st percentile, as well as estimated height in percentage of normal height under 90% and most cases of actual tibia length in percentage of normal tibia length for age under 80%. These four children show the greatest growth delay and are the most likely candidates for a diagnosis of severe malnutrition. Absolute discrepancies between dental and skeletal age in these children are, with one expectation, greater than 1 year and greater than 50% when standardized for dental age. However, other three other children showed standardized discrepancies greater than 50%. These children are the youngest in the sample and their large standardized discrepancies result from a slight overestimation of dental age combined with a very young dental age with which to standardize the discrepancies between dental and skeletal age.

Table 9.1 provides a summary of the results when the two general approaches are applied to the group of four children below the 1st percentile for height. With the exception of child #1, all indicators seem to provide consistent results. Due to problems in height estimation (see above) the Waterlow classification for protein-energy malnutrition cannot be applied straightforwardly and it is impossible to assess reliably how good % tibia length is a substitute for % height. Standardized discrepancies between dental and skeletal age may tend to overestimate the amount of growth delay, particularly in younger children. Absolute discrepancies may be more reliable, regardless of the child’s age.

### Table 9.1

Contrasting results of the two approaches proposed for the detection of growth failure from the skeleton, when applied to the identified immature skeletons in the Lisbon collection (<3 years of age). Only the children under the 1st percentile (WHO growth reference) for estimated height are depicted \((n = 4)\)

<table>
<thead>
<tr>
<th>Child#</th>
<th>Age</th>
<th>DA</th>
<th>SA</th>
<th>DA-SA</th>
<th>(DA-SA)/DA</th>
<th>Tibia</th>
<th>% Tibia</th>
<th>z-score</th>
<th>Height</th>
<th>% Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.20</td>
<td>0.93</td>
<td>0.25</td>
<td>0.68</td>
<td>73</td>
<td>96</td>
<td>80.3</td>
<td>–4.1</td>
<td>72.4</td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>2.60</td>
<td>2.25</td>
<td>1.00</td>
<td>1.25</td>
<td>56</td>
<td>129</td>
<td>79.3</td>
<td>–4.5</td>
<td>84.0</td>
<td>91</td>
</tr>
<tr>
<td>3</td>
<td>2.80</td>
<td>2.30</td>
<td>1.00</td>
<td>1.30</td>
<td>57</td>
<td>127</td>
<td>78.0</td>
<td>–4.7</td>
<td>83.3</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>3.50</td>
<td>1.95</td>
<td>0.75</td>
<td>1.20</td>
<td>62</td>
<td>110</td>
<td>59.8</td>
<td>–8.1</td>
<td>77.3</td>
<td>77</td>
</tr>
</tbody>
</table>

Ages are in years; DA, dental age; SA, skeletal age; DA-SA, discrepancy between DA and SA in years; \((DA-SA)/DA\), standardized discrepancy in percentage; Tibia, tibia diaphyseal length in mm; % Tibia, tibia length as percentage of expected tibia length for age [97]; z-Score, z-score for tibia length [97]; Height, estimated height in cm from tibia length using Telkkä and co-workers [82] method; % Height, estimated height as percentage of expected height (WHO) for age
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Available information obtained from civil registration of death and autopsy records (child #1 and #2 were autopsied), provides the opportunity to know in greater detail some aspects of the lives (and deaths) of these children, which may help understand the observed pattern of growth delay. Child #1 is a 1-year-old boy who died of giant cell pneumonia. The diagnosis was made at autopsy, whose records also described the child as being poorly nourished. From available documentary evidence, child #2 may have been a victim of medical neglect. This 2-year-old boy died of purulent otitis and was autopsied because death was presumed to have occurred from lack of medical assistance. The family address in the civil registration of death suggests that they lived in a poor suburban neighborhood in the Lisbon outskirts. Bilateral bronchopneumonia was the cause of death of child #3, a 2-year-old illegitimate son of a docker, according to the civil birth registration. The family address in the same record also suggests a poor neighborhood, but in this case in the old core of the city of Lisbon. Child #4 died of tuberculous meningitis in 1913. This 3-year-old boy was son of a navy sailor who lived in one of the old port areas of the city of Lisbon. From cross-referencing records, it was found that he had a 14-month-old sister who died 7 months after him. All of the children under analysis show a large growth deficit and seem to have suffered from mild to severe malnutrition. The context of their lives and deaths points to several risk factors of child neglect cases, particularly poverty. However, with the possible exception of child #2, all cases also suggest that growth failure may have had other etiologies, particularly infectious diseases. Although data in Table 9.1 is not meant to provide the means for the diagnosis of child neglect, it may provide some guidance in the assessment of malnutrition from measures of growth delay from the skeleton.

9.5 Discussion and Conclusions

Assessing growth status from immature skeletal remains requires accurate methods for dental and skeletal age estimation and up-to-date sex- and age-specific reference data for skeletal growth. Reference data for dental and skeletal development of modern populations is generally lacking, and this can potentially represent a major obstruction in forensic and criminal investigations by complicating the detection of growth failure and, consequently, the identification of a potential case of neglect or abuse. Due to well-documented secular changes toward increase in height and acceleration in maturation, earlier standards may not be appropriate to modern forensic cases. In particular, references used by skeletal biologists to assess skeletal development, such as long bone length data from the Child Research Council or the Fels Longitudinal Growth Study, are dated to 1960s and 1970s and earlier. Although there is up-to-date developmental data for the permanent dentition and skeletal maturation, long bone reference values are lacking and are unlikely to be updated due to wide concerns of excessive x-ray exposure for research purposes. Consequently, experts will have to be aware of the limitations of the available data and make informed choices and cautious decisions. In addition, some of the methods
or reference data do not provide age information with sufficient detail, particularly in the younger age groups where growth is fastest. This complicates the detection of growth failure in these children, who are already at greater risk for neglect. In addition, utilizing long bone lengths to assess growth failure are probably better than using height estimates, due to uncertainty in the later. On the other hand, there are no guidelines for classifying malnutrition according to long bone length, such as the Waterlow scheme devised for height.

The limitations of the reference sources for dental and skeletal development are directly related with the diagnostic limits of child neglect from ostelogical observations. Although the forensic anthropologist may be able to assess whether the child shows growth failure of some magnitude from developmental observations of bone and teeth, this alone will not warrant a case of fatal child neglect and cannot provide confirmation of death by starvation or severe malnutrition. Criteria described here are meant to provide guidance in the detection of growth failure from immature skeletal remains and not a straightforward diagnosis of neglect. In fact, failure to thrive as a manifestation of child neglect represents only a minority of children with failure to thrive [109] and a diagnosis of neglect must consider a history of withholding of food from the child and/or disregard for nutritional needs that endanger the child. Although a clinical evaluation for failure to thrive involve a comprehensive family history, physical examination, feeding observation, and a home visit by an appropriate health professional, when dealing with a fatal case in a forensic anthropology context, diagnosis relies on the post-mortem examination of the remains, on a comprehensive family history and, eventually, on previous information collected during a home visit while the child was alive or collected during a doctor’s appointment (subsequent to an episode of injury or not). If available, medical records are essential to determine evidence of malnutrition from growth deficits. Finally, assessing the circumstances surrounding the death and the findings at the scene, such as sanitary conditions of the child’s home, provide vital clues for the detection of case of neglect.

Although neglect should not be a diagnosis by exclusion in a clinical setting [109], this is even more compelling in a forensic anthropology situation, which requires greater care and precaution in the interpretation of the growth data, in the context of other evidence obtained. The forensic anthropologist and other experts working in the case must collect as much evidence as possible because it is the underlying cause of the starvation (i.e., withholding of food or neglect), and not the diagnosis of starvation itself, that will be valued in criminal proceedings [29]. In this context, it is essential to establish differential diagnosis of growth failure with other cases of natural etiology.

Since growth failure is not an enough condition for the diagnosis of child neglect, other skeletal indicators of malnutrition should be used to support the identification of a potential case of neglect. These include lines of arrested growth identified in radiographs of long bones, known as Harris lines [110], and the histological analysis of pathological striae of Retzius in enamel microstructure, known as Wilson bands, indicative of growth disruption [111]. However, these osteological and dental changes require that the individual survive and recover from the episode of
Evidence of Neglect from Immature Human Skeletal Remains: An Auxological... malnutrition or disease. Although there are problems with the etiology of Harris lines, Walker and co-workers [4] considered them suggestive of episodes of stress in abuse cases. Failure to thrive may also be accompanied with lesions indicative of metabolic deficiencies, namely iron deficiency anemia, and vitamin D and C deficiencies [2]. Iron deficiency anemia, in particular, is the most common known nutritional deficiency, especially among young children and women. For example, in the 2004 report by the Massachusetts Department of Public Health, where 1700 children were referred to as showing failure to thrive in the previous 6 years, nearly 30% were anemic [112]. Consequently, skeletal development delay can concur with lesions indicative of various nutritional deficiencies, of growth disruption in long bone and enamel, and even changes in appositional bone growth [44]. Other findings, consistent with child neglect, are general poor dental health and greater prevalence of dental disease [113–115].

In the most severe cases of neglect it may be useful to use other indicators of developmental status which seem to be affected last. One example of such an indicator is the measurement of head circumference, since the brain is usually spared from malnutrition. Only in cases of extreme malnutrition or starvation will head size suffer a delay in growth. For example, in five cases of severe malnutrition in infants, four showed normal head circumference and only one showed reduced circumference [116]. Consequently, due to head size stability, head circumference is probably a more accurate indicator of extreme growth failure. However, postmortem changes to the skeleton are unlikely to preserve an intact and pristine skull which can be accurately measured. This is particularly true for the immature and fragile cranium of children. Even if the skull is not intact and the different elements are preserved, an accurate reconstruction of the skull may be difficult to accomplish due to postmortem modifications that may cause deformation and warping of the skull bones. If measurement or reconstruction is possible, a correction may have to be introduced while converting skull circumference to head circumference [117].

Assessments of growth status in a forensic context from osteological findings need careful consideration of the limitations of the evidence and of the auxological methods employed. Data suggest that a diagnosis of growth failure alone will likely identify several cases of moderate to severe malnutrition unrelated to child neglect or abuse. Only a careful examination of the circumstances surrounding the death and the findings at the death scene, as well as a thorough family and medical history will be able to associate growth failure with child neglect or abuse. Ultimately, a diagnosis of neglect requires the assessment of multiple lines of evidence and the work of a multidisciplinary team of experts and professionals involved in any given case.

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