ANALYSIS OF ENAMEL HYPOPLASIAS IN THE OLD FRANKFORT CEMETERY: COMPARISONS BETWEEN ADULT MALE AND FEMALE AND JUVENILE PREVALENCE AND AGE AT ONSET OF DEFECTS

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ABSTRACT

Enamel hypoplasias are presented for 61 adult male, 47 adult female, and 39 individuals represented by deciduous dentition from the Old Frankfort Cemetery. The age at onset of enamel hypoplasias was calculated for all individuals by measuring the location of the defects on maxillary and mandibular incisors and canines. These measurements were then placed in regression equations formulated to calculate the age of onset of the defect for each particular group. The regression equations were developed based on the chronology of Massler, et al. (1941) and Goodman and Rose (1990, 1991).

The chronological distribution of enamel hypoplasias represented by individuals in the Old Frankfort Cemetery is similar to that found in previous studies, with hypoplasias most frequently occurring between the ages of 2.0 and 4.0 years of age. The frequency of individuals affected is high with 97.5 percent of the adult individuals and 67 percent of the juveniles showing one or more defect.

INTRODUCTION

The Old Frankfort Cemetery was rediscovered during construction of the new KYTC Office building in downtown Frankfort, Kentucky. In the Spring of 2002 archaeologists from the Kentucky Archaeological Survey recovered 272 individuals from the site. Based on archival research and the age of the buildings that were constructed on top of the Old Frankfort Cemetery after it fell into disuse, the Old Frankfort Cemetery dates to between 1800 and 1860 (Stahlgren and Stottman 2006). Coffin hardware and artifacts recovered during the excavation of the burials support this date range (Miller 2007).

The types of grave goods recovered, the style of coffins, and the supporting skeletal and dental evidence indicate that the Old Frankfort Cemetery served the lower class

2007 - In Current Research in Kentucky: Volumen Nine, edited by E. Nicole Mills, Richard V. Williamson, and Richard Davis, pp. 87-102. Kentucky Heritage Council, Frankfort.

residents of the city of Frankfort. The demographic profile obtained from the skeletal and dental analysis indicates the people interred at the Old Frankfort Cemetery were a mixed group of African Americans, Native Americans, and Europeans. A total of 272 graves were discovered in the cemetery. About 34 percent of these burials were juvenile skeletons. The adult population was pretty evenly spread between males and females. The skeletal and dental analysis indicates these people were in very poor health with many showing signs of chronic diseases, tuberculosis, Vitamin D deficiencies, and arthritis (Peter Killoran, personal communication 2003).

Although a detailed dental inventory was created and numerous dental attributes (including morphologic traits) were recorded, this paper will focus on the interpretation of the enamel hypoplasias (EH) observed within this population. The intent of this paper is to present the EH data and make preliminary observations of the ramifications of the results. In-depth analyses of these results is out of the scope of this paper.

ENAMEL HYPOPLASIAS

Human dentition can reflect the nutritional status of an individual during the years of tooth development. Markers in dentition such as enamel hypoplasias have consistently been associated with malnutrition and disease (Goodman and Rose 1990, 1991; Goodman, et al. 1989; Solomons and Keusch 1981; Chavez and Martinez 1982). By examining enamel hypoplasias (EH), an overall nutritional state of an individual can be inferred. Enamel hypoplasias are the result of a temporary disturbance in amelogenesis, or enamel development. This disturbance leaves visible markers in the relatively permanent enamel that is deposited during the time of stress. They are defects in the thickness of the enamel and can be manifest as single or multiple pits, narrow or wide troughs, or areas of entirely missing enamel (Figure 1). Enamel hypoplasias are deficiencies in the amount or thickness of enamel (Suckling 1989; after Weinmann, et al. 1945). These are quantitative defects as opposed to enamel opacities, which are qualitative defects. Opacities involve change in color and opacity of enamel, indicating differences in hardness or quality of enamel (Federation Dentaire International 1982). Because enamel does not remodel once it is formed, enamel hypoplasias are permanent markers left on the tooth crown that are not lost except from heavy wear or pathological conditions such as caries.

Examination of enamel hypoplasias in a population can give a glimpse as to the general health status of that population. They cannot be attributed to a specific pathological condition or nutritional deficiency. They can, however, be used as an indicator of developmental disturbances caused by some sort of metabolic stress. The locations of these defects can then be measured to obtain a relatively accurate estimate of the age of the individual during the time of stress. Due to the regular and ring-like deposition of human enamel, and the permanent, non-regenerative nature of enamel, measurements of enamel hypoplasias can be placed in regression equations to calculate the age of the individual at the time of the disturbance.

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Figure 1 shows linear enamel hypoplasias on the mandibular dentition (permanent incisors and first molars) of Burial 91 from the Old Frankfort Cemetery. The first and second deciduous molars still in occlusion do not exhibit hypoplasias as enamel had already been formed on these teeth prior to the physiological stress causing the EH on the permanent dentition. The age at death of this individual was determined to be around 9 years old +/- 24 months based on tooth eruption and development. The age at occurrence of the physiological stress causing the EH was calculated to be between 2 and 4 years of age.

Figure 1. Enamel Hypoplasias on an Individual from the Old Frankfort Cemetery.

MATERIALS AND METHODS

All individuals represented in the Old Frankfort Cemetery collection with dentition were observed for the presence of enamel hypoplasias. Enamel Hypoplasias were scored on all teeth recovered in the sample with a total of 199 individuals being represented in the dental sample. However, only 170 individuals had teeth present to record hypoplasias. The 29 individuals without dentition had either lost teeth pre-mortem, had not fully developed dentition, or the teeth were not recovered during excavation of the burials. Of the 170 individuals with teeth available for hypoplasia analysis, 67 (39.4 percent) adults were retained for the enamel hypoplasia statistical analysis. That is, they had maxillary and mandibular incisors and canines with wear scores of "2" or lower according to wear

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scoring techniques presented in Standards for Data Collection from Human Skeletal Remains (Buikstra and Ubelaker 1994). Teeth that were assigned a wear score of "3" or higher were omitted from the sample due to the possibility that enamel defects had been worn away. All individuals with deciduous maxillary and mandibular incisors and canines (39) were included in the statistical analyses of the sample due to very low patterns of wear on these teeth. These numbers for adult and subadults in the Old Frankfort Cemetery dental collection includes six individuals who had both permanent and deciduous dentition (such as the individual represented in Figure 1). The permanent dentition from these six individuals was included with the indeterminate adult group for statistical analyses while the deciduous dentition was included with the subadults.

ANALYSES

Through a series of studies, Goodman, et al. (1980, 1984) suggest that enamel hypoplasia analysis focus on incisors and canines. In the 1980 study on a prehistoric population from Illinois, Goodman, et al. (1980:526) report that the maxillary central incisors combined with the mandibular canines were the most hypoplastic, with over 95 percent of the total growth disruptions observed in their study being observed on at least one of these teeth. They determined that in general, stress episodes that produced defects on the anterior teeth were concurrently manifest on the anterior teeth forming at the same time. Subsequent studies have focused on maxillary and mandibular incisors and canines (Goodman, et al. 1987; Goodman and Rose 1991; Hodges 1987; Hutchinson and Larsen 1988; Lanphear 1990; Van Gerven, et al. 1990). The study of the Old Frankfort Cemetery population follows this example and examines the enamel defects represented on the maxillary and mandibular incisors and canines. For each tooth type, only the left side of the arcade is reported. When the left tooth was not observable, the right antimere was substituted. This eliminates duplicitous reporting of single stress episodes.

Hypoplasias were scored on the labial surface of each tooth with the aid of a magnification light. Measurements were taken from the mid-point of the defect to the cemento-enamel-junction (CEJ) by use of sliding calipers to the nearest 0.02 mm. Defects were scored as linear horizontal grooves, linear vertical grooves, linear horizontal pits, non-linear arrays of pits, and single pits. These are all treated as a single class of defect in the statistical analyses.

The labial crown height was recorded for each tooth from the left side of the arcade. When the left tooth was not observable, the right antimere was substituted. Rather than using Goodman (1988) standards of crown heights, which was derived from a Swedish population, a population specific series of regression equations was developed to calculate age of onset of hypoplasias for the Old Frankfort Cemetery collection. The mean maximum crown height was calculated for males, females, adult indeterminate, and subadults for each tooth type to use in the linear regression equations used to calculate the age of onset of hypoplasias for each individual (Tables 1, 2, and 3). Based on the assumption that the Old Frankfort Cemetery population is relatively homogenous and tooth size variation within each group is small, the error involved in using this method

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should be minimal (Hodges and Wilkinson 1988; Blakely and Armelagos 1985). Adult teeth with wear scores of 3 or greater (according to the Scott 1979 scoring system) were omitted from this calculation. Due to preservation, a mean crown height for each deciduous tooth type was obtained from measuring crown heights of a sample from the Old Frankfort Cemetery collection (N=12) and taking the average for each tooth type.

Table 1. Mean Crown Heights for Deciduous Dentition from the Old Frankfort Cemetery Collection.

Tooth	Mean Crown Height
Maxillary and Mandibular	
C	7.25
I2	5.98
I1	5.86

Table 2. Mean Crown Heights for Male Permanent Dentition from the Old Frankfort Cemetery Collection.

Tooth	Mean Crown Height
Maxillary	
C	8.875
I2	8.555
I1	8.60
Mandibular	
C	9.64
I2	8.52
I1	8.005

Table 3. Mean Crown Heights for Female Permanent Dentition from the Old Frankfort Cemetery Collection.

Tooth	Mean Crown Height
Maxillary	
C	8.625
I2	8.95
I1	9.86
Mandibular	
C	9.01
I2	7.264
I1	6.23

The age of enamel formation was taken from the developmental sequences of Massler, et al. (1941) and Shaw and Sweeney (1973). Table 4 lists permanent tooth crown formation times according to Massler et al. (1941) while Table 5 lists deciduous tooth crown formation times according to Shaw and Sweeney (1973).

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Table 4. Permanent Tooth Crown Formation Times According to Massler, et al. (1941).

Tooth	Year Crown Formation Begins	Year Crown Formation Ends	Years of Formation
Maxillary			
C	0.0	6.0	6.0
I2	1.0	4.5	3.5
I1	0.0	4.5	4.5
Mandibular			
C	0.5	6.5	6.0
I2	0.0	4.0	4.0
I1	0.0	4.0	4.0

Table 5. Deciduous Tooth Crown Formation Times According to Shaw and Sweeney (1973).

Tooth	Crown Formation Begins (Prenatal Month)	Crown Formation Ends (Postnatal Month)	Duration of Formation
Maxillary and Mandibular			
M2	6th	11th	15 months
M1	5th	6th	11 months
C	6th	9th	13 months
I2	5th	5th	10 months
I1	5th	4th	9 months

The calculation for the age of onset of enamel defects was based on the method presented by Goodman and Rose (1990), which was modified from Swardstedt (1966), using the developmental sequence of Massler et al. (1941). Age of onset of hypoplasias was calculated using regression equations that incorporate the average maximum crown height for the Old Frankfort Cemetery collection and the ages of enamel formation. These equations assume a constant velocity of enamel formation as recommended by Goodman and Rose (1990, 1991). The regression equation is as follows:

$$\text{Age at formation of defect} = \text{Age at crown completion} - \frac{\text{years of formation}}{\text{crown height}} \times \text{defect height from CEJ}$$

The equations developed for each of the groups in the Old Frankfort Cemetery collection (males, females, adult indeterminate, and subadults) are listed in Tables 6, 7, 8, and 9. The following analysis of enamel hypoplasia presence in the Old Frankfort Cemetery reports both the occurrences of hypoplasias per individual from the Old Frankfort Cemetery and prevalence of hypoplasias per specific tooth type.

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Table 6. Regression Equations for Estimations of Age at Formation of Linear Enamel Hypoplasias (in years) for Adult Males at the Old Frankfort Cemetery.

Tooth	Regression Formula
Maxillary	
C	Age = -(.676 x Ht) + 6.0
I2	Age = -(.409 x Ht) + 4.5
I1	Age = -(.523 x Ht) + 4.5
Mandibular	
C	Age = -(.622 x Ht) + 6.5
I2	Age = -(.470 x Ht) + 4.0
I1	Age = -(.500 x Ht) + 4.0

Table 7. Regression Equations for Estimations of Age at Formation of Linear Enamel Hypoplasias (in years) for Adult Females at the Old Frankfort Cemetery.

Tooth	Regression Formula
Maxillary	
C	Age = -(.696 x Ht) + 6.0
I2	Age = -(.391 x Ht) + 4.5
I1	Age = -(.456 x Ht) + 4.5
Mandibular	
C	Age = -(.666 x Ht) + 6.5
I2	Age = -(.551 x Ht) + 4.0
I1	Age = -(.642 x Ht) + 4.0

Table 8. Regression Equations for Estimations of Age at Formation of Linear Enamel Hypoplasias (in years) for Adults of Indeterminate Sex at the Old Frankfort Cemetery.

Tooth	Regression Formula
Maxillary	
C	Age = -(.545 x Ht) + 6.0
I2	Age = -(.357 x Ht) + 4.5
I1	Age = -(.421 x Ht) + 4.5
Mandibular	
C	Age = -(.550 x Ht) + 6.5
I2	Age = -(.433 x Ht) + 4.0
I1	Age = -(.462 x Ht) + 4.0

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Table 9. Regression Equations for Estimations of Age at Formation of Linear Enamel Hypoplasias (in years and months) for Subadults at the Old Frankfort Cemetery.

Tooth	Regression Formula (Years)	Regression Formula (Months)
Maxillary and Mandibular		
Canine	Age = -(.149 x Ht) + .750	Age = -(1.79 x Ht) + 9
Second Incisor	Age = -(.139 x Ht) + .417	Age = -(1.67 x Ht) + 5
First Incisor	Age = -(.128 x Ht) + .333	Age = -(1.54 x Ht) + 4

RESULTS

ADULT DATA

Table 10 summarizes the adult hypoplasia data. Of the 67 adults in the sample, 98.5 percent had one or more hypoplasia. One hundred percent of the females, 95 percent of the males, and 100 percent of the indeterminate individuals had one or more hypoplasias. A total of 263 permanent maxillary and mandibular incisors and canines representing a total of 67 individuals were retained for statistical analysis. Figure 2 shows the number of defects recorded per permanent tooth type for each of the adult sub-groups in the Old Frankfort Cemetery population. This shows that the mandibular canine averaged the most number of defects for the females (3.00 per tooth) while the mandibular incisor averaged the most number of defects for the males (3.28). The maxillary canine averages the lowest number of defects for both the males and females (2.5 and 2.47, respectively).

Table 10. Defects Per Permanent Tooth Type

	Central Incisor (I1)		Lateral Incisor (I2)		Canine	
	# Defects Recorded (# of teeth observed)	Average # of Defects per Tooth	# Defects Recorded (# of teeth observed)	Average # of Defects per Tooth	# Defects Recorded (# of teeth observed)	Average # of Defects per Tooth
Maxilla						
Males	29 (12)	2.41	45 (16)	2.81	30 (12)	2.5
Females	33 (12)	2.75	37 (15)	2.47	47 (19)	2.47
Indeterminate	44 (15)	2.93	32 (14)	2.29	33 (14)	2.36
Mandible						
Males	23 (7)	3.28	43 (14)	3.07	48 (15)	3.2
Females	31 (12)	2.58	48 (18)	2.67	69 (23)	3.00
Indeterminate	34 (13)	2.62	43 (16)	2.69	54 (16)	3.38

SUBADULT DATA

Table 11 summarizes the subadult hypoplasia data. Of the 39 subadults in the Old Frankfort Cemetery dental collection with maxillary and mandibular incisors and canines, 67 percent of the population had one or more hypoplasias. A total of 171 deciduous

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maxillary and mandibular incisors and canines representing a total of 39 individuals were retained for statistical analysis. Figure 3 shows the number of defects recorded per deciduous tooth type. The deciduous mandibular canine averaged the most number of defects while the mandibular first incisor averages the lowest.

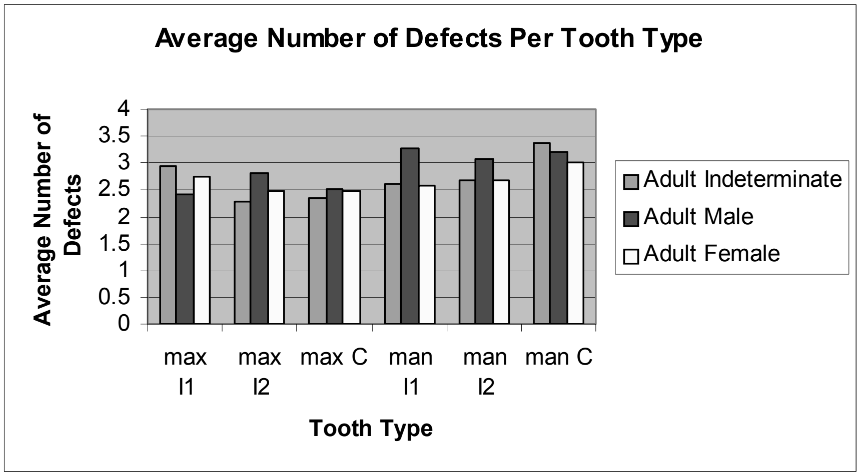

Figure 2. Average Number of Defects Per Permanent Tooth Type for Each of the Adult Subgroups in the Old Frankfort Cemetery.

Table 11. Defects Per Deciduous Tooth Type

	Central Incisor (I1)		**Lateral Incisor (I2)**		**Canine**	
Maxilla						
	# defects Recorded (# of teeth observed)	Average # defects per tooth	# defects recorded (# of teeth observed)	Average # defects per tooth	# defects Recorded (# of teeth observed)	Average # defects pertooth
Deciduous	8 (32)	0.25	7 (30)	0.23	22 (27)	0.81
Mandible						
Deciduous	4 (26)	0.15	6 (28)	0.21	25 (28)	0.89

POPULATION SUMMARY

It appears that the mandibular canine was the most affected tooth in the Old Frankfort Cemetery collection. For the adults, the maxillary canine showed the lowest number of defects while the mandibular first incisor showed the lowest for the juveniles. Notably, the permanent dentition averaged, overall, more defects per tooth, regardless of tooth type, than the deciduous dentition.

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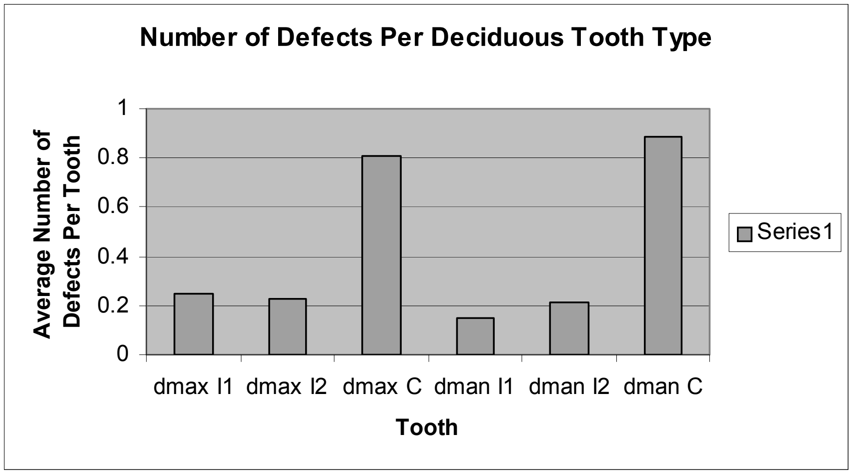

Figure 3. Average Number of Defects Recorded Per Deciduous Tooth Type.

Figure 4 displays the percent of permanent teeth affected by hypoplasias in the Old Frankfort Cemetery. The mandibular first incisor is the most frequently affected tooth, with 100 percent of these teeth for both the males and females in this sample having one or more hypoplasias. The maxillary first incisor is the least frequently affected tooth for the males (83.33 percent), while the mandibular second incisor shows the lowest frequency for the females (88.89 percent).

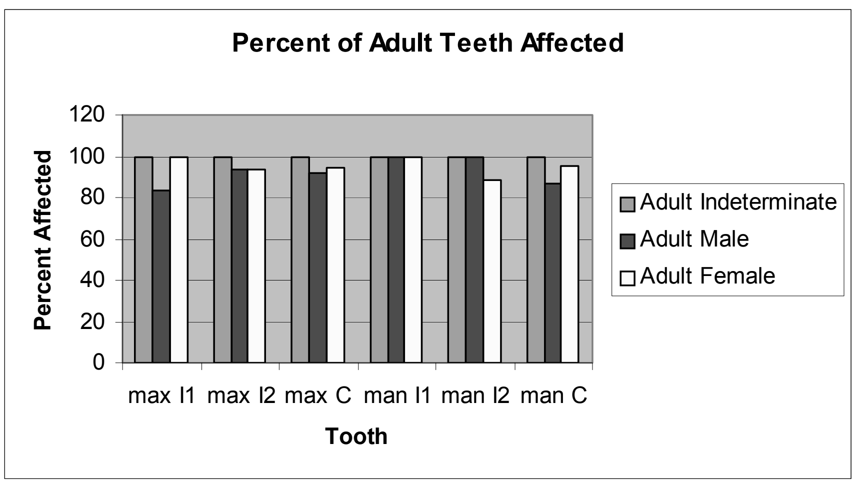

Figure 4. Percent of Permanent Teeth Affected by Hypoplasias in the Old Frankfort Cemetery.

Figure 5 shows the percent of deciduous teeth affected by hypoplasias in the Old Frankfort Cemetery. The deciduous mandibular canine is the most frequently affected tooth, with 100 percent of these teeth being affected. The deciduous mandibular first incisor is the least frequently affected tooth with only 11.11 percent of these teeth having one or more hypoplasias.

The measurement of each hypoplasia was inserted into a regression equation in order to estimate the age at onset of the defect. The resulting data is presented in half-year growth interval for the adult population from birth to 7.0 years of age. The data was then plotted as total number of hypoplasias per age interval. Figure 6 shows that there is a peak of hypoplasia occurrence at 3.0-3.5 years of age for the adults, with most hypoplasias occurring between the ages of 2.0 and 4.5 years of age. This data is consistent with that reported by numerous other researches on both historic and prehistoric populations (Allen, et al. 1987; Corruccini, et al. 1985; Goodman 1988; Goodman, et al. 1984; Goodman, et. al. 1987; Powell 1988). Many of these researchers have concluded that the peak in hypoplasia occurrence at this age is associated with the stresses of weaning. Although weaning is a gradual shift from breast feeding to solid foods, it is considered to be the most dramatic transition of childhood and likely has strong influence on the presence and occurrence of hypoplastic defects.

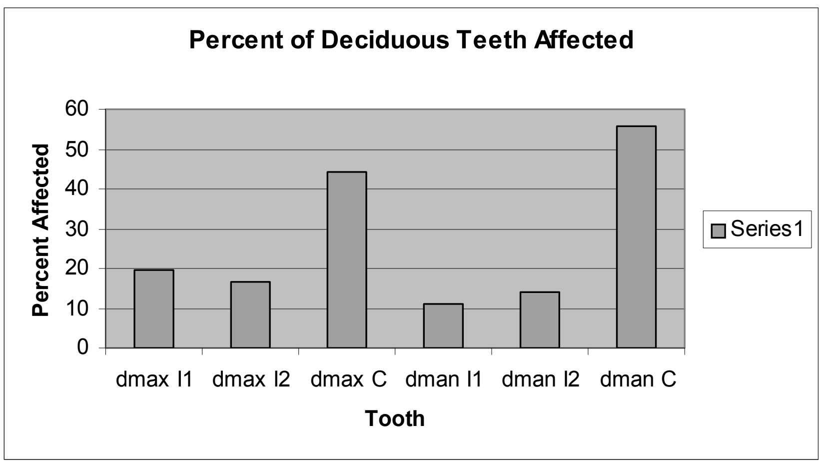

Figure 5. Percent of Deciduous Teeth Affected by Hypoplasias in the Old Frankfort Cemetery.

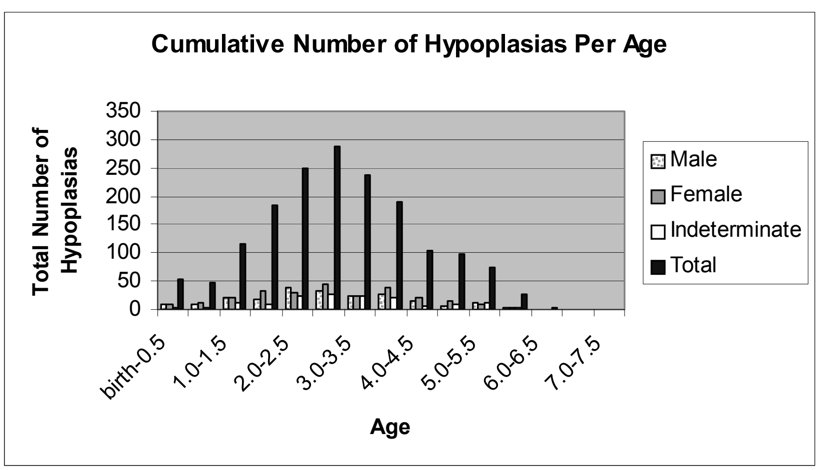

Figure 6. Cumulative Number of Hypoplasias Per Age Group of Adults from the Old Frankfort Cemetery.

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The percent of hypoplasias observed in the adults from the Old Frankfort Cemetery per half year age interval (Figure 7) shows similar results with around 17% of all hypoplasias occurring around 2.5-3.0 years of age. Again, the most hypoplasias occur between about 1.0/1.5 and 4.5 years of age.

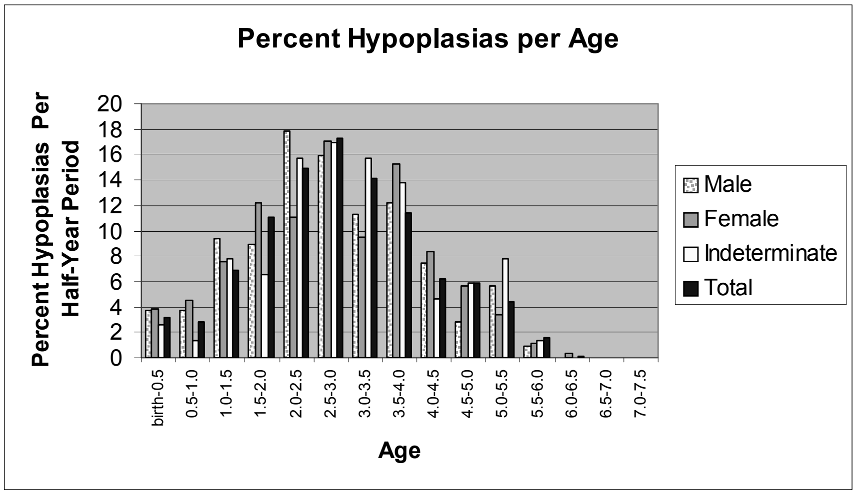

Figure 7. Percent of Hypoplasias Per Age Interval of Adults from the Old Frankfort Cemetery.

The measurements of each hypoplasia were again inserted into regression equations in order to estimate the age at onset of defects in the deciduous dentition from the Old Frankfort Cemetery. The resulting data is presented by month, rather than years, from the fifth prenatal to the ninth postnatal growth interval (Figure 8).

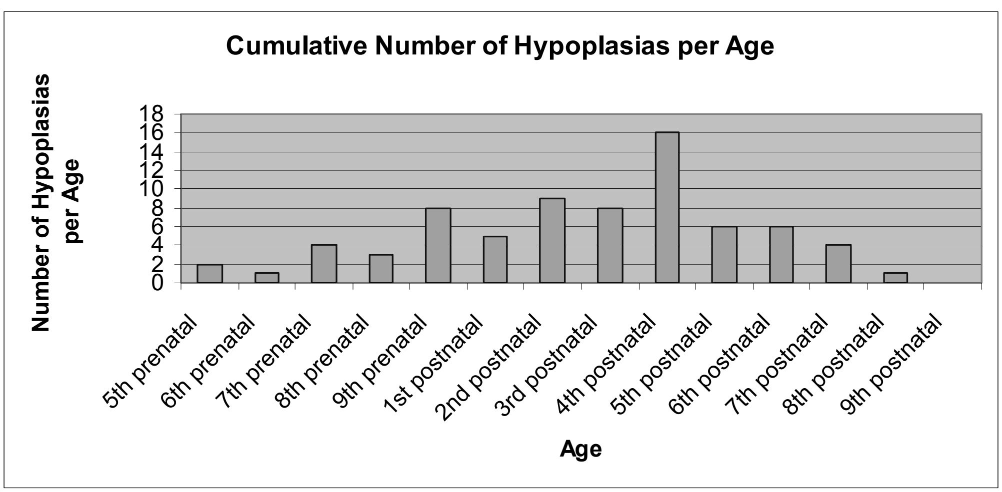

Figure 8. Cumulative Number of Hypoplasias of Deciduous Teeth Per Age Interval from the Old Frankfort Cemetery.

The deciduous tooth data shows that there is a peak of hypoplasia occurrence during the 4th postnatal month. This data is not consistent with other studies. Most researchers have reported a gradual increase in hypoplasia occurrence over the course of the prenatal development period, which accompanies fetal nutritional demands. There is typically a peak around birth, followed by a rapid decline in the postnatal period (Goodman, et al. 1987; Blakely and Armelagos 1985). The typical ages at which there is a more frequent occurrence is between the 8th prenatal and the 2nd postnatal month. This has been attributed to increased stress associated with birth (Kronfield and Schour 1939; Via and Churchill 1959). The subadults from the Old Frankfort Cemetery do not follow this trend, rather, there is a peak of hypoplasia occurrence during the 4th postnatal month. The subadult data indicates there is the possibility that the children were not receiving the proper nutrition from their mothers and were therefore more susceptible to malnutrition and disease.

There is general acceptance that the frequency of hypoplasias may provide an indication of general health status of a population. The high prevalence of enamel defects in the Old Frankfort Cemetery, with over 90 percent of the adult individuals and 37 percent of the subadults showing one or more hypoplasias, indicates the individuals interred in this cemetery lived under less than desirable conditions and were exposed to chronic malnutrition and/or disease.

Further, the late peak at the 4th postnatal month in the juveniles from the Old Frankfort cemetery suggests the possibility that the children were not receiving the proper nutrition from breastfeeding and were therefore more susceptible to malnutrition and disease. Infants are weaker and more susceptible to disease and malnutrition than are adults, especially when they are not receiving proper nourishment from breast milk. A peak in enamel defects at this late stage is another indication of the dire conditions in which the individuals interred at the Old Frankfort Cemetery resided.

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