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Human Age Assessment by Dental Analysis

ADA American Dental Association®

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AMERICAN DENTAL ASSOCIATION TECHNICAL REPORT NO. 1077 FOR HUMAN AGE ASSESSMENT BY DENTAL ANALYSIS

The ADA Standards Committee on Dental Informatics (SCDI) has approved ADA Technical Report No. 1077 for Human Age Assessment by Dental Analysis. Working Groups of the ADA Standards Committee on Dental Informatics (SCDI) formulate this and other standards and technical reports for the application of information technology and other electronic technologies to dentistry's clinical and administrative operations. The ADA SCDI has representation from appropriate interests in the United States in the standardization of information technology and other electronic technologies used in dental practice. The ADA SCDI confirmed approval of ADA Technical Report No. 1077 on July 23, 2020.

This ADA technical report was prepared by the National Institute of Standards and Technology Crime Scene/Death Investigation Scientific Area Committee Forensic Odontology Subcommittee's Age Assessment Task Force in conjunction with the SCDI Joint Working Group 10.12 on Forensic Odontology Informatics, a joint working group with Working Group 11.1 on Standard Clinical Data.

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AMERICAN DENTAL ASSOCIATION TECHNICAL REPORT NO. 1077 FOR HUMAN AGE ASSESSMENT BY DENTAL ANALYSIS

FOREWORD

(This Foreword does not form a part of ADA Technical Report No. 1077 for Human Age Assessment by Dental Analysis).

In 1992, there was interest in the standardization of clinical information systems related to electronic technology in the dental environment. After evaluating current informatics activities, a Task Group of the ANSI Accredited Standards Committee MD156 (ASC MD156) was created by the ADA to initiate the development of technical reports, guidelines, and standards on electronic technologies used in dental practice. In 1999, the ADA established the ADA Standards Committee on Dental Informatics (SCDI). The ADA SCDI is currently the group that reviews and approves proposed American National Standards (ANSI approved) and technical reports developed by the standards committee's working groups. The ADA became an ANSI accredited standards development (ASD) organization in 2000.

The scope of the ADA SCDI is

> *The ADA SCDI shall develop informatics standards, technical reports and guidelines and interact with other entities involved in the development of health informatics standards aimed at implementation across the dental profession.*

AMERICAN DENTAL ASSOCIATION TECHNICAL REPORT NO. 1077 FOR HUMAN AGE HUMAN AGE ASSESSMENT BY DENTAL ANALYSIS

PREFACE

The assessment of chronologic age for living or deceased individuals requires careful documentation. Procedures to assess human chronologic age have been recommended by numerous forensic organizations, including the American Board of Forensic Odontology (ABFO), American Society of Forensic Odontology (ASFO), and the International Organization for Forensic Odonto-Stomatology (IOFOS) as well as others.

The goal of this technical report is to provide the best available current information and guidance for estimating age from the human dentition. It includes guidelines on how to obtain forensic dental data and the selection of recommended methodologies to establish accurate assessments of human chronologic age. It is intended for practitioners performing dental age assessments and for individuals, groups, or agencies utilizing the age assessment information.

Dental age assessment is highly technical and requires skill, training, education, and experience to execute correctly.

This document provides a guideline to generate an estimated dental age and age interval utilizing databases and scientifically reviewed algorithms. However, dental age assessment is based on large identifiable human group populations and has an associated level of uncertainty. It is beyond the scope of this document to determine the appropriate use of this assessment by any entity in determining appropriate actions based on the estimated *age* interval as it relates to the chronological age of any specific individual. It is beyond the scope of this document to recommend the application of the assessment by any user in determining appropriate actions as it relates to chronological age.

BACKGROUND

Forensic dental age assessment is the estimation of an individual's chronologic age through scientific evaluation of the dentition and maxillofacial structures. Medico-legal applications in the deceased include estimation of the age at death and assist in the identification of missing and unidentified individuals by narrowing search parameters. In the living, it will assist the legal system in answering questions regarding immigration, legal age of majority, and legal age of license. In the US, only the courts or designated agencies determine legal disposition of the individual. The forensic dental age assessment practitioner reports the facts as best as they are understood and does not get involved with policymaking.

The complexity of the age estimation process requires forensic dental age assessment practitioners to follow these guidelines to the fullest extent applicable, practical, and appropriate to ensure scientific integrity. In addition, the consequences of inappropriate assessment of age can have emotional and legal ramifications. Age assessment methods vary in their advantages and disadvantages and are dependent upon the availability of suitable population-specific reference data. In addition, whenever possible, multiple independent dental and non-dental methodologies should be performed by qualified practitioners.

1 RATIONALE

Forensic dental age assessment produces an estimate of chronologic age through dental analysis. The intent of this technical report is to describe current best practices for the process of human dental age assessment*;* however, it is not intended to supersede local, state, or federal regulations. As a resource, this document could assist in the development of regulations for those agencies.

2 SCOPE

This document describes the methodologies and best practices for estimating the chronologic age of a living or deceased individual by analysis of the human dentition and associated maxillofacial structures.

Note 1: This document is not an implementation guide; therefore, the practitioner needs to evaluate the proper techniques and applicability for each method.

Note 2: This is not a legal document and is not intended for that purpose.

3 TERMS AND DEFINITIONS

3.1

Age assessment Database

Information that can be processed to generate normal distribution data or percentile data and assembled to create a reference data set.

3.2

Adolescent Dental Age Interval

The interval in human dental development that begins after all primary teeth are normally shed, and the permanent teeth are developing or developed. The adolescent interval ends when all permanent teeth present are fully developed.

Note: During the adolescent and adult dental age intervals, primary teeth may be atypically retained for various reasons, including congenital absence or ectopic eruption of the permanent teeth that would typically replace them.

3.3

Adult Dental Age Interval

The interval begins when human dental development ends and all permanent teeth have completely formed crowns and roots and continues throughout life.

Note: During the adolescent and adult dental age intervals, primary teeth may be atypically retained for various reasons, including congenital absence or ectopic eruption of the permanent teeth that would typically replace them.

3.4

Age at Assessment (AaA)

The estimated age and estimated age interval derived from the dental developmental stage or stages present at the time an individual's estimated age is calculated by the forensic dental age assessment practitioner. (For example, the mean age for a subject with observed dental characteristics similar to the individual being evaluated is estimated to be 10.34 years with a minimum and maximum age distribution of 8.67 to 14.33 years on the day of assessment).

3.5

Bias

The variance of measured results as influenced by human perceptions or systemic factors.

Note: It is beyond the scope of this document to outline the numerous types of biases.

3.6

Biologic Age

The age corresponding with the developmental, degenerative, biochemical or isotopic status of an individual.

Note: The rate at which organ systems age may differ from the individual's chronologic age.

3.7

Blinding

The process of withholding information that may *bias* the forensic dental age assessment practitioner.

3.8

Chronologic Age

The difference between the individual's date of birth and a specific later date.

Note: Chronologic age may be expressed in varying degrees of precision and can be derived from computer programs that report age values using multiple significant digits. To correctly interpret and report results, consultation with a statistician may be necessary.

3.9

Dental age assessment

The processes used to produce an estimation of an individual's biologic *age* using dental data and subsequently correlate biologic age to chronologic age.

3.10

Dental Emergence (Eruption)

The process of tooth migration from its initial position in its bony crypt through the gingival tissue and into the occlusal plane.

3.11

Dental Age Estimation

The estimated mean age and the corresponding distribution of ages that result from dental age assessment.

3.12

Dental Age Estimation Technique

A method used for age assessment.

3.13

Dental Data

Dental age assessment involves analysis of available dental data of an individual in her/his current state. The term 'prior data' refers to data collected when that individual was in a previously known and documented circumstance and does not mean a specific point in time. The term 'current data' refers to the available data for the individual or remains in her/his current state. For a deceased individual requiring age assessment, the current data is referred to as postmortem data. For a living individual requiring age assessment, the data is simply referred to as prior dental data and current dental data.

3.14

Developmental Stages of Dental Growth

Intervals in the morphologic appearance of teeth as the crown or root mature.

3.15

Estimated Age Interval

The estimated age interval expresses the mathematically determined minimum and maximum associated age range at a particular level of uncertainty.

3.16

Expression of Uncertainty (EoU): The parameter, associated with the assessment method used, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

3.17

Forensic Dental age Assessment Practitioner

An individual who provides an assessment of an individual's dental age based upon accepted methodology.

Note: The term "practitioner" will be used instead of "Forensic Dental age assessment Practitioner" throughout this document as an abbreviated way to describe an individual who provides an assessment of an individual's dental age based upon accepted methodology.

3.18

Gingival Dental Emergence

The interval in the migration process from a tooth's initial appearance through the gingival soft tissue to the point of final eruption.

3.19
Identifiable Human Group
A population of individuals based on ancestry or population specificity that reflects a similar genetic, geographic, and environmental background.

3.20
Independent Verification
The process of obtaining a second analysis from a forensic dental age assessment practitioner, blinded to the results of the first practitioner's assessment.

3.21
Infant/Child Dental Age Interval
The interval in human dental development that begins at birth, includes the presence of the developing, developed and resorbing primary dentition as well as the initial development of the permanent dentition. This interval includes the early period of mixed primary and permanent dentitions and ends when the last primary tooth is exfoliated normally.
Note 1 to entry: During the adolescent age and adult dental age intervals, primary teeth may be atypically retained for various reasons, including congenital absence or ectopic eruption of the permanent teeth that would typically replace them.

3.22
Level of Uncertainty (LoU)
This characterizes the dispersion of values used for measuring dental age assessment based on the variation within the data.

3.23
Measurand
A physical quantity or property which is measured.

3.24
Prenatal Dental Age Interval
The interval in human development that occurs prior to birth.

3.25
Reference Data Set (RDS)
The assembly of data related to a specific identifiable human group comprising all the relevant information to enable dental age assessment.

3.26
Reference Study
A detailed investigation and analysis of a specific population to relate chronologic age to dental development and maturation.

4 SCIENTIFIC METHODS OF DENTAL AGE ASSESSMENT

The scientific evaluation of dental and maxillofacial structures for assessment of age can be divided into four criteria:

1. Gross formation and developmental growth changes: The progressive morphologic development of the crown, root, and apex of any given tooth or its timed emergence/eruption sequence. In addition, emergence occurs

through alveolar bone or gingival tissue. These changes are discernible radiographically showing progressive mineralization of the crown and roots of each tooth in the human dentition.

2. Maturation and post-formation changes: These are changes following complete morphologic development of the tooth crown and root.

3. Histologic changes: Microscopic changes that include but are not limited to secondary dentin apposition, cementum apposition, root transparency, periodontal attachment, root resorption, and attrition.

4. Biochemical changes: Changes over time in the biochemical nature of teeth that can be measured by laboratory techniques, including but not limited to amino acid racemization, carbon-14 dating, and rare isotope analysis.

The specific circumstances of each individual case will determine the dental age assessment method(s) to be employed. Forensic dental age assessment methods for estimating age are dependent upon the specified developmental growth interval of the individual and the availability of specific teeth for the precise technique.

4.1 Data utilization: Data utilized in dental age assessment is based on reference data sets from sex and population-specific studies. Other factors that may or may not affect dental development, post-formational dental changes, histologic, and biochemical changes are typically not included. The relative contributions of genetic, environmental, and other factors, when examining variability within and between populations has not been established.

The practitioner provides the best and most accurate assessment of an age interval and is responsible for being familiar with and utilizing current age assessment scientific methodology. Thoughtful consideration should be given to sex, identifiable human group, geographic population specificity, and environmental factors.

4.2 Limits to Scientific Dental Age Assessment Methods: The precise rates at which the processes of developmental, maturational, and post-developmental dental changes occur are unique to each individual. Consequently, age assessment procedures estimate biological age intervals of an individual, from which a chronologic age interval is derived. Biologic age does not necessarily correspond with chronologic age. These procedures generally involve comparison of the individual being evaluated with one or more reference data sets that are described statistically in terms of an average, minimum, and maximum age at which developmental or post-developmental changes occur. The individual being evaluated may or may not progress through these changes at a rate comparable to the subjects in the reference study, thereby giving an over or underestimation of chronologic age. A point estimate of age alone is not an accurate way to describe a dental age estimation. It is unacceptable because it may lead an investigator to misinformed conclusions about the value of the estimation.

It is advised that reference population studies be utilized, when available, for dental age assessment of an individual to address these limitations. This will increase the probability that the individual is compared to a human reference sample representative of genetic and environmental factors associated with their developmental, maturational, and post-developmental dental changes. In cases where there is not a reference population study comparable to the individual being assessed for age, then the reference population study that most closely aligns with the individual being assessed should be utilized, and direction of possible error reported. The basis for the choice of the reference population should be fully described.

4.3 Ancestry: Analogous to a genetic description of the individual, ancestry refers to a genetic line of descent of an individual, an association with an identifiable human group. Reference population studies used in dental age assessment techniques should recognize identifiable human groups and their respective phenotypic characteristics that may affect age estimation. Comparison of an individual within the same identifiable human group is a comparison of an individual that would more likely possess similar dental formation and developmental growth changes, maturational and post-formation changes, histologic changes, or biochemical changes.

Scientifically, both maternal and paternal sides of descent are considered. Practitioners should maintain awareness that self-reported identifiable human groups may be a sensitive, multidimensional concept influencing the reporting of one line of descent

over others that may or may not represent the outcome of genetic testing.

4.4 Geographic Population Specificity: This is the specific location in the world that a population resides, and the ethnic, cultural, environmental, and socioeconomic conditions experienced by that population. Variation in dental development, maturation, and post-developmental change have been observed among populations within the same country or region.

4.5 Sex: Some differences in tooth development and maturational and post-developmental changes between sexes have been documented. In cases where the definitive assignment of sex cannot be determined, a method that does not require a designation of sex should be used, or the assessment using both sexes should be reported.

4.6 Nutritional Health: Consistency of diet may account for gross anatomical changes to teeth such as attrition and secondary dentin formation. These processes will affect the final dental age assessment in some techniques. The rate and extent of development of somatic and non-dental skeletal structures are more readily affected by nutritional status than the dentition in children and adolescents. However, extreme environmental factors may affect the developing teeth. It is prudent that the practitioner is aware of this limitation when assessing the age of an individual who is exposed to such conditions.

4.7 Current and Prior Systemic Diseases: The rate and extent of tooth and skeletal formation can be affected by systemic conditions such as endocrine disorders, especially in the developing individual. Moreover, cancer treatments such as chemotherapy, or radiation therapy applied to developing anatomic regions, may interrupt tooth formation, affecting tooth morphology. In adults who have completed dental formation, the effects of systemic diseases may also influence maturational and post-formation dental changes.

4.8 Socioeconomic Status: This represents external factors where an individual may or may not have the financial ability or access to adequate health care, dental care, and good nutrition. An individual who is deficient in any of these areas can have delayed development or accelerated deterioration of their teeth and skeleton, which may affect dental age assessment.

4.9 Habits and Addictions that may Affect Health or the Maxillofacial Structures: The following may have unintended consequences to the dentition because of the habits or addictions of the individual: staining, extensive caries, extensive restorations, bruxism, wear, traumatic occlusion, periodontitis, pulpal and periapical disease, tooth loss, and tooth fracture. Specifically, alcohol and drug addictions, drinking dark-colored liquids, tobacco usage and betel nut chewing, poor oral hygiene, and excessive carbohydrate intake are several habits that may adversely alter the teeth and affect dental age assessment. The significance of each condition may vary with the age assessment methodology.

4.10 Additional environmental factors that may affect developmental or post-formation dental and skeletal development include growth hormone therapy, endocrine or immunosuppressive therapies, traumatic injuries, conditions that affect physical development, and postmortem changes.

5 TOOTH DEVELOPMENT AND DENTAL AGE ASSESSMENT

Humans who survive to adulthood normally develop two distinctive sets of teeth: Twenty (20) deciduous teeth with four incisors, two canines, and four molars in both the upper (maxillary) and lower (mandibular) jaws; and thirty-two (32) permanent teeth with four incisors, two canines, four premolars, and six molars in each upper and lower jaw.

Tooth development, the formation and mineralization of the dental tissues (enamel, dentin, and cementum), begins at the most occlusal or incisal portion of each tooth and continues until each root tip is fully formed. Simultaneous with tooth formation is the movement of the forming teeth through the alveolar bone toward the surface of that bone and the overlying gingival tissues. This movement is the process of emergence of the forming teeth first through the bone, then through the gingiva, and normally continuing to the level of occlusion with teeth in the opposing jaw.

Dental development begins before birth and development and emergence can continue for more than twenty (20) years after birth. Visualization of the stages of dental development and emergence of multiple teeth by various imaging techniques facilitate dental age assessment. The assessments result in estimations of the chronologic age of individuals based on comparison to

data from a robust collection of peer-reviewed reference studies. Specific techniques should be selected based on case-specific factors, including the general estimated age interval (prenatal, infant/child, adolescent, adult), sex, identifiable human group and whether the individual is living or deceased. In general, techniques based on dental development are more accurate than tooth emergence techniques. Techniques based on gingival emergence, the clinical appearance of the teeth through the gingiva, are the least dependable. Other techniques exist based on post-development changes to teeth for cases in which all teeth are fully developed.

Teeth are well suited for use in the analysis of age assessment. Dental enamel is the hardest tissue in the human body and teeth can survive many perimortem insults and postmortem conditions. Dental development is less affected by environmental factors, socioeconomic status, nutritional variation, dietary habits, endocrinological, or disease influences than other age assessment methodologies. Relatively simple techniques for assessing age based on dental development are available.

5.1 Tooth Development Stages

This is defined as the various degrees in the development of human teeth that represent specific points of mineralization discernible through a variety of diagnostic imaging modalities.

Tooth development and emergence of human teeth through alveolar bone, as previously mentioned, are more accurate in human dental age assessment than dental emergence through soft tissues. Those tooth development staging systems that use crown/root development or emergence through alveolar bone should be used where indicated over those techniques that are dependent on tooth emergence through soft tissues.

Different dental age assessment techniques use different tooth developmental staging systems. Currently, there is no consensus on what staging system is better. Dental developmental staging systems are method dependent and it is recommended that they be utilized based upon the appropriate reference study.

5.1.1 Assessment of Tooth Stages

When assessing tooth development from dental radiographs or other imaging modality, one can distinguish between consecutive developmental stages more easily using internal hard tissues, such as the shape of the pulp chamber or root canal. This improves sensitivity and performance measures.

5.1.1.1 Crown assessment: The practitioner should assess the thickness and continuity of enamel in the incisal or occlusal surface of any tooth, followed by the presence of dentin and ending with the shape of the roof of the pulp.

5.1.1.2 Root assessment: The practitioner should assess the root as initiated when small divergent spicules appear from the edges of the crown. Thereafter, the amount of root developed should be compared to the size of the crown (lengthwise) until the length of the root exceeds the length of the crown, then attention should be on the root apex in terms of maturity (open, closed and the width of the apical periodontal ligament space).

5.2 Basic Theory of Age Assessment

Most age assessment processes and techniques conform to a specific mathematical probability function called normal distribution. Typical normal distribution can be demonstrated by bell curves that define the extent of the variation for the specific feature(s) the technique investigates. Bell curves can have very similar or very different shapes and are based on the data gathered using the specific method. The bell curves for the different techniques may be similar with a midline peak and symmetry around the midline. They can also appear dissimilar with different height, width, and peak location based on the dispersion of the data and the location of the mean (signified by the peak). Most bell curves demonstrate normal distribution of data; however, the shape may show variations to illustrate the terminal developmental stage.

There are multiple statistical expressions to describe the dispersion of data or level of uncertainty. That statistical expression will be dependent on the specific population reference study used for the dental age assessment.

The use of databases in the evaluation of tooth maturation and post-developmental dental changes is an essential component of dental age assessment. There is still no uniform consensus concerning the appropriate statistical methodology that considers both the age intervals reported in the tables as well as the age interval among the individual teeth utilized in the assessment. Therefore, the reporting of an appropriate standard deviation methodology is beyond the scope of this document.

5.3 Scientific Basis for Dental Age Assessment and Age Interval Calculations

Tooth maturation, which includes developmental and post-developmental changes, as with most biological processes, follows a continuous progression. In addition, the assignment of a predicted time range for a specific stage of maturation is the basis of numerous fields of science and medicine, including embryology, obstetrics, pediatric medicine, and child psychology. The success of key diagnostic and therapeutic decisions based on time intervals listed in published development tables is an established principle of modern medicine.

6 AGE ASSESSMENT DATABASES

6.1 Databases

A dental age assessment database is one or more reference data sets from one or more reference studies. It uses robust, reproducible methods of analysis to estimate the distribution of ages associated with dental development, maturation, and post-developmental dental changes.

The desired attributes of a database include:

1. Adequate sample size: Defined by individual reference studies, or of a combined dataset based on more than one reference study.
2. The provenance of the data: (i.e., The source(s) or identifiable human group from which the data came).
3. Methods and units of measurements clearly defined and described.
4. The ability to assess the impact of varying assumptions or analytic methods on the results.
5. A sufficient level of detail provided in published materials or available from study authors to provide the practitioner with the information needed to address items 1-4 above.

Note 1: Each dental age assessment database uses different metrics and the practitioner shall be responsible for understanding those differences when applying the data to a specific human dental age assessment technique.

Note 2: Dental age assessment database information changes regularly. Current resources for databases can be found in the bibliography section of this document.

6.2 Sexual Dimorphism of Databases

The differences in tempo of development and maturational changes in teeth between males and females are well established. It is recommended that databases reflective of each sex be maintained separately.

Dental age assessment databases need to have distinct sex categories for males and females. Additionally, if sex is not known, then include an unknown category in the database.

6.3 Ancestral Diversity of Databases

The differences in tempo of development and maturational changes in teeth between identifiable human groups are well established. It is recommended that data reflective of a specific identifiable human group be maintained separately.

Dental age assessment databases need to have distinct, identifiable human group categories for ancestry or population specificity. Additionally, if the identifiable human group is not known, it is recommended that an unknown category be added to

the database.

6.4 Validation Studies

In dental age assessment, reference datasets and methodologies are created by researchers to develop statistical information for calculating a dental age interval. Testing the reliability of the reference datasets and methodologies to an unrelated population-specific database of a statistically appropriate size and with subjects of a confirmed chronological age can be an important tool for evaluating the dental age assessment process. Dental age assessment research projects should utilize these independent databases and include calibration and testing of the dental age assessment examiners. Once the age interval for each individual is calculated, the test should report how often the chronologic age falls within the assessed age interval. An appropriate accuracy rate for legal purposes is beyond the scope of this document.

7 CONSENT AND PROFESSIONAL CONSIDERATIONS

Forensic dental analysis on living and deceased individuals, including issues of consent, are subject to legal regulations and ethical considerations beyond the scope of this document.

8 COLLECTION OF EVIDENCE

Evidence collection for dental and maxillofacial age assessment techniques should follow the published criteria for the technique(s) selected. Technique selection should be based on criteria specific to the individual case. Evidence can include radiographs, photographs, and teeth or portions of teeth. Teeth or portions of teeth should only be collected as evidence following ethical considerations. It is recommended that the evidence collected be comprehensive and specific to the circumstances of each case. When applicable, the case identification and biographical information data discussed below should also be collected.

8.1 Case Identification Data

To the greatest extent possible and practical, it is recommended that the following case identification data be recorded and archived:

8.1.1 Case Number: A unique alphanumeric identifier. When appropriate, this identifier can be of a type agreed to or designated by the referring agency.

8.1.2 Referring Agency: The agency or authority requesting the analysis. This agency may or may not be responsible for the case investigation or disposition of the case. The referring agency address should also be documented.

8.1.3 Name(s) of the Examiner(s): Full name and pertinent degree(s) of the individual(s) conducting the examination, evidence collection, or analysis of case evidence.

8.1.4 Date of the Examination: Month, day, year, as per the convention of investigating agency.

8.1.5 Setting of Examination: The specific location where the dental age assessment occurred.

8.1.6 Name of Subject: Full or partial name as reported by the subject or by family, witnesses, agencies, or authorities, or provided in documents. It is recommended that known aliases or nicknames be included. If the subject's name is unknown, a suitable unique pseudonym or alphanumeric case number identifier can be used.

8.1.7 Birth Data: Record the date and place of birth claimed or stated by the subject or other information related to the subject's date, and place of birth . Supporting information from family members, witnesses, agencies, authorities, or other documents can be used to reinforce the claimed date and place of birth.

8.1.8 Other Data: Any additional data that may affect the assessment results.

8.2 Biographical Information of the Individual

In addition to the case identification data collected, collect and consider biographical information for each subject.. The biographical data evidence collected should include information that is as comprehensive as possible and practical.

Include in the biographical data available information related to the subject individual's sex, identifiable human group, geographic origin, subsequent places lived, current and former health issues, current and former nutritional status, current and former habits that may relate to skeletal, oral, or dental development or conditions, current and former medications or addictions that may relate to skeletal, oral, or dental development or conditions, and any other environmental or cultural factors that may have affected skeletal, oral, or dental development or contributed to post-development skeletal, oral, or dental changes.

8.3 Dental Evidence Observed, Collected and Measured

The dental evidence observed, collected, and measured is case-specific and may be limited by medical ethics, quality and quantity of dental and maxillofacial remains, best practice techniques available, and permission granted or denied by the medical examiner or pathologist to extract, section or expose dental/maxillofacial structures. Although all dental/maxillofacial structures should be considered, the practitioner needs to list specific teeth or other structures utilized in the assessment of age. It is the responsibility of each practitioner to apply the appropriate scientific methodologies that are consistent with the reference studies' methods and designs.

8.3.1 Dental age assessment Criteria

1. Morphologic developmental tooth staging
2. Dental emergence pattern
3. Any other measured dental developmental or post-formation characteristics
4. Chemical or isotopic analysis

8.3.1.1 Occlusion

This may present as one of several factors contributing to the development of variables utilized in dental age assessment in adults, especially attrition and secondary dentin formation. Factors to consider when evaluating occlusion can include: incisal/occlusal wear, traumatic occlusion, lack of occlusion, enamel quality, diet, function and habits, dental restorations, occlusal adjustments, dental therapy, and dental appliances.

8.3.1.2 Oral Hygiene

Plaque, calculus and debris present risk factors for the development of caries and periodontal disease and are conditions that should be considered in many dental age assessment methods. The practitioner should collect oral hygiene data that may affect dental age assessment outcomes.

8.3.1.3 Pathology

In addition to clinical and radiographic findings of common dental diseases, localized and systemic conditions may affect tooth development or post-developmental changes. Hard and soft tissue lesions of the maxillofacial complex may indicate factors potentially affecting the rate of development or aging. Systemic conditions leading to the absence of teeth and disease processes or therapies affecting morphology or rate of development can preclude dental age assessment.

8.3.1.4 Photographs

A series of extraoral and intraoral clinical or postmortem photographic images are useful in documenting gross clinical or postmortem findings in dental age assessment. Use macro and microscopic photographic techniques when the dental age assessment technique warrants it.

8.3.1.5 Radiographs

Intraoral or extraoral radiographic images consistent with clinical diagnostic views for both living and deceased individuals can be used for most dental age assessment techniques. Standard 2-dimensional radiographic images are typically used in reference studies, although emerging 3-dimensional images show great promise for the future of dental age assessment. Radiographs reveal the current state of morphologic development of dental structures for individuals still undergoing developmental and maturational changes. Also, post-maturational dental changes can be demonstrated and measured in radiographs of teeth and maxillofacial structures. In addition, the detection of dental disease, trauma, and systemic conditions that may affect dental age assessment can often be detected in dental radiographs.

9 DENTAL RADIOLOGY

Dental radiographs are an adjunct to the physical and visual examination of the dental and maxillofacial structures. Depending on the precise context of the issues to be resolved, radiographs provide significant and detailed information enabling accurate age estimation. Radiographs that have been shown to be useful are the dental periapical, panoramic, computed tomography (CT) scans, and cone-beam computed tomography (CBCT). In addition, views comprising lateral, lateral oblique, and anterior-posterior (AP) cranial views may be useful. In both the living and the deceased, dental and maxillofacial radiographs are the source of the most accurate information for age estimation.

Although the primary objective in obtaining radiographs is for age estimation, practitioners are bound by ethical and clinical best practices when assessing subjects. Even though this is a nonmedical or dental referral, the primary responsibility is to ensure that the individual is provided appropriate and accurate information for an individual to give informed consent. In addition, make the subject and those responsible for his or her medical and dental care aware of any clinical issues that are detected during that process.

Obtain the radiographs under review in compliance with all applicable federal, state, and local health requirements and privacy laws.

9.1 Image Acquisition

Practitioners who take radiographic images need to:

1. Establish and maintain operating and safety procedures that ensure radiation exposures are as low as reasonably practicable. This applies to both the subject receiving ionizing radiation and staff who are in the area of the ionizing radiation-emitting device.

2. Provide personal protective equipment (PPE) for the individual being irradiated if appropriate. The best method for minimizing radiation dose for a subject is to limit the irradiated field and reduce the number of exposures.

3. Establish and monitor the designated zone of radiation. This includes correcting breaches of radiation protection protocols. In the unlikely event of overexposure to the subject, immediately refer to a radiation protection physician.

4. Ensure the radiation safety of all persons accompanying the individual, especially when imaging is performed outside a dedicated lead-lined x-ray room. This may occur if handheld imaging equipment is used.

5. Ensure that all images have the correct subject information, identification number, date of birth, date of radiographic exposure, sex, and correct labeling of right or left sides.

6. Be trained in forensics and ionizing radiation methods and competent in the operation of the respective imaging technique.

7. Understand imaging techniques and appropriately explain the reasons for selecting a specific technique to answer the legal question(s) posed, based on knowledge of the capabilities and limitations of the various aspects of imaging.

8. Be familiar with the most frequently used image processing tools and techniques. [1]

10 DENTAL AGE ASSESSMENT METHODS AND TECHNIQUES

Base the age assessment method or technique selection upon the specific circumstances and evidence available for each case (See 4, Scientific Methods of Dental age assessment). When practical, practitioners should utilize multiple independent statistical methodologies. Additionally, the practitioner should utilize and apply the most appropriate statistical data in the assessment of an individual's chronologic age. This includes consideration of the individual's sex, identifiable human group, population specificity, and environmental factors when known. The practitioner needs to precisely follow the methodology of the reference study utilized. This includes but is not limited to the methods for morphologic staging and criteria measurement(s). The use of malformed, diseased, or extensively restored teeth should be avoided when the dental age assessment technique dictates. Staging methods are based on subjective interpretation of observations, and methods have some level of rater variability (inter- and intra-variability). Best practice includes the use of independent assessments of the development stage, with a predefined and documented method for recording each evaluator's results and resolving differences.

Dental age assessment methods/techniques are categorized based upon their applicability to the perceived estimated age interval of each subject and ethical considerations for both living and deceased subjects.

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards, and Guidelines. [2] https://abfo.org/resources/abfo-manual/

An additional resource is published through the European Asylum Support Office, EASO Practical Guide on Age assessment. It is available at: [3] https://www.easo.europa.eu/sites/default/files/easo-practical-guide-on-age-assesment-v3-2018

10.1 Atlas

Atlas-based dental age assessment techniques utilize graphic and diagrammatic representations of the morphology of developing tooth structures. Some include the associated emergence patterns. Most, but not all, atlas techniques are non-sex specific and have a limited number of population-specific data sets resulting in a higher degree of variability, particularly in mid-childhood through adolescence. In addition, Atlas techniques are often based on mixed population and ethnic data. Atlas techniques are particularly useful in mass victim identification and clustered victim situations to assist investigators to more efficiently characterize remains by estimated age interval.

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards and Guidelines. [2] https://abfo.org/resources/abfo-manual/

10.1.1 Infant/Child

For the purpose of forensic dental age assessments, the infant/child interval has been defined in the "Terms and Definitions" Section 3 of this document.

Infant/child dental age assessment techniques utilize radiographic evaluation to stage the degree of morphologic development of the primary or secondary dentition as well as resorption of the primary dentition. Infant/child methods/techniques should consider sex, identifiable human group, and population specificity. Therefore, these methods/techniques will generally provide a more accurate and reliable estimate of age over eruption and atlas methodologies. Additional factors that may affect dental age assessment are prenatal conditions and preterm birth. The significance of each condition may vary with the dental age assessment methodology.

The rights of children are enshrined in the United Nations Convention on the Rights of the Child (UNCRC) [4]. This framework underpins all international guidance in relation to children. The1989 UNCRC is a universally agreed set of non-negotiable standards and obligations that set minimum entitlements and freedoms that should be respected by governments.

Article 37 relates specifically to children who are in conflict with the law and states that they have a right to be treated "*in a*

manner which takes into account the needs of persons of his or her age" [4]. Therefore, a credible age assessment is crucial in safeguarding children and juveniles, thus ensuring appropriate treatment. Where the age is not known, the benefit of the doubt should prevail, and he or she is presumed to be a child. The Committee on the Rights of the Child (CRC) recommends that each State party:

> *…give the benefit of the doubt in age-disputed cases of separated children seeking asylum and seek experts' guidance on how to determine age*. [4,5]

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards and Guidelines. [2] https://abfo.org/resources/abfo-manual/

10.1.2 Adolescent

For the purpose of forensic dental age assessments, the adolescent interval has been defined in the "Terms and Definitions" Section 3 of this document.

Adolescent dental age assessment techniques utilize radiographic evaluation to stage the degree of dental development toward the latter half of dental morphologic maturation. Although the third molar exhibits the highest degree of morphologic developmental variability, it remains extremely useful in the assessment of age. Utilize early adolescent age assessment methodology when teeth other than the third molar continue to undergo morphologic development. Utilize late adolescent age assessment techniques when the third molar is the only remaining tooth continuing to undergo morphologic development. These techniques play a useful role in assisting legal authorities in determining the disposition of cases involving immigration, asylum seekers, and legal age of majority or license.

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards and Guidelines. [2] https://abfo.org/resources/abfo-manual/

10.1.3 Adult

For forensic dental age assessments, the adult interval has been defined in the "Terms and Definitions" Section 3 of this document.

Adult dental age assessment techniques may utilize either radiographic morphological evaluation or gross/microscopic observation of post-formation changes within the dentition following the cessation of morphologic dental development. Although others have been described, six traditional post-formation variables have been utilized in the assessment of adult chronologic age. They are:

1. Root translucency – The phenomenon that occurs from the deposition of hydroxyapatite crystals within the dentin tubules over time; it begins at the apex and progresses coronally after the approximate chronologic age 20 years.
2. Secondary dentin deposition – The physiologic or reparative process of laying down additional dentin in the pulp throughout a tooth's lifecycle.
3. Periodontal attachment – The epithelial and ligamentous attachment between the tooth and the gingival tissues and alveolar bone.
4. Cementum apposition – The continual and usually regular process of depositing new cementum on the root of a tooth throughout its lifecycle; often greater at the apical region than near the cementoenamel junction.
5. Attrition –The gradual wearing away of the tooth surfaces because of chronic, tooth-to-tooth frictional contact, often due to mastication.
6. Root resorption – Resorption of root cementum and dentin by multinucleated odontoclast activity, often associated with traumatic injuries and prolonged inflammation; it may be internal or external.

Ethical considerations may restrict the use of many adult dental age assessment methodologies due to the requirement of

sacrificing tooth structure.

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards and Guidelines. [2] https://abfo.org/resources/abfo-manual/

10.2 Biochemical

Biochemical dental age assessment techniques require the sampling of dental tissues to evaluate amino acid racemization within the dentin or level of radioactive carbon 14 within the dental enamel. Aspartic acid racemization can estimate the age at tooth extraction or death, while radioactive carbon 14 may estimate the date of birth for individuals born after World War II. These techniques are useful in all age groups and do offer a report of relatively low estimated age intervals. Currently, available biochemical techniques pose ethical considerations for use in the living because of the amount of tooth structure required for testing. The testing methods are complex and laboratory procedures require considerable time to process.

A dental age assessment procedure selection chart can be found in the ABFO *Diplomate's Reference Manual*, Section IV, Standards and Guidelines. [2] https://abfo.org/resources/abfo-manual/

11 REPORTED FINDINGS FOR DENTAL AGE ASSESSMENT

Label the forensic dental age assessment report, "Dental Age Assessment Opinion or Expert Report," and include the following:

11.1 Introduction

This section provides background information, including:

- Organization requesting report (to include address of individual or organization making request);
- Reason for the request, date of examination, name, and position of practitioner;
- Whether the subject in question was accompanied by a guardian (if so, with name of guardian);
- Documentation of written informed consent and the setting in which the examination was undertaken.

The type of information collected, and the amount of information collected is specific to the circumstances of each case.

11.2 Case Identification Data

This section includes a case identification number and if any age-related legal documents were presented at the date of subject examination, birth certificate, national identification, passport, vaccination certificate, etc.

11.3 Biographical Information regarding the Individual

This section includes the identifiable human group of the individual in question, sex, and the presence or absence of any syndromes or diseases. Also, include a written note regarding the mental and cognitive ability of the individual in question, their general status, and their height and weight.

11.4 Inventory of Evidence

This section lists all evidence received, observed, or collected, including a list of the dentition and anatomic structures analyzed by the practitioner and details the source of the evidence.

11.5 Method(s) of Analysis

This section describes the analytic method(s)/scientific technique(s) and population-specific reference data used in the dental age assessment. A list of anatomic structures analyzed (number and type of teeth analyzed and why specific teeth and structures were used), unit of measurement used, tooth numbering system used, specific technique(s) utilized, and the published reference study where statistical information was obtained should be included in this section of the forensic report.

11.6 Opinion/Conclusions:

This section summarizes the practitioner's results. The final age assessment is a matter of the practitioner's expert judgment by synthesizing all available information. Conclusion statements specific to each methodology employed includes estimated age, it's corresponding level of uncertainty, and an estimated age interval. If a reference study utilized to assess chronologic age does not provide this, then state it in the forensic report. For cases involving immigration, asylum seekers, and legal age of majority or license, include a probability statement that the individual has attained the age in question. When statistical mean age and standard deviation are known, statistical probability can be calculated. The practitioner needs to keep in mind the best interest of the subject undergoing dental age assessment evaluation as the priority.

The report is signed by the practitioner and dated.

11.6.1 Disclaimer

A disclaimer statement indicating that the opinion is subject to review or modification if additional information or evidence becomes available should be added.

12 DATA BACKUPS

Back up digital data on a local computer server and on at least one secure stand-alone backup hard drive; and on secure off-site media or cloud storage. In all cases, follow the appropriate security protocols. Maintain hard copies of material that cannot be readily digitized in a master file and follow security protocols in place for other types of physical evidence for these hard copies as well.

12.1 Cloud Storage of Data

Traditionally, forensic data have been stored on a local server or a personal computer. Cloud storage of data is the use of remote hosting servers on the Internet to store, manage, and process these data. When processing and analytical software are included on the same remote server with the forensic data, and delivered over the network, this type of cloud computing is called Software as a Service, or SaaS. Cloud computing has raised issues for the practitioner. These issues are covered in ADA Technical Report No. 1091*, Cloud Computing: Implications and Recommendations for Dental Practice.*

12.2 Data Disposition Guidelines

The practitioner maintains data acquired during a dental examination, records received, written reports and any documented communications in accordance with standard dental/medical protocol.

The examining practitioner may also retain copies of the data in age assessment cases, if security protocols allow, in order to refer to the data should the need arise. However, if security protocols require the ultimate destruction of the data, dispose of the data following approved data destruction protocols. Shred paper documents shredded using crosscut shredding devices. Do not delete electronic media but utilize “wiped clean” specialized software. In addition, encourage physical destruction of electronic media as an additional security measure.

13 DE-IDENTIFICATION OF DATA FOR RESEARCH AND EDUCATIONAL PURPOSES

There are currently no approved guidelines for the proper protocol to anonymize forensic dental data for research and educational purposes. Due to the sensitive nature of this data, exercise extra care in its use and consultation with the appropriate institutional review committees is strongly advised.

It has been suggested, that at a minimum, to follow federal HIPAA de-identification protocols for the Electronic Health Record prior to using this data. This includes the removal of all 20 HIPAA "Identifiers" of an individual as listed at the government web site for “Guidance Regarding Methods for De-identification of Protected Health Information in Accordance with the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule” at http://www.hhs.gov/ocr/privacy/hipaa/understanding/coveredentities/De-identification/guidance.html

Remove the following identifiers of the individual or of relatives, employers, or household members of the individual:

1. Names

2. All geographic subdivisions smaller than a state, including street address, city, county, precinct, ZIP code, and their equivalent geocodes, except for the initial three digits of the ZIP code if, according to the current publicly available data from the Bureau of the Census:

   i. The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and

   ii. The initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to 000.

3. All elements of dates (except year) for dates that are directly related to an individual, including birth date, admission date, discharge date, death date, and all ages over 89 and all elements of dates (including year) indicative of such age, except that such ages and elements may be aggregated into a single category of age 90 or older.

4. Telephone numbers.

5. Fax numbers.

6. Email addresses.

7. Social security numbers.

8. Medical record numbers.

9. Health plan beneficiary numbers.

10. Account numbers.

12. Certificate/license numbers.

13. Vehicle identifiers and serial numbers, including license plate numbers.

14. Device identifiers and serial numbers.

15. Web Universal Resource Locators (URLs).

16. Internet Protocol (IP) addresses.

17. Biometric identifiers, including finger and voiceprints.

18. Full-face photographs and any comparable images.

19. Any other unique identifying number, characteristic, or code.

Researchers need to also consider that eliminating all 20 identifiers would still allow for the possibility of re-identification of the individual. In those cases, consider additional aggregation of data to de-identify individuals further.

14 DISPOSITION OF RADIOGRAPHS

Like other forms of digital data, digital radiographs should be backed-up with on-site as well as off-site media or cloud storage media. If photographic (film) media was utilized to image the remains, double pack intraoral film is recommended. Retain one set of films by the practitioner for his/her case file. In identification cases, the second set may be mounted and forwarded with a written report to the referring entities for the master file. As a general guideline, back up digital radiographs in the same manner as other digital media.

15 QUALITY ASSURANCE (QA)

Blinding includes avoiding personal contact with living individuals and obtaining any unnecessary information that can alter the practitioner's perception. It can originate from many sources, including biases, workplace pressures, or even the introduction of external relevant or irrelevant data from the actual investigation.

Independent verification includes an assessment of the use of proper technique, methodology, and conclusions.

16 CONCLUSION

The use of proper methodology and procedure in estimating chronologic age is of utmost importance. Dental age assessment is a common method of estimating age in both the living and the deceased. It is recommended that Forensic dental age assessment practitioners implement these developed guidelines to the fullest extent applicable, practical, and appropriate.

17 BIBLIOGRAPHY

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[2] ABFO *Diplomate's Reference Manual*, Section IV, Standards, and Guidelines. Available: https://abfo.org/resources/abfo-manual/

[3] European Asylum Support Office Practical Guide on Age Assessment. Available: https://www.easo.europa.eu/sites/default/files/easo-practical-guide-on-age-assesment-v3-2018.(pdf Included).

[4] United Nations.1989. Convention for the Rights of the Child [Online]. Available: http://www.ohchr.org/Documents/ProfessionalInterest/crc.pdf [Accessed 18/12/2016].

[5] United Nations. 2008. Committee on the Rights of the Child (CRC) [Online]. Available: http://www2.ohchr.org/english/bodies/crc/docs/AdvanceVersions/C

18 ADDITIONAL RESOURCES

ADA Technical Report No. 1094, *Quality Assurance for Digital Intra-Oral Radiographic Systems*

ADA Technical Report No. 1091, *Cloud Computing: Implications and Recommendations for Dental Practice*

ISO 1942, *Dentistry – Vocabulary*

ISO 3950, *Dentistry — Designation system for teeth and areas of the oral cavity*

ASTM E1732 – 12, *Standard Terminology Relating to Forensic Science*

ASTM E1459 – 13, *Standard Guide for Physical Evidence Labeling and Related Documentation*

ASTM E1188 – 11, *Standard Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator*

ASTM E678 – 07, *Standard Practice for Evaluation of Scientific or Technical Data*

ASTM E620 – 11, *Standard Practice for Reporting Opinions of Scientific or Technical Experts*

HIPPA 45 CFR (*Code of Federal Regulations*)

ANSI/ADA Standard No. 1058, *Forensic Dental Data Set*

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