LONDON DENTAL ATLAS: INDIVIDUAL TOOTH VERSUS TOTAL DENTAL AGE ESTIMATION

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MASTER OF SCIENCE

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by
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ABSTRACT

Objectives: The London Atlas of Human Tooth Development and Eruption was created in 2010 to evaluate tooth and root development and predict an age. The London Atlas uses a dental quadrant cartoon depiction of dental development for each age group based on the illustrations from Moorrees method. This study aims to determine if the London Atlas estimated dental age matched chronological age in a multiethnic North Philadelphia population. In addition, to determine how many individual teeth deviate from their total dental age estimation.

Materials & Methods: 200 panoramic radiographs taken of patients aged 7-12 at Temple University's Orthodontic Department were evaluated. A dental age was chosen for each panoramic radiograph based on the London Atlas. The right dentition excluding the third molars were recorded if they deviate from the selected dental age depiction (accelerated or delayed relative to the London Atlas's year interval depictions).

Results: A total of 200 patients were included in the study with a mean age of 10.15 years. There was a strong correlation between the London Atlas dental age estimation and chronological age (p<.001:rho:0.835). The overall difference between estimated age and chronological age was 0.23 years. The average number of deviations from estimated dental age per tooth was 25.9. There was a weak negative correlation between dental age and the number of individual tooth outliers that had accelerated age (p=0.018:rho=-0.167) and delayed age (p=0.005:rho=-0.197). Furthermore, there was a weak to moderate negative correlation between estimated dental age and total number of teeth that were either accelerated or delayed (p<0.001:rho=-0.364).

Conclusion: The London Atlas has a 71% accuracy for dental age estimation being highly correlated with chronological age. The most common tooth with deviations compared to the selected dental age estimate was the upper second molar and children with older estimated dental ages have fewer teeth that are delayed or accelerated. This suggests that it may be highly accurate to use the London Atlas for the North Philadelphia population especially for older children.

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CHAPTER 1

INTRODUCTION

Age estimation of a growing child, based on dental development, has been used throughout history. Some of the reasons include the precise time to treat orthodontic patients as well as aiding in documentation of unknown people in asylums and mass shootings (Sato et al., 2022). Dental development and eruption sequence and their association with chronological age have been extensively studied. This has led to the development of many dental-based age estimation tools (Demirijian, 1985). One of the earliest was developed by Moorrees (1963) based on children from Boston. He utilized depictions of crown and root development of single and multirooted teeth and determined average age associated for each tooth (Moorrees et al. 1963). Demirijan (1973) created a new age estimation based on a French-Canadian population which was then further adapted by Willems (2001) after applying it to Belgian Caucasian population. The most modern of these analyses is the London Atlas of Human Tooth Development and Eruption (AlQuahtani et al., 2010).

The London Atlas was developed in 2010 utilizing the depictions from Moorrees research. The goal of the study was to have an age estimation based on a study of various ethnicities including modern patients. The researchers evaluated the skeletal remains from Spitalfields Collection (Natural History Museum London) and Maurice Stack's Collection (Royal College of Surgeons of England) as well as living individuals' radiographs from London School of Medicine and Dentistry. The subjects were half white and half Banglasdeshi (AlQuahtani et al., 2010).j

From the data generated, the Atlas of Human Tooth Development and Eruption and an associated computer-generated scoring method was created (AlQuahtani et al., 2010). Many studies have evaluated the effectiveness of the London Dental Atlas in different populations and ethnicities for the accuracy in chronological age estimation. A systematic review looking solely at the effectiveness of the London Atlas concluded that it overestimates age non significantly. However, only a few of those studies were conducted in the United States (Jacobmetti et al. 2022). Furthermore, no studies have evaluated the likelihood of individual teeth to deviate from the London Atlas and how this is associated with dental age estimated.

Therefore, this study was conducted to evaluate the following aims: 1) To determine if the estimated dental age from the London Atlas matched chronological age in a multiethnic North Philadelphia population. 2) To identify the likelihood of individual teeth to deviate from the London Atlas estimated dental age. 3) To evaluate the correlation between the London Atlas's estimated dental age and the number of teeth that deviate from this age.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Measures of Age

Chronological age is defined by the number of years since birth of a living person. It is the most common way to quantitatively measure a human's life, but it lacks in describing their growth and developmental status (Tanner, 1962). Because human growth has high variability in timing, scientist have used different physical maturity markers for better a better description. The most common are somatic, skeletal, sexual, and dental age Typically, sexual maturity in females is determined by first menarche and males by facial hair growth. Skeletal age is assessed by appearance of ulnar sesamoid or assessment of shape of cervical vertebrae. Somatic age is evaluated by peak height velocity and dental age by development of teeth. (Marshall, 1973).

A study was conducted evaluating the relationship between somatic, sexual, skeletal, and dental age. The findings suggest dental development is under a different control compared to somatic, skeletal, and sexual development. In addition, there was less difference between dental development and chronological age (Demirijian, 1985). Therefore, using dental development, calcification, eruption, and root formation has become a common practice for predicting chronological age (Guy, 2001)

2.2 Dental Eruption

Primary teeth begin to form in utero at about 5-6 weeks. Permanent teeth vary but earliest formation is seen at 9 weeks in utero as cell proliferate and differentiate to form tooth buds. The stages of tooth development are induction, the bud stage, cap stage, bell stage, and crown stage. In time the crown is mineralized and can be seen on radiographs.

The outer and inner tissues that form the crown continues to grow and begin formation of the roots. Roots do not complete mineralization until after the tooth has erupted into the arch (Sheldahl, 2020). The accepted standard of tooth eruption is first molars erupt at 6 years old followed by upper and lower incisors, lower canines, upper and lower premolars, upper canines, and then second molars coming in around 12 years old (Proffitt, 2019).

2.3 Factors Affecting Dental Development

2.3a Sex

Many studies have looked and compared the eruption sequence of teeth between males and females. A study conducted in 1980 found that at earlier ages girls and boys have similar tooth eruption patterns. However, as the children age girls begin to develop quicker dentally (Demirijian et al. 1980). An additional study supports the earlier development of tooth eruption in females. This study found that girls on average develop teeth 0.8 years earlier than their male counterparts (Kutesa et al. 2013). In 2016, a study on school children found that boys had earlier eruption of maxillary and mandibular central incisors and first molars, but overall tooth eruption was more advanced in females (Sudan et al., 2016).

2.3b Obesity

Increased weight and obesity have been a primary concern for researchers in the United States. One way utilized to measure a patient's weight status is through calculating a patient's body mass index (BMI). The equation is BMI = weight/height^2. A shortcoming of using BMI is that it does not factor in differences in weight due to muscle or fat (Khanna et al., 2022). It has been shown that obesity in children and adolescents have increased by a factor of 2 and 3 respectively in the last 30 years and that the prevalence of overweight

and obesity has increased when comparing data from two different time points: 1976-1980 and 2011-2012 (Sanyaolu et al., 2019).

Obesity and increased weight have been shown to have effects not only a person's overall physical and psychological health but also their skeletal and dental maturation (Mack et al., 2013). An additional study found that obese kids had more teeth than normal weight children. It was found after adjusting for age, gender, and race and ethnicity (Must et al., 2012). Nicholas et al found that children experiencing obesity had tooth eruption increased by about a half a year to a whole year, indicating children with obesity experience earlier dental eruption (Nicholas et al., 2018).

2.3c Ethnicity

Another factor studied in tooth development has been ancestry and ethnicity. Liversridge et al., looked at children from Australia, Belgium, Canada, England, Sweden, Finland, France, and South Korea. The Demirjian method was employed for dental estimation and compared. The study concluded there were no differences in timing of tooth development (Liversridge et al., 2006). An additional study in 2017 compared ancestry and race for dental eruption. They evaluated difference in timing of children in Cape Verde, Morocco, Turkey, Netherlands, and Suriname and between European, African, and Asian races. It was found that Dutch children had delayed dental eruption compared to the other countries. In addition, Asian children had a 3-month acceleration and African children had 3 to 5 month acceleration compared to European children (Dhamo et al., 2017).

An additional study compared two different scoring methods for age estimation in different ethnic populations. One of these methods was the London Dental Atlas. This study evaluated children of Native American, African American, New Mexico Hispanics

and European Americans ethnicity. It was found that in Native Americans and Hispanic Americans the dental age estimation tools incorrectly identified older chronological ages for children. This potentially indicates earlier eruption patterns for children of this ethnicity and that age estimations need to be population specific (Adams et al., 2019).

2.3d Socioeconomic Status

Socioeconomic status (SES) has been questioned to play a role in timing of dental development. SES takes into account income, education, and occupation. Although, there has been speculation whether nutritional status related to SES factors was the causative agent. Kutesa et al., 2019 found that the eruption of the mandibular thirds molars was influenced by weight status and no correlation was seen with SES (Kutesa et al., 2019). In contrast, Garn found that children with lower SE, depending on ancestry, have slower eruption rates compares to their counterparts. However, nutritional status was not adjusted in this study (Garn et al., 1973)

2.4 Dental Age Estimation Tools

2.4a Dental Age Estimation

Age estimation based on development and mineralization of teeth has been shown to be the most accurate method compared to other organs in the body (Cunha et al., 2009). It has been found that teeth deviate less developmentally compared to other anatomical structures based on differences in environment. It is predicted that dental development and skeletal development are under independent controls (Demirijian, 1985). Age estimation from dental records is important in orthodontics for the timing of treatment. Knowing how long it will take for teeth to erupt, based on the radiographic evaluation of tooth development, can aid in proper communication with patients. In return this builds trust. It

is also useful in other fields of work including forensic sciences for identification purposes (Ambarkova et al., 2014). Therefore, many dental age estimation tools have been developed to accurately assess age based on tooth mineralization, root development, and extent of eruption (Guy, 2001).

Two different methods are utilized for age estimation in children: an atlas or scoring method. An age estimation dental atlas is a depiction of panoramic radiographs at each age time point. The depiction is based on the average development of teeth for children at that age. To use the atlas, one compares the depiction to the actual panoramic radiograph and an age is selected. The scoring method evaluates each tooth and assigns it a developmental value based on crown formation, root development, and apex closure. These values are then summed to generate a score that is associated with age estimation (Guy, 2001). Newer dental age estimation tools are utilizing the computer to calculate the dental age (AlQuahtani et al., 2010). Examples of common age estimation tools are the London Atlas of Human Tooth Development and Eruption, Demirijan Method, Wilhelms method and Moorrees method. Shortcomings of these methods have been described in literature, some of which include minimal variation of the sample population, difficulty in application, and outdated due to changes in the development of children (Demirijan et al 1973; Willems et al., 2001; Moorrees et al., 1963; AlQuahtani et al., 2010).

2.4b Moorrees Method

Moorrees method was developed in 1963 through data from Harvard University's School of Public Health. To utilize this scoring method two maxillary teeth and eight mandibular teeth (incisor though third molar) were evaluated. Each tooth is assessed for crown and root development. Depictions were made to help raters assess development of

the crown and root. Moorrees provides charts for the average age for each stage of crown and root development for each tooth. Then an age estimation can be generated from the data. This is the only method that allows for evaluation of primary teeth (Moorrees et al., 1963). The London Atlas of Human Tooth Development and Eruption utilizes the depictions from the Moorrees method of tooth estimation to create the atlas (AlQuahtani et al., 2010).

2.4c Demirijian Method

The Demirijan method was developed in 1973 based on French Canadian boys' and girls' panoramic radiographs. This method uses the central incisor to the second molar of the left mandible to evaluate tooth eruption. A letter A-H is assigned to each tooth representing stages of teeth from first calcification to stage of full apex completion. The combined letters are assigned a score, and that score generates and age estimation (Demirijian et al., 1973).

This method was accepted by many clinicians across the world and has been widely used. Many studies have evaluated the effectiveness of this method using different geographic populations. It was reported that the Demirijian method either over or underestimates age in other populations. (Davis, 1994; Mornstad et al., 1994; Liversridge, 1999; Baghdadi and Pani, 2012). Therefore, due to the number of studies done a systematic review was conducted in 2021 to evaluate the effectiveness of this method. Following PRSMA guidelines a total of 675 articles were initially identified and later narrowed to 89 to be reviewed. The paper concluded the Demirjian method predicts six months older regardless of sex and ethnicity and geography only play a small role in any differences of age (Hostiuc et al 2021).

2.4d Willems Method

Willems et. al utilized the Demirijian method in 2001 to produce a chronological age estimation based on panoramic radiographs of Belgian Caucasian boys and girls. The intent was to evaluate the accuracy of the Demirijian method and make changes as needed. It was found there was an overestimation in chronological age of the Demirijian method. The authors then turned the scoring system to fractions of the total age and sums were calculated for the overall age. The author stated that this was useful only for children in the Belgium Caucasian population (Willems et al., 2001). A systematic review looked at the efficacy of the Willems method. 31 articles were qualitatively analyzed, and a meta-analysis was performed on 15 articles. It was concluded that estimating dental age utilizing the Willems method is applicable for forensics because it more accurately estimates ages (Sehrawat et al, 2017). A study done in 2022 looked at the efficacy of the London Dental Atlas and Willems Method using Chinese children above 10 and below 17 years old. The results suggest the London Atlas was more accurate when the child was from 10-15 years old (Lin et al, 2022).

2.4e London Dental Atlas of Tooth Development

The London Atlas of Human Tooth Development and Eruption was completed in 2010 to create an age estimation tool. It analyzed tooth eruption in skeletal remains from Spitalfields Collection (Natural History Museum London) and Maurice Stack's Collection (Royal College of Surgeons of England) of individuals even prior to birth and panoramic images of the London School of Medicine and Dentistry patients 2-24 years of age. The sample included white and Bangladeshi males and female. Each tooth was evaluated and assigned a category based on the Moorrees method and eruption was assessed based on

Bengston Method (Moorrees et al 1963: Bengston, 1935). A table was created for each tooth present at each age and stage of development of those teeth. The median stage of each tooth for each age group was determined for each sex and combined sexes. From these medians an atlas was hand drawn for each age group. The atlas depicts from 30 weeks in utero until the age of 23.5. The majority of the atlas is in year increments. The intent of the atlas is for users to compare a panoramic radiograph to the depiction, to get an age estimate. An additional computer-based scoring method was also developed from the data collected. This method allows the user to input the sex of patient. Then the user can assign each tooth a developmental and eruption stage to get a more specific result (AlQahtani et al., 2010).

Studies have evaluated the effectiveness of the London Dental Atlas in different populations. Pavlovic et. al use a sample of a Portuguese population and found the London Atlas to overestimate age an average of 1.2 months which was not statistically significant. In addition, the right and left side had no difference (Pavlovic et al., 2017). Another study using the London Dental Atlas on a South African sample found the London Atlas overestimated age and this was statistically significant. There was also a difference between age estimation error between males and females (Ishwarkumar et al., 2022).

A systematic review and meta-analysis were conducted to evaluate the accuracy of the London Dental Atlas through five databases following the PRISMA guidelines. The overall search resulted in 24 studies to be reviewed qualitatively and 17 studies to be quantitatively assessed. 21 out of 24 of the studies had low risk of bias with sound methodology. Only a few of these studies had population from the United States of America. The meta-analysis found that the London Dental Atlas slightly overestimated chronological age, however, this was non-significant (Jacometti et al., 20222).

CHAPTER 3

AIMS OF THE INVESTIGATION

3.1 Specific Aims

The purpose of this study is to evaluate the accuracy of the London Atlas of Human Tooth Development and Eruption on the multiethnic North Philadelphia Population of Temple University Kornberg School of Dentistry's Department of Orthodontics. The specific aims of this study are:

1. To determine the accuracy of the London Atlas in dental age estimation compared to the chronological age of the current patients at Temple's Department of Orthodontics.
2. To identify the likelihood that individual teeth to deviate from the London Atlas estimated dental age.
3. To evaluate the correlation between the London Atlas's estimated dental age and the number of teeth that deviate from this age.

3.2 Significance

The importance of this study is to evaluate the effectiveness of the London Atlas in the North Philadelphia population and how individual teeth variations play a role in the accuracy. The result of the study may determine a need for re-evaluation of dental age estimation for the modern population.

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CHAPTER 4

MATERIALS AND METHODS

4.1 Data Collection

200 patients being evaluated for treatment at Temple University Kornberg School of Dentistry Department of Orthodontic were chosen for this study. All patients were evaluated prior to any orthodontic treatment from May 1st, 2022 to May 1st 2023. All patients had a dental radiograph in the form of a panoramic image taken for diagnostic purposes. Radiographs were initially stored on Dolphin Software and were standard of care for orthodontic screenings or records appointments. No additional imaging, photographs, or exams were needed for this study.

IRB approval was acquired shown in Appendix A, and 200 patients were selected that met the following inclusion/exclusion criteria:

Inclusion Criteria

- Subjects with panoramic radiograph from May 2022-May 2023
- Subjects aged 7-12 years old at time of radiograph imaging
- Subjects with panoramic images taken for diagnostic purposes at Temple University's Department of Orthodontics
- Panoramic images of diagnostic quality

Exclusion Criteria

- Subjects with radiographs taken outside the specified time period
- Subjects with radiographs taken younger than 7 years of age and 13 years or older
- Subjects undergoing orthodontic treatment

- Subjects with previous orthodontic treatment
- Subjects with previous extractions
- Subjects with congenitally missing teeth
- Subjects with radiographs that are of poor quality or do not capture all primary and/or permanent dentition

As patients were identified, an excel spreadsheet was created to list patients name in the first column followed by a de-identified study number. The excel spread sheet was stored on password-protected university computer (Table 1**).** The list was permanently deleted once data collection was complete. A second data collection spreadsheet was created to record the patient's de-identified number, gender, chronological age at time of radiograph, London Atlas dental age estimation, and each maxillary and mandibular right central to second molar. These teeth were abbreviated using the Alphanumeric notation for teeth numbering. (Table 2**).** Panoramic radiographs of diagnostic quality (Figure 1) were stored on a word document and de-identified by assigning them the same patient de-identified study number. All data collection templates were stored on HIPPA compliant, password-protected university computer.

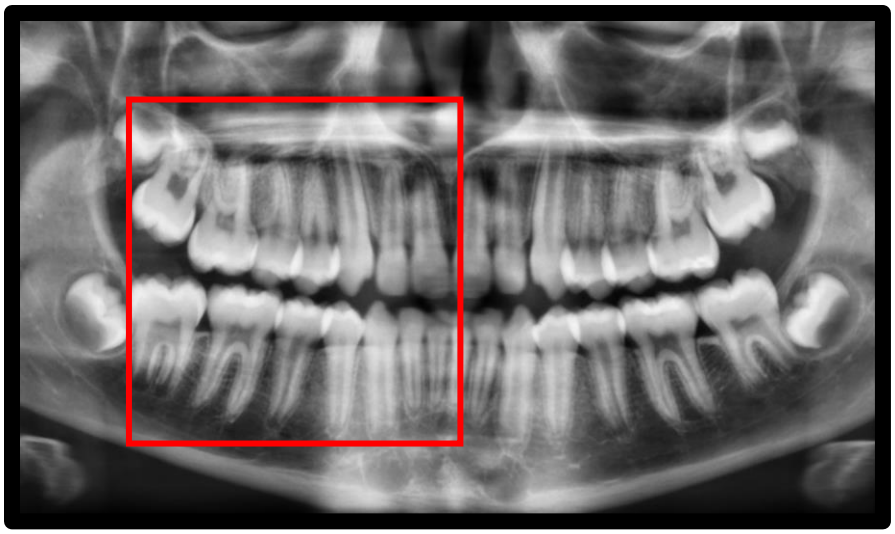

Figure 1. Diagnostic Radiograph. Radiograph of diagnostic quality where all roots are visible and with red box outlining teeth analyzed.

Table 1. *De-identified Spreadsheet*

Patient Name	Patient Study Number (#)

Table 2. *Data Collection for Panoramic Radiographs*

#	Gender	Chrono-logical Age	Dental Age	U 1	U 2	U 3	U 4	U 5	U 6	U 7	L 1	L 2	L 3	L 4	L 5	L 6	L 7

4.2 Dental Age Estimation

The Atlas of Human Tooth Development and Eruption was utilized to estimate the dental age for both male and females (Figure 2). The examiner evaluated each radiograph of the participants and compared it to the London Dental Atlas. All images were utilized except for the development of the third molars. Although only children ages 7-12 were utilized any age could be selected depending on the development of the majority of the developing teeth.

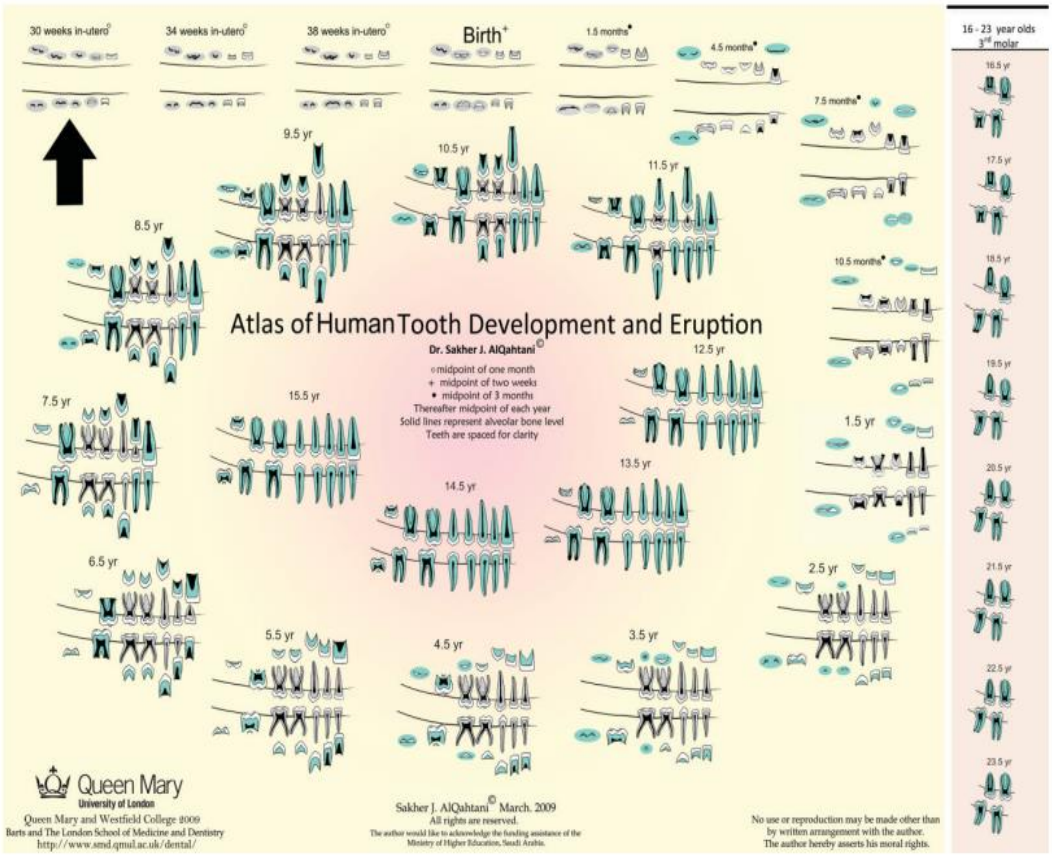

Figure 2. The London Atlas of Human Tooth Development and Eruption. (AlQahtani et al., 2010)

Each individual tooth on the right side of the panoramic image was assessed on the stage of development and compared to the Moorees stages (Moorees et al 1963) and eruption based on Bengston's method (Bengston, 1935) (Figures 3,4,5,6). Both primary and permanent teeth were evaluated and there relationship compared to the alveolar bone height or primary root length that is resorbed. The teeth were noted which stage they were at of each so that once a total age was selected each individual tooth could be compared.

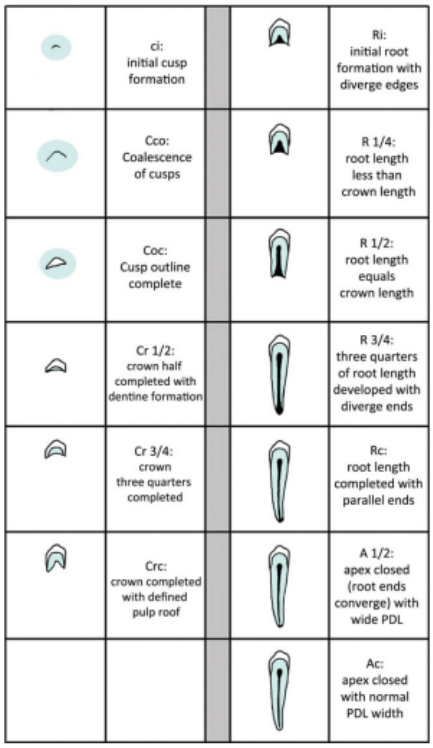

Figure 3. Moorrees' Stages of Tooth Development for Single Rooted Teeth. (Moorrees et al. 1963)

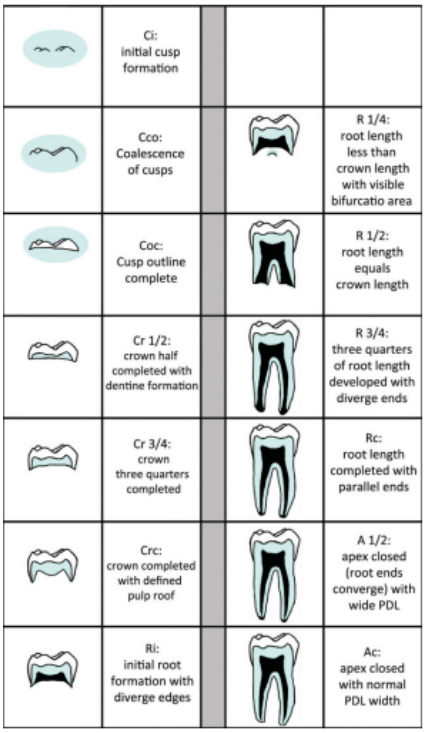

Figure 4. Moorrees' Stages of Tooth Development for Multi-rooted Teeth. (Moorrees et al. 1963)

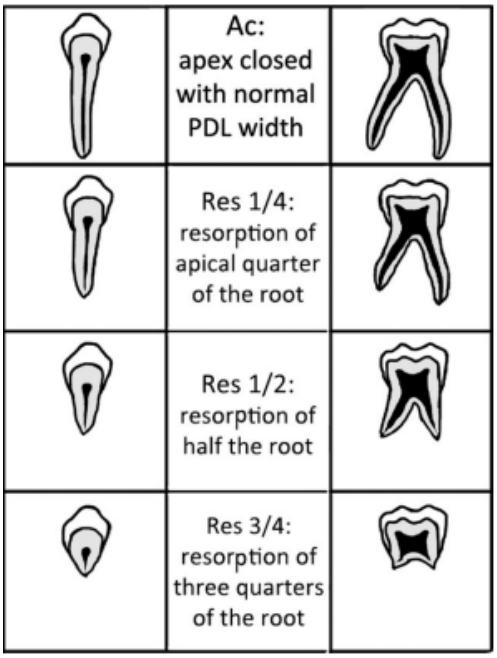

Figure 5. Moorrees' Stages of Tooth Development for Resorption of Primary Teeth. (Moorrees et al. 1963)

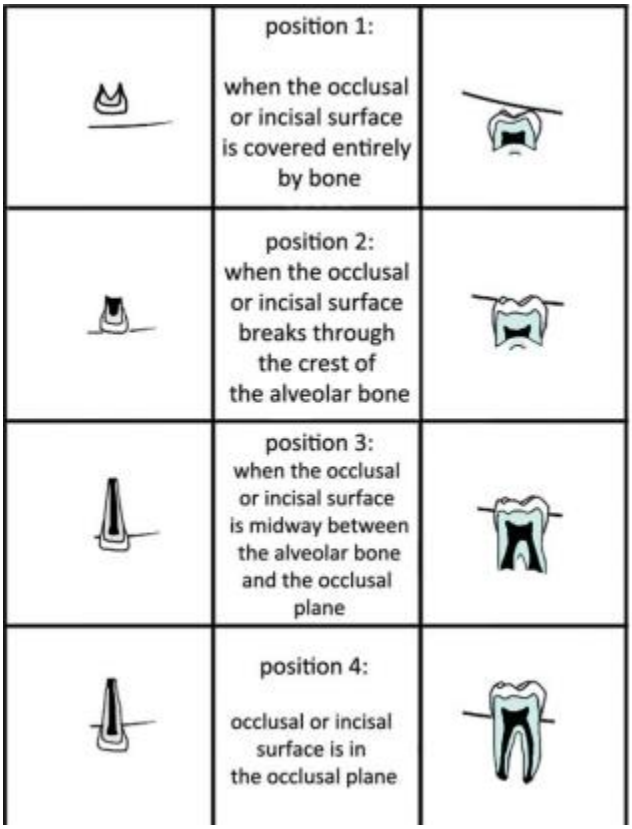

Figure 6. Bengston's Method of Dental Eruption to Alveolar Bone Height. (Bengston,1935)

An age was selected by evaluating which depiction of overall tooth development matched the panoramic image of the participant most accurately by comparing each tooth. To ensure the investigator was associating the London Dental Atlas depiction with the actual stage of tooth development, the associated table from AlQahtani et al., 2010 was used as a cross reference (Figure 7-9). When a participant had tooth development and eruption characteristics representative of multiple age groups the London Dental Atlas estimated age that had more teeth similar to the participants panoramic radiograph was selected. Patients age estimation use the Atlas of Human Tooth Development and Eruption was recorded under the Dental Age column in Table 2.

	Maxilla					Mandible				
			Tooth formation stage					Tooth formation stage		
Age (years)	Tooth	Number of teeth	Minimum	Median	Maximum	Tooth	Number of teeth	Minimum	Median	Maximum
7.5[a]	i^1	2	Res 3/4	–	–	i_1	–	–	–	–
	i^2	13	Res ½	Res 3/4	–	i_2	2	Ac	–	–
	c'	24	Ac	Ac	Ac	c,	24	Ac	Ac	Ac
	m^1	24	Ac	Ac	Res ½	m_1	24	Ac	Ac	Res ½
	m^2	24	Ac	Ac	Res ½	m_2	24	Ac	Ac	Res ¼
	I^1	24	R ¼	R 3/4	Rc	I_1	24	R 3/4	Rc	A ½
	I^2	24	R ¼	R ½	Rc	I_2	24	R ¼	R 3/4	A ½
	C'	24	Ri	R ¼	R ½	C,	24	Ri	R ¼	R ¼
	P^1	24	Cr 3/4	Ri	R ¼	P_1	24	Ri	Ri	R ¼
	P^2	24	Cr 3/4	Crc	R ¼	P_2	24	Crc	Crc	R ¼
	M^1	24	R ¼	R 3/4	A ½	M_1	24	R 3/4	R 3/4	A ½
	M^2	24	Cr ½	Cr 3/4	R ¼	M_2	24	Cr ½	Cr 3/4	R ¼
	M^3	4	–	–	Ci	M_3	8	–	–	Ci
8.5[a]	i^2	6	Res 3/4	–	–	i_2	–	–	–	–
	c'	24	Ac	Ac	Res ¼	c,	24	Ac	Ac	Res ½
	m^1	24	Res ¼	Res ½	Res ½	m_1	24	Res ¼	Res ¼	Res ½
	m^2	24	Ac	Res ½	Res ½	m_2	24	Ac	Ac	Res ¼
	I^1	24	R ½	Rc	A ½	I_1	24	R 3/4	Ac	Ac
	I^2	24	R ¼	R 3/4	Rc	I_2	24	R ¼	A ½	Ac
	C'	24	Ri	R ¼	R 3/4	C,	24	R ¼	R ¼	R 3/4
	P^1	24	Ri	Ri	R ½	P_1	24	Ri	R ¼	R ½
	P^2	24	Ri	Ri	R ½	P_2	24	Crc	Ri	R ¼
	M^1	24	R ½	Rc	Ac	M_1	24	R 3/4	R 3/4	A ½
	M^2	24	Crc	Ri	R ¼	M_2	24	Cr 3/4	Ri	R ¼
	M^3	13	–	Ci	Coc	M_3	20	–	Ci	Cco
9.5[a]	c'	22	Ac	Ac	–	c,	22	Ac	Res ¼	–
	m^1	24	Res ¼	Res ½	Res 3/4	m_1	24	Res ¼	Res ¼	Res 3/4
	m^2	24	Res ¼	Res ½	Res 3/4	m_2	24	Ac	Res ¼	Res ½
	I^1	24	R 3/4	Rc	A ½	I_1	24	Rc	Ac	Ac
	I^2	24	R ½	Rc	A ½	I_2	24	Rc	A ½	Ac
	C'	24	R ¼	R ½	R 3/4	C,	24	R ¼	R ½	R 3/4
	P^1	24	R ¼	R ¼	R 3/4	P_1	24	R ¼	R ½	R 3/4
	P^2	24	Ri	R ¼	R 3/4	P_2	24	Ri	R ¼	R 3/4
	M^1	24	Rc	Ac	Ac	M_1	24	R 3/4	A ½	Ac
	M^2	24	Ri	R ¼	R ½	M_2	24	Ri	R ¼	R ½
	M^3	17	–	Coc	Cr 3/4	M_3	22	–	Cco	Cr 3/4

Figure 7. AlQahtani Median Tooth Formation Stage Ages 7.5 -9.5. (AlQahtani et al., 2010)

	Maxilla					Mandible				
			Tooth formation stage					Tooth formation stage		
Age (years)	Tooth	Number of teeth	Minimum	Median	Maximum	Tooth	Number of teeth	Minimum	Median	Maximum
10.5[a]	c'	20	Ac	Res ¼	–	c,	–	–	–	–
	m^1	17	Res ¼	Res ½	–	m_1	16	Res ¼	Res ½	–
	m^2	21	Res ¼	Res ½	–	m_2	18	Ac	Res ¼	–
	I^1	24	Rc	A ½	Ac	I_1	24	A ½	Ac	Ac
	I^2	24	Rc	A ½	Ac	I_2	24	Rc	Ac	Ac
	C'	24	R ½	R ¾	R ¾	C,	24	R ¾	R ¾	Rc
	P^1	24	R ¼	R ½	Rc	P_1	24	R ¼	R ½	Rc
	P^2	24	Ri	R ½	Rc	P_2	24	R ¼	R ½	R ¾
	M^1	24	Rc	Ac	Ac	M_1	24	Rc	Ac	Ac
	M^2	24	R ¼	R ½	R ½	M_2	24	R ¼	R ½	R ½
	M^3	23	–	Coc	Cr ½	M_3	23	–	Cco	Cr ½
11.5[a]	c'	17	Ac	Res ¾	–	c,	4	Res ¼	–	–
	m^1	8	Res ½	–	–	m_1	6	Res ¼	–	–
	m^2	17	Res ¼	Res ¾	–	m_2	18	Ac	Res ½	–
	I^1	24	Rc	Ac	Ac	I_1	24	Rc	Ac	Ac
	I^2	24	R ¾	Ac	Ac	I_2	24	A ½	Ac	Ac
	C'	24	R ½	R ¾	Rc	C,	24	R ¾	R ¾	A ½
	P^1	24	R ½	R ¾	A ½	P_1	24	R ½	R ¾	A ½
	P^2	24	R ¼	R ¾	Rc	P_2	24	R ¼	R ¾	A ½
	M^1	24	A ½	Ac	Ac	M_1	24	A ½	Ac	Ac
	M^2	24	R ¼	R ½	Rc	M_2	24	R ¼	R ½	R ¾
	M^3	24	Ci	Cr ½	Ri	M_3	24	Ci	Coc	R ¼
12.5[a]	m^2	2	Res ¾	–	–	m_2	10	Res ¼	–	–
	I^1	24	Rc	Ac	Ac	I_1	24	A ½	Ac	Ac
	I^2	24	Rc	Ac	Ac	I_2	24	A ½	Ac	Ac
	C'	24	R ¾	Rc	Rc	C,	24	R ¾	A ½	Ac
	P^1	24	R ¾	Rc	A ½	P_1	24	R ¾	Rc	Ac
	P^2	24	R ½	R ¾	A ½	P_2	24	R ½	Rc	Ac
	M^1	24	Ac	Ac	Ac	M_1	24	Ac	Ac	Ac
	M^2	24	R ¼	R ¾	Rc	M_2	24	R ¼	R ¾	Rc
	M^3	24	Cco	Cr ¾	R ¼	M_3	24	Ci	Cr ½	R ¼

Figure 8. AlQahtani Median Tooth Formation Stage Ages 10.5 -12.5. (AlQahtani et al., 2010)

	Maxilla					Mandible				
			Tooth formation stage					Tooth formation stage		
Age (years)	Tooth	Number of teeth	Minimum	Median	Maximum	Tooth	Number of teeth	Minimum	Median	Maximum
13.5[a]	I^1	24	Ac	Ac	Ac	I_1	24	Ac	Ac	Ac
	I^2	24	Ac	Ac	Ac	I_2	24	Ac	Ac	Ac
	C'	24	Rc	Rc	A ½	C,	24	Rc	A ½	Ac
	P^1	24	Rc	A ½	Ac	P_1	24	R ¾	A ½	Ac
	P^2	24	R ½	Rc	Ac	P_2	24	R ¾	Rc	Ac
	M^1	24	Ac	Ac	Ac	M_1	24	Ac	Ac	Ac
	M^2	24	Coc	R ¾	A ½	M_2	24	R ½	R ¾	A ½
	M^3	24	Ci	Cr ¾	R ¼	M_3	24	Ci	Cr ½	R ¼
14.5[a,b]	C'	24	Rc	A ½	Ac	C,	24	A ½	Ac	Ac
	P^1	24	A ½	Ac	Ac	P_1	24	A ½	Ac	Ac
	P^2	24	Rc	Ac	Ac	P_2	24	Rc	Ac	Ac
	M^2	24	Rc	Rc	Ac	M_2	24	Rc	Rc	Ac
	M^3	24	Cr ¾	R ¼	R ¼	M_3	24	Cr ½	R ¼	R ¼
15.5[a,b]	C'	24	R ¾	Ac	Ac	C,	24	Ac	Ac	Ac
	P^1	24	Ac	Ac	Ac	P_1	24	Ac	Ac	Ac
	P^2	24	Ac	Ac	Ac	P_2	24	Ac	Ac	Ac
	M^2	24	Rc	A ½	Ac	M_2	24	Rc	A ½	Ac
	M^3	24	Cr ½	R ¼	R ¾	M_3	24	Cr ½	R ¼	R ¾
16.5[a,c]	C'	24	Ac	Ac	Ac	C'	24	Ac	Ac	Ac
	M^2	24	A ½	Ac	Ac	M_2	24	A ½	Ac	Ac
	M^3	24	Ri	R ½	R ¾	M_3	24	Crc	R ½	R ¾
17.5[a,c]	M^2	24	Ac	Ac	Ac	M_2	24	Ac	Ac	Ac
	M^3	24	Crc	R ½	Rc	M_3	24	R ¼	R ½	Rc

Figure 9. AlQahtani Median Tooth Formation Stage with Ages 13.5 -17.5. (AlQahtani et al., 2010)

4.3 Individual Tooth Versus Dental Age

The investigator compared the panoramic image of each subject to the depiction of the London Atlas for the dental age selected for that subject. Each tooth was specifically compared and assigned developmental status based on the Moorrees method of development. Any tooth that was accelerated or decelerated in development for the permanent central incisor to second premolar on patient's right maxilla and mandible was recorded. A plus symbol (+) was used for teeth that were accelerated and a minus symbol (-) was used for teeth that were decelerated compared to the estimated depiction. The cell was left without a plus or a minus for any teeth that match the selected depiction of the London Dental Atlas. All teeth on the patient's right side (from central incisor to second molar) were evaluated.

4.4 Statistical Analysis

20 panoramic radiographs were randomly selected and re-evaluated using the London Atlas. Intra-examiner reliability was assessed through intraclass correlation coefficients. Shapiro-Wilk normality test was used to calculate normality.

Aim 1**:** Average chronological age and estimated dental age was calculated. Accuracy for perfect agreement, 1/12-year deviation, and within one standard deviation of a chronological year was determined. Spearman correlation test was run to determine correlation between chronological age and dental age.

Aim 2**:** For inaccuracy of individual teeth compared to estimated dental age, frequencies were calculated for each tooth for total discrepancy, accelerated alone, and delayed alone.

Aim 3: Overall correlation between dental age and discrepancy of individual teeth were examined with Spearman correlation.

CHAPTER 5

RESULTS

5.1 Patient Characteristics

A total of 257 panoramic radiograph of patients who attended screening or records appointments within May 1st, 2022 to May 1st, 2023 were evaluated for this study. 57 of these radiographs were excluded due to poor diagnostic quality/inability to evaluate all root apices or due to congenitally missing or extracted teeth. A total of 200 panoramic radiographs were then evaluated for age estimation. These subjects were within the age range of 7-12 years old, did not have presence of congenitally missing or extracted teeth, and the panoramic radiographs were of diagnostic quality with visualization of root apices. Of the 200, 103 (51.5%) patients were female and 97 (48.5%) were male. The patients age ranged from 7.17 to 12.5 years old and the average age of the sample was 10.15 years old. This is summarized in Table 3. Shapiro-Wilks normality test indicated the data was not normally distributed. Therefore, Spearman correlation tests will be run to test correlation.

Table 3. *Baseline Patient Characteristics*

N	200
Average age	10.15
Gender (%)	
Female	103 (51.5%)
Male	97 (48.5%)

5.2 Chronological Age versus Dental Age

All panoramic radiographs included in the study were assigned a dental age. 20 of these radiographs were randomly reassessed for reliability. Inter class correlation analysis showed high reliability (ICC=0.976). Average dental and chronological age were compared. The average estimated age was 10.38. The overall difference between estimated age and chronological age was 0.23 years, with estimated age being advanced relative to chronological age. The London Dental Atlas provided dental age estimates that strongly correlated ($p<0.001$, rho=0.835) with chronological age. This was statistically significant. Accuracy for the London Atlas in the North Philadelphia population is seen in Table 4.

Table 4. *Accuracy of the London Atlas*

Set at	Frequency	Percentage (%)
0% Discrepancy	9/200	4.5
1/12 of year deviation	18/200	18
One standard deviation	143	71.5

Figures 10 shows an example of a subject whose chronological age is 9.5. When comparing the panoramic image to the London Atlas it is evident the patient's dental age is older. The patient's dental age was determined to be 11.5 years old. Note that the upper right second premolar and canine are accelerated in alveolar eruption and the lower right second premolar is delayed in root development compared to the estimated dental age depiction. Figure 11 gives a subject example where the London Atlas correctly matches dental age to chronological age. This subject had three teeth delayed in development which are upper right maxillary lateral incisor, upper right mandibular lateral incisor, and upper right maxillary central incisor. Overall, the patient dental age estimation of 8.5 matched

the chronological age. Appendix B and C show each patient's gender, chronological age, and estimated dental age.

Figure 10. Patient Example Age 9.5. London Atlas overestimated age to be 11.5.

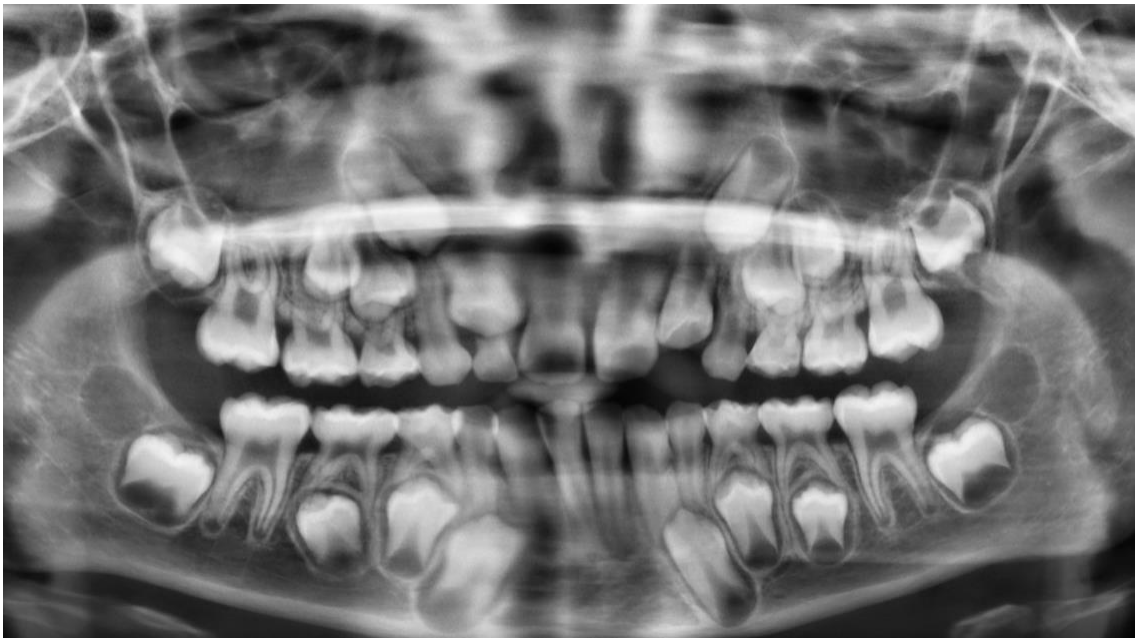

Figure 11. Patient Example Age 8.5. Example of a patient whose chronological age is 8.5 years old and estimated dental age is 8.5.

5.3 Individual Tooth Versus Dental Age

Each tooth per panoramic image was assessed to see if it developmentally matched the assigned dental age. The number of deviations per tooth was computed and summarized (Table 5 and 6). The average number of deviations per tooth was 25.9 (Table 7). The tooth with the most deviations was upper right second molar (UR7) with 49/200 (15 accelerated, 34 delayed) that deviated from predicted dental developmental stage. The tooth with the least amount deviations was lower right first molar (LR6) with 5/200 (2 accelerated, 3 delayed) that deviated from predicted dental developmental stage. Appendix B and C show the raw data for patients and highlights how each patient's individual teeth deviated from their estimated dental age with + (accelerated) or – (delayed).

Table 5. *Average Number of Deviation from Dental Age per Tooth*

Tooth	UR1	UR2	UR3	UR4	UR5	UR6	UR7
Total	19	17	24	26	41	7	49
Accelerated	5	5	11	20	25	4	15
Delayed	14	12	13	6	16	3	34

Table 6**.** *Total Number of Deviations of Dental Age of Each Tooth (Maxillary)*

Tooth	LR1	LR2	LR3	LR4	LR5	LR6	LR7
Total	22	21	22	32	48	5	29
Accelerated	3	4	10	15	26	2	21
Delayed	19	17	12	17	22	3	8

Table 7. *Total Number of Deviations of Dental Age of Each Tooth (Mandibular)*

Deviation	Mean	Standard Deviation
Accelerated	11.9	8.2
Delayed	14	7.8
Both	25.9	8.1

5.4 Dental Age Correlation with Tooth Deviations

Next, total number deviations per patient was compared to dental age. It was assessed for accelerated, delayed and both accelerated and delayed. Spearman correlation statistical results are summarized in Table 8. All results were found to be statistically significant. There was a weak negative correlation between dental age and number of teeth that were accelerated. Similar results were found with teeth that were delayed. When combining both teeth that were accelerated and delayed, there was a moderate to weak negative correlation. An example of a subject where more teeth are delayed or accelerated can be seen in Figure 12. The patient was 7.6 years at time the radiograph was taken. The stars show the 6 teeth that are either accelerate or delayed compared to the depiction of the London Atlas. This exemplifies the results that the younger the patient the more likely they will have an increase in number of teeth deviated. An example of a subject where minimal teeth are delayed or accelerated can be seen in Figure 13. The patient was one of the oldest subjects, highlighting the results that the older the patient is the less likely to have teeth that are accelerated or delayed.

Table 8. *Correlation between Deviated Teeth and Estimated Dental Age*

Deviation	Rho	P=Value
Accelerated	-0.167	0.018*
Delayed	-0.197	0.005*
Both	-0.364	<0.001*

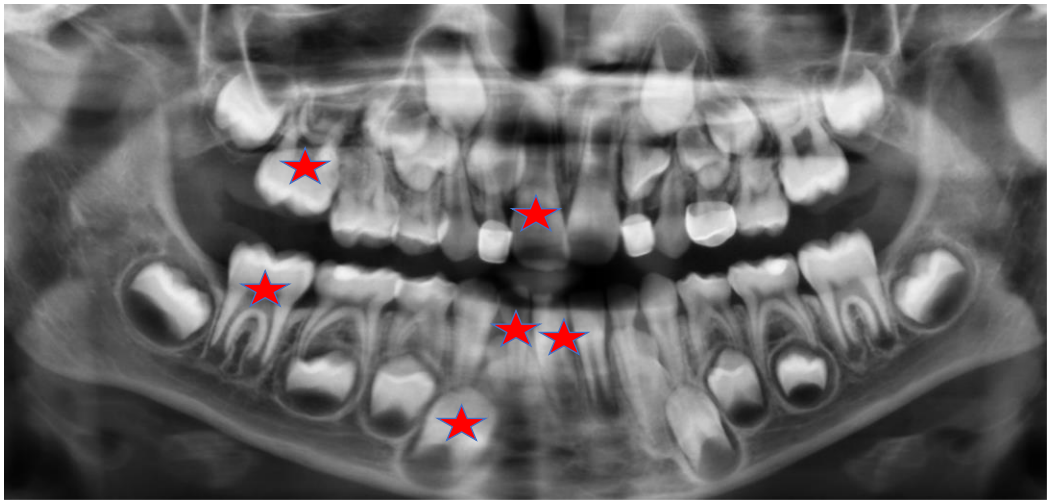

Figure 12. Patient Example Age 7.5. The patient's chronological age is 7.6 with 6 total teeth deviated (shown by stars).

Figure 13. Patient Example Age 12.5. The patient's chronological age is 12.5 and dental age estimation is 12.5.

CHAPTER 6

DISCUSSION

The eruption and development of teeth is a very common method of age estimation because teeth are proposed to be under different control than bone development and less susceptible to be influence by environmental factors ((Demirijian, 1985). The need for accurate age estimations is not only useful in branches of dentistry but also in situations of mass casualties and unknown person identification (Sato et al., 2022). Therefore, the development of different dental age estimators has continuously been published in the literature (Guy,2001). Since previous dental age estimators were developed from a single population, the London Dental Atlas was developed utilizing a more modern and diverse population base The London Dental Atlas was developed by recording the development of each tooth for each age of skeletal remains as well as white and Bangladeshi males and females. The median developmental stage of each tooth at each age was drawn as a panoramic image. All ages were combined to form an atlas. Users of the London Dental Atlas must compare the panoramic image of the patient and match it to the closest image of the atlas to get an age estimate (AlQahtani et al., 2010).

6.1 Interpretation of the Results

6.1a Comparing Chronological and Estimated Age

The average chronological age for each subject in the study was 10.15 years old and the estimated age was 10.38. The average difference in age was 0.23 with an overestimation of chronological age. When age was estimated exactly, there was 9 of 200 (4.5%) subjects who had the exact age estimated. When accuracy was set at within one standard deviation of each chronological age the accuracy was 71.5 %. From these results

it can be assumed that the London Atlas may be highly accurate at predicting chronological age for the North Philadelphia multiethnic population. Patient Example 8.5 shows how the London Atlas can match chronological age to dental age. However, it is noted there will be some deviations of teeth that do not perfectly match the median development for each tooth.

6.1b Individual tooth versus Dental Age

Dental age was selected for each of the 200 panoramic images and each tooth on the right side of the patient was evaluated for being accelerated or decelerated compared to the estimated age. To the best of the investigators knowledge no study has evaluated specific teeth development of each tooth for the London Atlas. The results of this study indicates that the upper right second molar has the most variation in comparison to the estimated dental age. When looking at the raw data in Appendix B and C and the associated radiographs, possible preliminary observations suggest relationship of the second molar to the third molar, insufficient alveolar bone, and developmental variations of the tooth lead to these deviations. The radiographs were also assessed for caries and previous dental work such as stainless-steel crowns and their impact on development. No observations were made that would indicate they would impact development of the teeth.

The second most common variation of dental development was found in the lower second premolar. This is expected based on previous observations of dental development (Klein et al. 2013). The least amount of variation of dental development was the lower and then upper first molar. This could be due to the fact they are the first permanent teeth to erupt into the arch and the first teeth to fully develop, so for older patients in this

sample they would have developed fully on average at 9.5 to 10.5 years old (Proffitt, 2019).

6.1c Dental Age Correlation with Tooth Deviations

This study showed that as a child ages, there is less teeth that are delayed or accelerated. There is slightly larger negative correlation between delayed teeth to age than accelerated teeth and even larger when accounting for both. When analyzing this result, one possible reason is due to the selected age range for the study. The highest age for evaluation was up to but less than 13 and the lowest was 7. Based on the atlas at 11.5 and 12.5 years old more teeth have reached their full development, and less variation would be expected. At the age of 7.5 all permanent teeth are still developing so the total amount of variation in development would be expected.

6.2 Comparison of Results and Literature

Since the development of the London Dental Atlas numerous studies have looked at the effectiveness and has found differing results. A study done in 2019 with a mixed sample of African Americans, Asian Americans, European American, and Native Americans found that the London Atlas underestimates dental age and is only accurate 23% of the time (Adams, 2019). This differs than the results of this study where the London Atlas slightly overestimates dental age and is accurate 71% of the time. Another study done evaluated panoramic radiographs of Brazilian children. The study further looked at evaluating differences between right and left side of patients and males versus females for difference in predicting dental age. This research found similar results to right and left sides of the jaw and that girls had higher estimated values. An interesting finding was that when determining dental age based solely on third molar development, high

variation in age estimation was seen compared to chronological age (Sousa, 2020). Another study also found similar results with males versus females as well as the London Atlas to be least predictive when groups were greater than 13 years old. This research was conducted on Western Saudi subjects 2-20 years of age (Alshiri, 2015). Due to the known variation in third molar analysis a younger age range was selected for this study. Therefore, we found there less variation with age because we evaluated a younger population without taking into account the third molars.

A systematic review for the London Atlas was completed in 2022. The aim of the meta-analysis was to evaluate estimated verse chronological age. The result of the literature search was 24 total studies eligible for qualitative analysis and only 17 of those included for quantitative analysis. Based on the description and summary of aims of each study included in the analysis, no studies evaluated individual teeth development to the whole (Jacobmetti et al. 2022). Each study was evaluated for bias and overall had a low risk. The results of the meta-analysis support the results found in this study. 12 studies found overestimation, 9 studies found underestimation, and one found neither. Overall, there is a slight tendency for overestimation which was insignificant (Jacometti, 2022). Only a few of the studies included were conducted in America (Santana et al. 2017 and Adams et al 2019). Santana et al. conducted their analysis on 194 subjects ages 6 to under 18. Their findings were a slight non-significant underestimation of age. A shortcoming to this study is the sample population was from three decades prior to 1999 (Santana et al. 2017). Since there has been changes in the US population since then, such as levels of obesity, the study lacks the ability to make conclusions on a contemporary US population.

6.3 Limitations

One limitation to the study is the number of investigators collecting and evaluating the subject data. One investigator found the sample and performed the London Atlas Dental age estimation. Although the investigator was tested for accuracy, having two investigators performing the London Atlas on the radiographs would have given better accuracy of evaluating the radiographs.

Another limitation to the study is that race and ethnicity were not recorded for the population being sampled for dental age estimation. Based on the United States Census Burea population estimates of 2020 to 2023, The percentage of racial breakdown of the city of Philadelphia is White alone (37%), Black or African American alone (40.1%), Asian alone (7.6%), Hispanic or Latino alone (15.7%) and Two or More races (6.3%) (US Census Bureau, 2023). Although Temple Orthodontic Clinic treats a diverse sample of patients, it cannot be assumed the sample was representative of the Philadelphia population. In addition, further racial and ethnic breakdown of statistical analyses could not be conducted to give more specific results and conclusions.

6.4 Future Research

Future research for dental age estimation can take on many forms. First to expand on the data that has been collected for this study, the patient's ethnicity could be recorded to evaluate if the London Dental Atlas is more accurate for a specific racial group or ethnicity. Furthermore, the data set can be analyzed with other dental age estimation methods such as Demorijian, Willems, and Moorrres. This can be used to determine the efficacy of different methods in the North Philadelphia multiethnic population. Then the

data can be analyzed to evaluate which dental age estimation method is most reliable and accurate for the North Philadelphia population.

Many studies have evaluated different factors on dental eruption. One of these factors include obesity. It has been noted that advanced physical and sexual maturity are correlated to an increased body mass index (Mack, 2013). Studies have looked at obesity and dental development and found that dental eruption can be increased up to a year and a half when the study subject was obese (Nicholas et al., 2018). When specifically looking at eruption of permanent first molars and incisors in six years old, overweight to obese children are two times more likely to have those teeth erupted than children of normal weight or below.

These findings fuel the need for re-evaluation of dental age estimation methods on contemporary populations. Additional studies evaluating the London Atlas can focus on weight of children, gender, and ethnicity, which could ultimately result in more accurate estimation tools accounting for these patient factors.

CHAPTER 7

CONCLUSION

Based on the results of this present study, the following conclusions have been made:

1. The London Dental Atlas has 71% accuracy with dental age being highly correlated with chronological age. This suggests that it may be highly accurate to use the London Atlas for the North Philadelphia population especially for older children.
2. The most common tooth with dental age deviations was the upper second molar. Preliminary observations suggest this is due to developmental variations of the tooth, relationship to third molar, and insufficient alveolar bone. The tooth with the least deviations was the mandibular first molar.
3. These findings suggest that children with older estimated dental ages have fewer teeth that are delayed or accelerated.

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APPENDIX A

IRB APPROVAL

Temple University
Office of the Vice President for Research

Research Integrity & Compliance
Student Faculty Center
3340 N. Broad Street, Suite 304
Philadelphia PA 19140

Institutional Review Board
Phone: (215) 707-3390
Fax: (215) 204-4609
e-mail: irb@temple.edu

Approval for a Project Involving Human Subjects Research that is Approved as Exempt

Date: 19-Jun-2023

Protocol Number:	30714
PI:	JAMES J. SCIOTE
Review Type:	EXEMPT
Approved On:	19-Jun-2023
Risk:	Minimal risk
Committee:	A2
Sponsor:	NO EXTERNAL SPONSOR
Project Title:	Evaluation of the London Dental Atlas inaccuracies: A retrospective chart review

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The IRB approved the protocol 30714.

The study was approved under Exempt review. The IRB determined that the research **does not require a continuing review**, consequently there is not an IRB approval period.

As this research was approved as Exempt, the IRB will not stamp the consent or assent form(s).

Note that all applicable Institutional approvals must also be secured before study implementation. These approvals include, but are not limited to, Medical Radiation Committee ("MRC"); Radiation Safety Committee ("RSC"); Institutional Biosafety Committee ("IBC"); and Temple University Survey Coordinating Committee ("TUSCC"). Please visit these Committees' websites for further information.

Finally, in conducting this research, you are obligated to submit the following:

- **Amendments - Any changes to the research that may change the Exempt status of this study must be reviewed and approved by the IRB prior to implementation.** Examples of such changes are: including new, sensitive questions to a survey or interview, changing data collection such that de-identified data will now be identifiable, including an intervention in the methods, changing variables to be collected from medical charts, decreasing confidentiality measures, including minors or adults lacking capacity to consent as subjects when previously only adults with capacity to consent were to be enrolled, no longer collecting signed HIPAA Authorization, etc. Please reach out to the IRB Staff with any questions about if a change to the study warrants an Amendment.
- **Reportable New Information** - Using the Reportable New Information e-form, report new information items such as those described in HRP-071 Policy - Prompt Reporting Requirements to the IRB **within 5 days**.
- **Closure report** - Using a closure e-form, submit when the study is permanently closed to enrollment; all subjects have completed all protocol related interventions and interactions; collection of private identifiable information is complete; and analysis of private identifiable information is complete.

For the complete list of investigator responsibilities, please see the HRP–070 Policy – Investigator Obligations, the Investigator Manual (HRP-910), and other Policies and Procedures found on the Temple University IRB website: https://research.temple.edu/irb-forms-standard-operating-procedures.

APPENDIX B

RAW DATA OF MAXILLARY TEETH FOR SUBJECTS

Table 9. *Data Collected for Subject's Maxillary Teeth*

PSN	Gender	Chronological Age	Dental Age	UR 1	UR 2	UR 3	UR 4	UR 5	UR 6	UR 7
1	F	7yr 1 mo	7.5			(+)	(+)	(+)		
2	F	12 yr 5 mo	13.5							
3	M	12 yr 2 mo	11.5							
4	M	10 yr 2 mo	9.5			(+)	(+)			
5	F	10yr 7mo	11.5		(-)		(+)			(+)
6	F	9yr 2mo	9.5	(+)	(+)		(+)	(+)		
7	M	8yr 2 mo	8.5	(-)		(+)			(-)	
8	M	11 yr 1 mo	12.5							
9	M	9yr 8 mo	9.5						(-)	
10	M	8 yr 11 mo	8.5				(+)			
11	M	8 yr 5 mo	9.5							
12	F	10 yr 4 mo	10.5			(+)	(+)	(+)		
13	F	7 yr 11 mo	8.5				(+)	(+)		
14	M	9 yr 5 mo	8.5	(-)	(-)		(+)			
15	F	10 yr 9 mo	10.5					(+)		(+)
16	F	11 yr 5 mo	12.5				(+)	(+)		
17	M	9 yr 2 mo	9.5		(+)	(-)	(-)			
18	M	7 yr 2 mo	7.5			(-)			(-)	
19	M	9 yr 8 mo	9.5				(+)	(+)		
20	F	10 yr 3 mo	10.5				(+)	(+)		
21	F	8 yr 5 mo	9.5							
22	F	9 yr 2 mo	9.5							
23	M	10 yr 0 mo	9.5							
24	F	7 yr 7 mo	7.5							
25	f	7yr 7 mo	7.5					(+)		(+)
26	F	9 yr	9.5							
27	F	7r 8 mo	8.5							
28	M	11 yr 1 mo	10.5							(-)
29	M	10 yr 8 mo	11.5							
30	F	8 yr 5 mo	8.5	(-)	(-)					
31	F	10 yr 3 mo	11.5							
32	M	9 yr 8 mo	9.5					(+)		

Table 9. *(continued)*

34	M	9 yr 8 mo	9.5	(-)	(-)					
35	F	12 yr 3 mo	12.5							(+)
36	M	9 yr 3 mo	8.5							(-)
37	M	10 yr 9 mo	10.5					(+)		(-)
38	M	11 ry 3 mo	11.5		(-)			(-)		
39	F	10 yr 7 mo	11.5							
40	F	10 yr 10 mo	10.5							
41	M	7 yr 5 mo	8.5				(+)			
42	F	8 yr 8 mo	8.5							
43	M	11 yr 3 mo	11.5							
44	F	9 yr 7 mo	10.5							(-)
45	F	7 yr 9 mo	7.5							(-)
46	F	10 yr 9 mo	10.5				(+)			(-)
47	M	11yr 5 mo	11.5							(+)
48	m	8 yr 6 mo	9.5							
49	F	11 yr 3 mo	10.5							
50	F	8 yr 8 mo	8.5							
51	F	11 yr 3 mo	11.5							
52	F	8 yr 8 mo	8.5							
53	M	12 5 mo	12.5				(-)	(-)		
54	F	11yr 6 mo	13.5							(-)
55	F	12 yr 0 mo	12.5							
56	M	8 yr 2 mo	8.5							
57	M	12ry 7 mo	11.5							
58	F	11 yr 4 mo	13.5							(-)
59	m	9 yr 5 mo	8.5							
60	f	8 yr 6 mo	8.5		(-)					
61	M	9 yr 11 mo	8.5	(-)			(+)			
62	M	10 yr 6 mo	9.5	(-)	(-)	(-)				
63	M	11 yr 0 mo	10.5							
64	M	10 yr 0 mo	9.5		(-)					
65	F	8 yr 11 mo	8.5	(-)	(-)			(-)		
66	M	7 yr 9mo	7.5					(+)		(+)
67	F	9 yr 10 mo	11.5							
68	F	10 yr 3 mo	11.5							
69	M	10 yr 2 mo	10.5							
70	F	11yr 1mo	10.5			(-)				
71	F	11 yr 5 mo	13.5							

Table 9. *(continued)*

72	M	11 yr 7 mo	11.5						(+)	
73	M	11yr5 mo	12.5							
74	F	12 yr 9 mo	12.5							
75	M	11 yr 9 mo	9.5							
76	F	12 yr 2 mo	12.5					(-)		(-)
77	M	9 yr 9 mo	10.5							(-)
78	M	11 yr 2 mo	10.5							
79	M	11 yr 0 mo	11.5							
80	F	12 yr 2 mo	13.5					(+)		
81	M	11 yr 7 mo	12.5							(-)
82	F	9 yr 3 mo	9.5					(+)		
83	M	10 yr 9 mo	9.5							
84	F	7 yr 10 mo	8.5	(-)						
85	F	8 yr 6 mo	8.5			(+)	(+)			
86	M	7 yr 7 mo	7.5		(-)	(-)				(+)
87	F	11 yr 4 mo	10.5			(-)				
88	M	11 yr 9 mo	11.5			(+)				
89	F	11 yr 5 mo	11.5							
90	F	10 yr 7 mo	12.5							
91	M	12 yr	11.5							
92	M	10yr 3 mo	10.5					(-)		(-)
93	F	11 yr 9 mo	12.5					(-)		
94	M	11 yr 6 mo	11.5							
95	M	11 yr 9 mo	11.5				(-)			(+)
96	F	10 yr 2 mo	10.5							(-)
97	M	11 yr 9 mo	11.5					(-)		
98	M	10 yr 1 mo	10.5							(-)
99	F	9 yr 4 mo	9.5							
100	M	10 yr 11 mo	11.5							
101	F	11 yr 7 mo	10.5							
102	M	9 yr 5 mo	11.5							
103	F	10yr 9 mo	11.5							
104	F	9 yr	9.5							
105	M	8yr 8 mo	8.5							
106	M	11.5 mo	11.5				(+)			
107	F	11 yr 3 mo	11.5							
108	F	10 yr	11.5							(-)
109	F	11 yr 4 mo	13.5			(+)				
110	M	9 yr	8.5							

Table 9. *(continued)*

111	F	10 yr	10.5			(-)				
112	M	11 yr 2 mo	11.5					(-)		
113	M	11 yr 11 mmo	12.5							(+)
114	F	9 yr 6 mo	9.5					(-)		
115	F	10 yr 4 mo	10.5							(-)
116	F	10 yr 8 mo	11.5							
117	F	8 yr 3 mo	9.5							(-)
118	M	11 yr 4 mo	12.5							(+)
119	F	8 yr 11 mo	8.5			(-)				(-)
120	F	8 yr 10 mo	10.5					(-)		(-)
121	F	9 yr 9 mo	9.5							(-)
122	M	8 yr 3 mo	8.5	(-)						
123	M	11 yr 11 mo	12.5					(+)		
124	M	10 yr 5 mo	10.5							
125	M	11 yr 6 mo	9.5		(-)	(+)				
126	F	10 yr 8 mo	13.5							
127	M	8 yr 1 mo	7.5				(-)			(+)
128	F	11 yr 2 mo	12.5							
129	F	11 yr 1 mo	12.5					(+)		
130	M	8 yr 8 mo	8.5				(+)	(+)		
131	M	11 yr 10 mo	11.5					(+)		
132	F	10 yr	11.5							(-)
133	M	11 yr 3 mo	11.5				(+)			
134	M	11 yr 8 mo	11.5							(-)
135	F	11yr 7 mo	10.5					(-)		(-)
136	F	10 yr 2 mo	10.5	(-)				(-)		(-)
137	M	11 yr 7 mo	10.5	(+)						
138	F	11yr 6 mo	12.5					(+)		
139	F	10 yr 4 mo	9.5			(+)				
140	F	11 yr 1 mo	11.5							
141	F	9 yr 1 mo	9.5				(+)	(+)		
142	M	10 yr 6 mo	9.5			(-)				
143	F	8 yr 5 mo	8.5					(+)	(+)	
144	F	11 yr 1 mo	10.5	(+)	(+)					
145	F	11 yr 3 mo	11.5							(+)
146	F	9 yr	8.5	(-)				(+)		
147	F	8 yr 8 mo	9.5							(-)
148	M	7 yr 1 mo	7.5							
149	M	7 yr 8 mo	8.5							(-)

Table 9. *(continued)*

150	M	10 yr 0 mo	9.5			(-)				(-)
151	F	11 yr 5 mo	12.5							
152	M	11 yr 11 mo	12.5							
153	F	11yr 9 mo	9.5							(-)
154	F	9 yr 1 mo	9.5							
155	M	10 yr 2 mo	11.5					(-)		(-)
156	M	11 yr 5 mo	10.5							(-)
157	M	11 yr 3 mo	11.5							
158	F	10 yr 9 mo	11.5							(-)
159	F	10 yr 1 mo	11.5							
160	F	10 yr 6 mo	11.5							
161	M	10 yr 8 mo	10.5				(+)		(+)	
162	F	7 yr 6 mo	7.5					(+)		
163	M	7 yr 10 mo	7.5							(+)
164	M	8 yr 7 mo	8.5		(+)					
165	M	7 yr 9 mo	7.5							(+)
166	M	11yr 8 mo	10.5					(+)		
167	F	9 yr 5 mo	10.5			(-)				
168	F	10 yr 11 mo	10.5							
169	F	10 yr 7 mo	10.5	(+)						(+)
170	M	9 yr 10 mo	9.5							
171	M	11 yr 9 mo	15.5							
172	M	11 yr 7 mo	11.5				(+)			
173	M	7 yr 11 mo	7.5							
174	M	11 yr 1 mo	10.5							
175	M	11 yr 0 mo	12.5							
176	M	8 yr 3 mo	7.5							
177	F	9 ry 10 mo	9.5							
178	F	9 yr 6 mo	10.5			(-)				
179	F	10 yr 10 mo	9.5							(-)
180	F	8 yr 8 mo	7.5					(-)		
181	F	11 yr 10 mo	11.5					(-)		
182	M	10 yr 10 mo	11.5							
183	M	11 yr 6 mo	11.5							
184	M	9 yr	9.5							
185	M	10 yr 4 mo	11.5							
186	F	8 yr 1 mo	8.5	(-)	(-)					
187	F	8 yr 11 mo	8.5	(-)						
188	F	11 yr	12.5					(+)		

Table 9. *(continued)*

189	F	12 yr 0 mo	11.5	(+)	(+)					
190	F	9 yr 0 mo	9.5							(-)
191	F	10 yr 6 mo	11.5							
192	F	10 yr 9 mo	12.5			(+)				
193	F	11 yr 7 mo	12.5							
194	F	11 yr 1 mo	11.5							
195	F	10 yr 0 mo	10.5			(-)				
196	M	7 yr 6 mo	7.5	(-)				(-)		
197	M	8 yr 11 mo	8.5			(+)	(+)			
198	M	10 yr 8 mo	11.5						(+)	
199	M	10 yr 10 mo	10.5							
200	M	12 yr 1 mo	12.5							(+)

APPENDIX C

RAW DATA OF MANDIBULAR TEETH FOR SUBJECTS

Table 10. *Data Collected for Subject's Mandibular Teeth*

PSN	Gender	Chronological Age	Dental Age	LR 1	LR 2	LR 3	LR 4	LR 5	LR 6	LR 7
1	F	7yr 1 mo	7.5			(+)				
2	F	12 yr 5 mo	13.5							
3	M	12 yr 2 mo	11.5							
4	M	10 yr 2 mo	9.5	(+)		(+)	(+)	(+)		
5	F	10yr 7mo	11.5			(+)				(-)
6	F	9yr 2mo	9.5	(+)	(+)					
7	M	8yr 2 mo	8.5							
8	M	11 yr 1 mo	12.5							
9	M	9yr 8 mo	9.5			(-)	(-)			
10	M	8 yr 11 mo	8.5					(+)		
11	M	8 yr 5 mo	9.5				(-)			
12	F	10 yr 4 mo	10.5				(+)			
13	F	7 yr 11 mo	8.5							
14	M	9 yr 5 mo	8.5							(+)
15	F	10 yr 9 mo	10.5							
16	F	11 yr 5 mo	12.5				(+)			
17	M	9 yr 2 mo	9.5			(+)				
18	M	7 yr 2 mo	7.5			(-)		(-)		
19	M	9 yr 8 mo	9.5			(+)				
20	F	10 yr 3 mo	10.5				(+)			
21	F	8 yr 5 mo	9.5							
22	F	9 yr 2 mo	9.5							
23	M	10 yr 0 mo	9.5					(+)		
24	F	7 yr 7 mo	7.5							(+)
25	f	7yr 7 mo	7.5					(+)		(+)
26	F	9 yr	9.5							(+)
27	F	7r 8 mo	8.5							
28	M	11 yr 1 mo	10.5							(-)
29	M	10 yr 8 mo	11.5							
30	F	8 yr 5 mo	8.5		(-)					
31	F	10 yr 3 mo	11.5					(-)		
32	M	9 yr 8 mo	9.5							(+)
33	M	8 yr 4 mo	8.5							

Table 10. *(continued)*

34	M	9 yr 8 mo	9.5	(-)	(-)	(-)				
35	F	12 yr 3 mo	12.5					(-)		
36	M	9 yr 3 mo	8.5	(-)	(-)					
37	M	10 yr 9 mo	10.5			(-)				
38	M	11 ry 3 mo	11.5							
39	F	10 yr 7 mo	11.5							
40	F	10 yr 10 mo	10.5					(-)		
41	M	7 yr 5m	8.5			(+)				
42	F	8 yr 8 mo	8.5	(-)			(-)			(+)
43	M	11 yr 3 mo	11.5			(+)				(+)
44	F	9 yr 7 mo	10.5				(+)			(-)
45	F	7 yr 9 mo	7.5					(+)		(+)
46	F	10 yr 9 mo	10.5	(-)	(-)		(+)			
47	M	11yr 5 mo	11.5							(+)
48	m	8 yr 6 mo	9.5	(-)						
49	F	11 yr 3 mo	10.5				(+)			
50	F	8 yr 8 mo	8.5	(-)						
51	F	11 yr 3 mo	11.5							(+)
52	F	8 yr 8 mo	8.5					(+)		
53	M	12 5 mo	12.5				(+)			
54	F	11yr 6 mo	13.5					(-)		
55	F	12 yr 0 mo	12.5					(-)		
56	M	8 yr 2 mo	8.5		(-)					
57	M	12ry 7 mo	11.5							
58	F	11 yr 4 mo	13.5							
59	m	9 yr 5 mo	8.5							
60	f	8 yr 6 mo	8.5							
61	M	9 yr 11 mo	8.5	(-)						
62	M	10 yr 6 mo	9.5							
63	M	11 yr 0 mo	10.5				(+)	(+)		
64	M	10 yr 0 mo	9.5				(-)			
65	F	8 yr 11 mo	8.5	(-)	(-)					
66	M	7 yr 9mo	7.5		(-)			(+)		(+)
67	F	9 yr 10 mo	11.5							
68	F	10 yr 3 mo	11.5							
69	M	10 yr 2 mo	10.5			(-)				
70	F	11yr 1mo	10.5				(+)			
71	F	11 yr 5 mo	13.5							
72	M	11 yr 7 mo	11.5							

Table 10. *(continued)*

73	M	11yr5 mo	12.5					(-)		
74	F	12 yr 9 mo	12.5							
75	M	11 yr 9 mo	9.5	(-)						
76	F	12 yr 2 mo	12.5							
77	M	9 yr 9 mo	10.5			(-)				
78	M	11 yr 2 mo	10.5					(+)		
79	M	11 yr 0 mo	11.5							
80	F	12 yr 2 mo	13.5					(+)		
81	M	11 yr 7 mo	12.5					(-)		(-)
82	F	9 yr 3 mo	9.5				(-)	(+)		
83	M	10 yr 9 mo	9.5							
84	F	7 yr 10 mo	8.5							
85	F	8 yr 6 mo	8.5							
86	M	7 yr 7 mo	7.5	(-)	(-)					
87	F	11 yr 4 mo	10.5							
88	M	11 yr 9 mo	11.5							
89	F	11 yr 5 mo	11.5							
90	F	10 yr 7 mo	12.5							
91	M	12 yr	11.5							
92	M	10yr 3 mo	10.5			(-)				
93	F	11 yr 9 mo	12.5					(-)		
94	M	11 yr 6 mo	11.5	(-)						
95	M	11 yr 9 mo	11.5							(+)
96	F	10 yr 2 mo	10.5	(-)	(-)					
97	M	11 yr 9 mo	11.5							
98	M	10 yr 1 mo	10.5			(-)				
99	F	9 yr 4 mo	9.5				(-)	(+)		
100	M	10 yr 11 mo	11.5							
101	F	11 yr 7 mo	10.5				(+)			
102	M	9 yr 5 mo	11.5							
103	F	10yr 9 mo	11.5				(-)	(-)		
104	F	9 yr	9.5							
105	M	8yr 8 mo	8.5					(-)		
106	M	11.5 mo	11.5							
107	F	11 yr 3 mo	11.5							
108	F	10 yr	11.5							
109	F	11 yr 4 mo	13.5							
110	M	9 yr	8.5						(+)	
111	F	10 yr	10.5				(-)			(+)

Table 10. *(continued)*

112	M	11 yr 2 mo	11.5	(-)	(-)			(-)		
113	M	11 yr 11 mmo	12.5							(+)
114	F	9 yr 6 mo	9.5		(-)					
115	F	10 yr 4 mo	10.5							
116	F	10 yr 8 mo	11.5							
117	F	8 yr 3 mo	9.5						(-)	
118	M	11 yr 4 mo	12.5				(+)			
119	F	8 yr 11 mo	8.5							
120	F	8 yr 10 mo	10.5							(-)
121	F	9 yr 9 mo	9.5				(-)			
122	M	8 yr 3 mo	8.5		(-)		(-)			
123	M	11 yr 11 mo	12.5							
124	M	10 yr 5 mo	10.5			(-)				
125	M	11 yr 6 mo	9.5							
126	F	10 yr 8 mo	13.5							
127	M	8 yr 1 mo	7.5					(+)		
128	F	11 yr 2 mo	12.5					(-)		
129	F	11 yr 1 mo	12.5					(-)		
130	M	8 yr 8 mo	8.5	(-)				(-)		
131	M	11 yr 10 mo	11.5							
132	F	10 yr	11.5							
133	M	11 yr 3 mo	11.5							(+)
134	M	11 yr 8 mo	11.5							
135	F	11yr 7 mo	10.5					(-)	(-)	
136	F	10 yr 2 mo	10.5							
137	M	11 yr 7 mo	10.5							
138	F	11yr 6 mo	12.5							
139	F	10 yr 4 mo	9.5							
140	F	11 yr 1 mo	11.5							
141	F	9 yr 1 mo	9.5					(+)		
142	M	10 yr 6 mo	9.5				(-)			
143	F	8 yr 5 mo	8.5				(-)			
144	F	11 yr 1 mo	10.5							
145	F	11 yr 3 mo	11.5					(+)	(-)	
146	F	9 yr	8.5		(-)	(+)				(+)
147	F	8 yr 8 mo	9.5					(+)		
148	M	7 yr 1 mo	7.5					(+)		
149	M	7 yr 8 mo	8.5	(-)	(-)		(-)			
150	M	10 yr 0 mo	9.5				(-)			

Table 10. *(continued)*

151	F	11 yr 5 mo	12.5					(-)		
152	M	11 yr 11 mo	12.5					(+)		
153	F	11yr 9 mo	9.5							
154	F	9 yr 1 mo	9.5	(-)				(-)		
155	M	10 yr 2 mo	11.5							
156	M	11 yr 5 mo	10.5			(-)				
157	M	11 yr 3 mo	11.5							
158	F	10 yr 9 mo	11.5		(-)					(-)
159	F	10 yr 1 mo	11.5							
160	F	10 yr 6 mo	11.5			(+)				
161	M	10 yr 8 mo	10.5							
162	F	7 yr 6 mo	7.5					(+)		(+)
163	M	7 yr 10 mo	7.5				(+)	(+)		
164	M	8 yr 7 mo	8.5				(-)			
165	M	7 yr 9 mo	7.5	(+)	(+)			(+)		
166	M	11yr 8 mo	10.5					(+)		
167	F	9 yr 5 mo	10.5			(-)		(+)		
168	F	10 yr 11 mo	10.5							
169	F	10 yr 7 mo	10.5					(+)		
170	M	9 yr 10 mo	9.5					(+)	(+)	
171	M	11 yr 9 mo	15.5							
172	M	11 yr 7 mo	11.5					(-)		
173	M	7 yr 11 mo	7.5		(-)					(+)
174	M	11 yr 1 mo	10.5					(-)		
175	M	11 yr 0 mo	12.5							
176	M	8 yr 3 mo	7.5							
177	F	9 ry 10 mo	9.5		(+)					
178	F	9 yr 6 mo	10.5							
179	F	10 yr 10 mo	9.5							
180	F	8 yr 8 mo	7.5				(+)			(+)
181	F	11 yr 10 mo	11.5				(+)			
182	M	10 yr 10 mo	11.5				(-)			(+)
183	M	11 yr 6 mo	11.5					(-)		(+)
184	M	9 yr	9.5	(-)	(-)					
185	M	10 yr 4 mo	11.5							
186	F	8 yr 1 mo	8.5		(-)		(-)			
187	F	8 yr 11 mo	8.5	(-)						
188	F	11 yr	12.5							
189	F	12 yr 0 mo	11.5							

Table 10. *(continued)*

190	F	9 yr 0 mo	9.5							(-)
191	F	10 yr 6 mo	11.5			(+)		(-)		
192	F	10 yr 9 mo	12.5							
193	F	11 yr 7 mo	12.5					(+)		
194	F	11 yr 1 mo	11.5							
195	F	10 yr 0 mo	10.5			(-)				
196	M	7 yr 6 mo	7.5	(-)						
197	M	8 yr 11 mo	8.5							
198	M	10 yr 8 mo	11.5		(+)					
199	M	10 yr 10 mo	10.5							
200	M	12 yr 1 mo	12.5							(-)