

Five Cases of Dental Anomalies Attributable to Congenital Syphilis from Early 20th Century American Anatomical Collections

Stella Ioannou^{1*}, David Hunt², and Maciej Henneberg¹

¹ Biological Anthropology and Comparative Anatomy Research Unit, Adelaide Medical School, The University of Adelaide, Adelaide, South Australia, 5005

² Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington, DC, 20013-7012

Keywords: congenital syphilis, disrupted amelogenesis, severe hypoplasia, tooth morphology

ABSTRACT Specific dental abnormalities are considered pathognomonic of congenital syphilis (CS); however, European physicians recognized their variation during the late 19th to mid 20th centuries. Observations of syphilis-related dental abnormalities in American individuals from similar time periods are made to determine types of variation among the American population.

From a survey of the Smithsonian Institution's National Museum of Natural History anatomical human skeletal collection, five individuals demonstrated dental characteristics consistent with CS (P00011R, P219398, P000707, P000679, and P000161). Hutchinson's three categories of dental anomalies were used to describe variations among syphilitic individuals.

Previously identified pathological dental characteristics related to CS were present in the analyzed individuals. P00011R, 24-year-old Black female, has a maxillary right Moon's molar. P219398, approximately 20-year-old Black female, has Hutchinson's incisors and Fournier's molars. P000707, 26-year-old Black male, displays severe hypoplasia on all incisors, canines and maxillary first molars. P000679, 33-year-old Black female has "screw-driver" shaped maxillary central incisors, altered occlusal morphology of first maxillary molars and hypoplasia. P000161, 45-year-old Black female, demonstrates severe hypoplasia on incisors and canines (molars lost).

"Classic" dental characteristics of CS are not ubiquitous to all identified cases. This study exemplifies that dental anomalies associated with CS do not all have to be present for diagnosis. Although other causes for some of these anomalies are possible, observations in these five cases are most consistent with CS.

Prior to the introduction of penicillin in the 1940s, syphilis was a public health problem in the United States (Lancet, 1930; Lancet, 1937a). The prevalence of syphilis in the United States at that time is difficult to determine, as data collection for syphilis by state health departments did not begin until the early 20th Century, and the Venereal Disease Division of the U.S. Public Health Service was not created until 1918 (Nakashima et al., 1996).

To control venereal disease, various states implemented programs (free treatment, and clinics that offered free, pay, and part pay clinics) (Lancet, 1937a), and legislation (marital examination law and prenatal law) (Lancet, 1917; Prebble, 1938; Lancet, 1940; DePorte, 1941). In cases of medical intervention, mercury was used to treat congenital syphilis in the 19th and early 20th centuries throughout the United States (Conrad and McCann, 1922; Cole et al., 1929; Scheer and Fraser, 1930; Cole et al., 1933; Chargin and Saunders, 1939). Treatments of syphilis also included chemotherapies of arsenic and bismuth compounds (Lee, 1878; Cole et al.,

1929; Eller and Maloney, 1929). The chemotherapies most favored in the treatment of congenital syphilis included mercury, arsphenamine and potassium iodide (United States. Public Health Service. Division of Venereal Diseases, 1930).

The effectiveness of mercury as a treatment for syphilis has been questioned (Miller, 1858; Weatherill, 1833); although, the treatment remained popular with some physicians. In some cases, syphilitic lesions completely healed and patients became seronegative (Wakerlin, 1934). In syphilitic women treated with mercury during their pregnancy, 91.5% were efficient in completing their pregnancies successfully by live birth, while 47.6% non-treated women experienced fetal death (United States. Public Health Service. Division of Venereal Diseases, 1930). Mercury and its compounds were seen to

*Correspondence to:

Stella Ioannou
The University of Adelaide
Adelaide 5005, South Australia, Australia
email: stelzy_25@hotmail.com

have antibacterial properties that actually reduced, or cured infections with *Treponema pallidum* (Smith, 1844; Hare, 1858; Warner, 1881; Wakerlin, 1934). Despite their possible curative effects on syphilis, mercurial treatments yield serious side effects including scarlatiniform rashes, stomatitis, pyrexia, bleeding of the rectum, and death in some cases (Chopping, 1899; French, 1909). Therefore, the use of mercury was abandoned later in the 20th century when other effective forms of treatment (i.e., penicillin) became available and mercuric treatments were dropped from clinical practice.

In paleopathology, the diagnosis of congenital syphilis (CS) is based on skeletal and dental signs. However, when skeletal signs are not present specific dental abnormalities caused by a disturbance in odontogenesis are associated with the disease (Hillson et al., 1998). Signs include Hutchinson's crescentic notched or screwdriver incisors (Hutchinson, 1859; 1887), Moon's dome-shaped molar (Moon, 1884), and Fournier's molars of "upset appearance" (Bouleversée d'aspect) (Fournier, 1886:84). These changes occur when odontogenesis is affected during the early stage of the disease. During the 19th century, Jonathan Hutchinson, was the first to note that syphilitic treatments containing mercury also affected dental development, disrupting amelogenesis. Hutchinson described that these mercury-induced dental malformations were significantly different from those caused by congenital syphilis alone, and in some cases, patients exposed to a treatment regimen involving mercury could manifest dental signs associated with the disease and treatment (Hutchinson, 1888; Moon, 1884; summarized in Ioannou et al., 2015, 2016). It should be noted that 10-30% of patients clinically diagnosed with congenital syphilis do not manifest changes associated with disturbed odontogenesis (Švejda, 1952; Lipski and Przyłipiak, 1959). It is clear that these inconsistencies caused confusion among physicians in the past (Hutchinson, 1878) and with diagnoses in both clinical and paleopathological settings.

During late 19th and early 20th centuries, various institutions produced collections of skeletons for future research purposes. These collections included skeletons of individuals who suffered from various diseases including treponemal diseases. Today such collections provide hard evidence of the disease and its treatments, independent of government records and the literature. For some individual skeletons, there is medical documentation stating the cause of death, while others have been given differential diagnosis based on the skeletal evidence by the curator. Such diagnoses were based on paleopathological knowledge of the curator at the time.

While previous studies have focused on "typical"

dental characteristics associated with congenital syphilis, this paper will also assess the possibility of some of the dental anomalies being from the medical treatments. Therefore, the aims of this paper are: (1) to describe the variation and similarities in dental abnormalities associated with congenital syphilis in individuals either medically diagnosed with the disease or who were posthumously diagnosed by skeletal pathological conditions or dental anomalies to have been afflicted with congenital syphilis, and (2) to evaluate whether there are any indications of dental features that could be the result of treatments for congenital syphilis. Differential diagnoses of other diseases or genetic conditions that could have effects on dental characteristics are reviewed, including tuberculosis, leprosy, amelogenesis imperfecta, rickets, fluorosis, and some of the chemicals used to treat these diseases are also considered, such as mercury, arsenic, bismuth, lead and cadmium.

MATERIALS AND METHODS

As stated above, 10-30% of patients clinically diagnosed with congenital syphilis do not manifest dental anomalies (Švejda, 1952; Lipski and Przyłipiak, 1959). To assess the range of expression of the dental anomalies attributed to congenital syphilis, those conditions as described by Jonathan Hutchinson (1859, 1863, 1878, 1887, 1888), Henry Moon (1877, 1884), Alfred Fournier (1886), and Hillson et al. (1998) are used as the criteria for the cases observed here to evaluate the likelihood of congenital syphilis in the anatomical collections and to see if comparable dental abnormalities are present. The criteria are reviewed and described by Ioannou et al. (2016).

A review of dentition in the early 20th century Robert J. Terry anatomical skeletal collection and cadaver room skeletons from the Howard University Medical School was made at the Smithsonian National Museum of Natural History (NMNH) in Washington DC. The survey focused on individuals listed as having pathological conditions related to the following: congenital syphilis, treponemal disease, lues disease, syphilis, tuberculosis, and rickets. These pathological identifications came from death certificate records, reports from the morgue records, or diagnoses made by observations of the cadavers or the skeletal elements in dissection or after skeletonization. Some of the observations made by curators were independent from the cause of death of these individuals.

Out of 38 individuals that were narrowed down from the initial survey, five individuals exhibited various dental malformations consistent with those in patients diagnosed with congenital syphilis (Excel file with data is available from SI upon request). The five individuals were P00011R, P219398, P000707,

P000679 and P000161, of which only P00011R was clinically diagnosed with congenital syphilis while living. The dentition of these individuals was analyzed to document the types and range of malformations in tooth morphology. Since human variation and their effects from disease are individualistic and often do not present the “typical” pathological manifestations of a particular disease.

To evaluate the possibility of mercury treatment of any of these subjects, portable x-ray fluorescence (pXRF) spectrometry was conducted to determine whether mercury could be detected in the enamel and bone in each of the individuals.

Dental Malformation Criteria for Evaluation of Treponemal Disease

Hutchinson (1859, 1863, 1878, 1887, 1888) recognized that dental malformations observed in children with congenital syphilis varied so considerably that he deemed it necessary to create various categories to distinguish kinds of anomalies in dental formation. His three categories of dental malformations were - syphilitic teeth, mercurial teeth, and syphilitic-mercurial teeth.

In the syphilitic category, the maxillary central incisors are the “test teeth”. The central incisors can appear “peg like” or screwdriver in shape, are dwarfed and display a crescentic notch on the incisal edge (Hutchinson’s incisors). Some of these features can also be observed in the maxillary lateral incisors and mandibular incisors (Hutchinson, 1887; Hillson et al., 1998). Other characteristics within the syphilitic category include malformations observed in the first permanent molars (Hutchinson, 1887) labeled as Moon’s molar and Fournier’s molars. Moon’s molar is “smaller than usual and dome-shaped” (Moon, 1877), while Fournier’s molars either have several nodules and tubercles or have a flat surface (Fournier, 1886). Both varieties of Fournier’s molars have a clear demarcation between healthy and diseased enamel.

Mercurial teeth demonstrate severe enamel hypoplasia, caused by treatments containing mercury. The first permanent molars are the “test teeth”. The enamel is deficient and appears rugged, pitted, and dirty with a honeycomb appearance (Hutchinson, 1878; Ioannou et al., 2016). Dentine is affected in severe cases with the appearance of multiple spines or tubercles. The entire occlusal surface or a central area can be affected. Incisors and canines are also affected with severe linear enamel hypoplasia that crosses these anterior teeth at the same level. The enamel between the linear enamel hypoplasia and the tip of the crown is deficient (Hutchinson, 1878), and pitting hypoplasia is also common. Premolars in most cases appear normal. However, the characteristic notch

observed in syphilitic incisors is not mimicked in mercurial conditions only (Hutchinson, 1878). Syphilitic-mercurial teeth demonstrate a combination of both syphilitic and mercurial dental malformations (Hutchinson, 1878; Moon, 1884; Ioannou et al., 2016). The upper central incisors can have a peg-like or screw-driver shape (outline), the incisal edges appear characteristically notched, and any part of the enamel surface can be hypoplastic, pitted and discolored. The first permanent molars can show an absence of enamel on the occlusal surface of the crown but have healthy enamel on its sides (Hutchinson, 1878).

RESULTS

Terry Collection P00011R (Fig. 1) is an African American female, born in 1918 and died in 1942, at 24 years old. The primary cause of death was attributed to lobar pneumonia, but was clinically diagnosed with congenital syphilis in 1930 and was subsequently institutionalized until her death, 11 years and 2 months later. This is the only individual that was diagnosed with congenital syphilis during the life of the individual.

All maxillary incisors and left maxillary canine were lost many years before death (Fig. 1A). The first right upper molar has a clearly narrowed occlusal surface with pitting hypoplasia resembling a dome shape (Moon’s molar) (Fig. 1B & 1C). The left first upper molar has a narrowed occlusal surface, and is largely destroyed by dental caries. All the premolars and right canine have normal morphology. The second and third permanent molars have normal molar morphology. The left third molar has a single carious lesion on the disto-buccal aspect. Upper alveolar process shows periodontal changes on both sides.

The mandibular teeth present include the left and right lateral incisors, left canine, left and right first premolars, left second premolar and left and right second and third permanent molars. The lateral incisors appear peg like in shape (Fig. 1D & 1E). Both first permanent molars were lost many years before death, and the alveoli are completely healed (Fig. 1F). The occlusal surface of the left second premolar and second and third permanent molars are destroyed by caries. Bone resorption suggests periodontal disease (Fig. 1D & 1F). Cranial morphology is normal, no ‘saddle nose’ is present, and the nasal cavity and palate are normal. The molars in P00011R are syphilitic.

Howard Collection P219398 (Fig. 2) is an African American female who died in 1903 in Washington, DC with no recorded cause of death and was autopsied at Howard University School of Medicine. There is not a reported age at death, but dental and skeletal development indicators suggest this individual died between 20 and 25 years of age. Previous evaluation

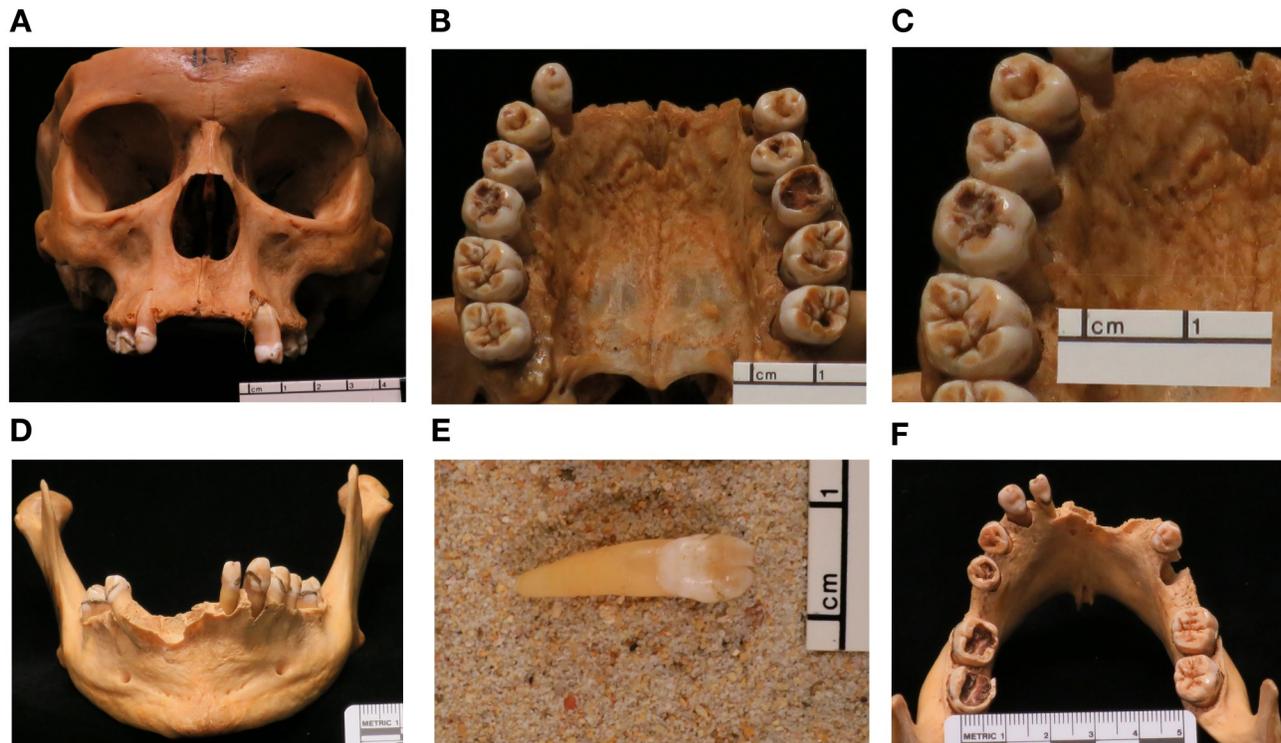


Figure 1. Individual P00011R, 24yrs old female. (A) Anterior view of maxilla: Central and lateral incisors, and left canine missing. No saddle nose. (B) Occlusal view: Most teeth have normal morphology. Carious destruction of the left first molar does not allow precise observation, but it seems that the crown has a narrow occlusal surface. (C) First right permanent molar has a narrow and reduced occlusal surface resembling Moon's molar. Pitting is also present. (D) Anterior view of the mandible. Periodontal disease is evident. (E) Loose anterior tooth of mandible; lateral right incisor. (F) Occlusal view of mandible: No first molars, most likely lost to caries.

by researchers and curators identified the dental anomalies and considered them to be the product of congenital syphilis and this was noted in the Smithsonian pathology files. All maxillary teeth are present, except the left second and third permanent molars. The maxillary central incisors are marked by rounded mesial and distal incisal edges. The labial aspects of the incisal one-third of both crowns have centrally located hypoplastic defects. On the right central incisor, this hypoplasia resulted in a smooth crescentic pit, while on the left central incisor there is irregular hypoplastic pitting in the same location (Fig. 2A). Multiple short lines of hypoplastic enamel are also apparent on the lingual surface of both teeth. The mesial and distal edges of the right and left lateral incisors are also rounded off, giving both teeth a peg-like shared crown. Multiple pits are present on the lingual surface of both lateral incisors. The tips and lingual aspects of the canines display hypoplastic pitting. The occlusal surfaces of the first permanent molars have diminished areas compared to the dimensions of the rest of the crown (Fig. 2B & 2C). There are also scattered hypoplastic pits and various

areas of the occlusal surfaces have irregular grooves (Fig. 2C). The molars resemble both types of Fournier's molars. The second right permanent molar has normal molar morphology. The left second molar was lost during life, as the alveolar bone has healed.

The mandibular dentition is nearly complete. The left canine was lost post-mortem, while the alveolus of the lower left third molar is healed. The central incisors are affected by severe enamel hypoplasia and exposed dentine on the incisal one-fourth of the crown (Fig. 2D). The morphology and enamel of all other teeth, except the first permanent molars, appears normal. The occlusal surfaces of the crowns of the first permanent molars are reduced in size and severely hypoplastic (Fig. 2E & 2F). The cusps appear to be reduced in size and multiple tubercles are visible (Fig. 2F). This appears similar to Fournier's nodule-type molar. The dentine is also exposed in places. The morphology of the second permanent molars appears normal, with the left demonstrating signs of crenulation. The entire crown of the third right permanent molar is missing with only the root present while the left was lost during life as indicated by

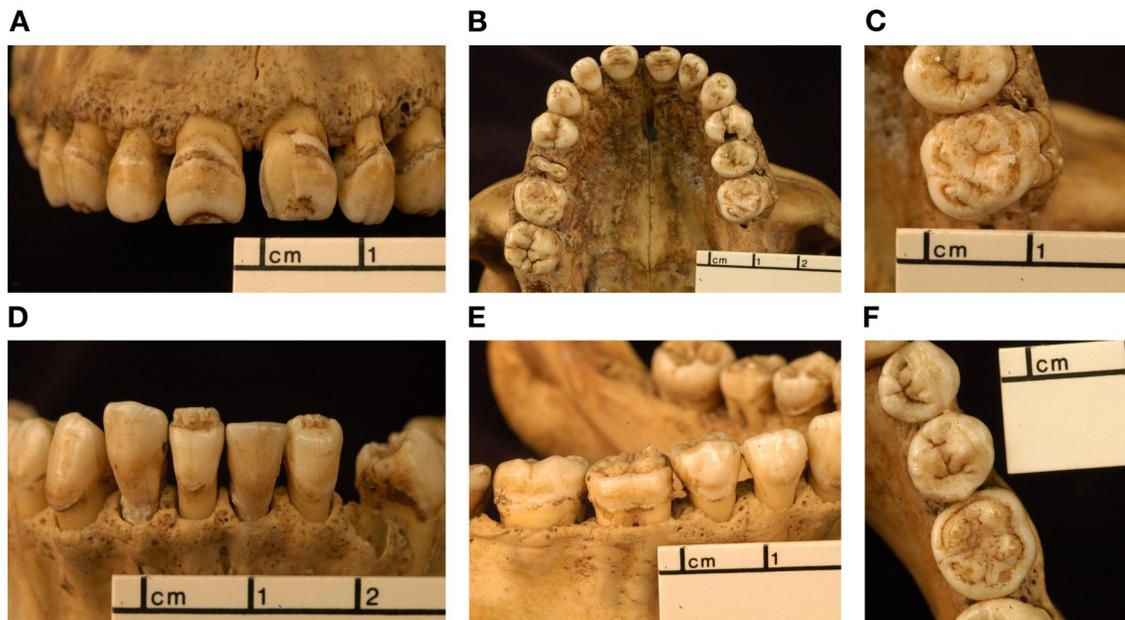


Figure 2. P219398, 20yrs old female. (A) Anterior view of maxilla: Labial aspect of permanent central incisors. Right incisor has thin enamel along incisal edge forming a crescentic pit. Irregular pitting is noted in the same location on the left incisor. Lateral incisors are peg-like in shape. (B) Occlusal view of maxilla: Occlusal surfaces of the first permanent molars are reduced and demonstrate scattered hypoplastic pits and irregular grooves. (C) Occlusal view of the left first permanent molar of maxilla demonstrates pitting and grooves in enamel. The occlusal surface is also reduced. (D) Anterior view of mandible: Central incisors demonstrate enamel hypoplasia and exposed dentine on the 1/4 of the crown. Note, the central and lateral incisors appear to be incorrectly inserted into mandible post mortem. (E) Lateral view of right side of mandible: First permanent molar resembles that in the maxilla. (F) Occlusal view of right mandibular first permanent molar: it has reduced surface, multiple tubercles and pitting hypoplasia.

healed alveolar bone. The morphology of the alveolar bone suggests some periosteal inflammation was present at the time of death. The dental abnormalities in P219398 are most consistent with syphilitic malformations.

Terry Collection P000707 (Fig. 3) is an African American male, aged 26 years at the time of his death in 1929 in St. Louis, Missouri from pulmonary tuberculosis. Previous evaluation by researchers and curators identified the dental anomalies and considered them to be the product of congenital syphilis and this was noted in the Smithsonian pathology files. All permanent teeth, including the third molars, are present. The central incisors are marked by minor notches and isolated pits along the incisal edges. Enamel adjacent to the incisal edge appears healthy with minor pitting, however, the middle third of the crown shows progressively more severe pitting hypoplasia that ends with extremely deep defects that likely penetrate the pulp cavity (Fig. 3A). The cervical portion of the crowns appears normal. The left lateral incisor is affected by a similar progressively pitted enamel defect on the incisal third of the crown (Fig. 3A). The incisal third of the right lateral incisor has been lost at a point where the pitting morphology appears like that observed in its left-side antimer. A similar

enamel defect affects the left canine (Fig. 3B). The enamel of the right canine appears to have broken off postmortem. The lingual surfaces of these anterior maxillary teeth are affected by irregular hypoplastic defects, demonstrating a mottled like appearance. The premolars have normal morphology. The occlusal two thirds of the crown of the first permanent molars are hypoplastic, with pitting hypoplasia and reduced surfaces in comparison to the other permanent molars present (Fig. 3C). However, some normal groove patterns of the occlusal surfaces are preserved. Minor pitting is present on the second and third permanent molars. The second left and third right permanent molars demonstrate crenulation. The alveolar bone suggests some periosteal inflammation was present.

The mandibular dentition consists of all permanent teeth, except the left and right first molars. Two thirds of all incisors and canines are affected by severe hypoplastic defects (Fig. 3D). The left and right first molars were lost antemortem. The alveoli for the first molars are healed but not completely resorbed (Fig. 3E). The second permanent molars and the left third permanent molars have normal molar morphology but demonstrate crenulation (Fig. 3F). The third left molar appears larger than the second permanent molars. A supernumerary fourth molar is present on

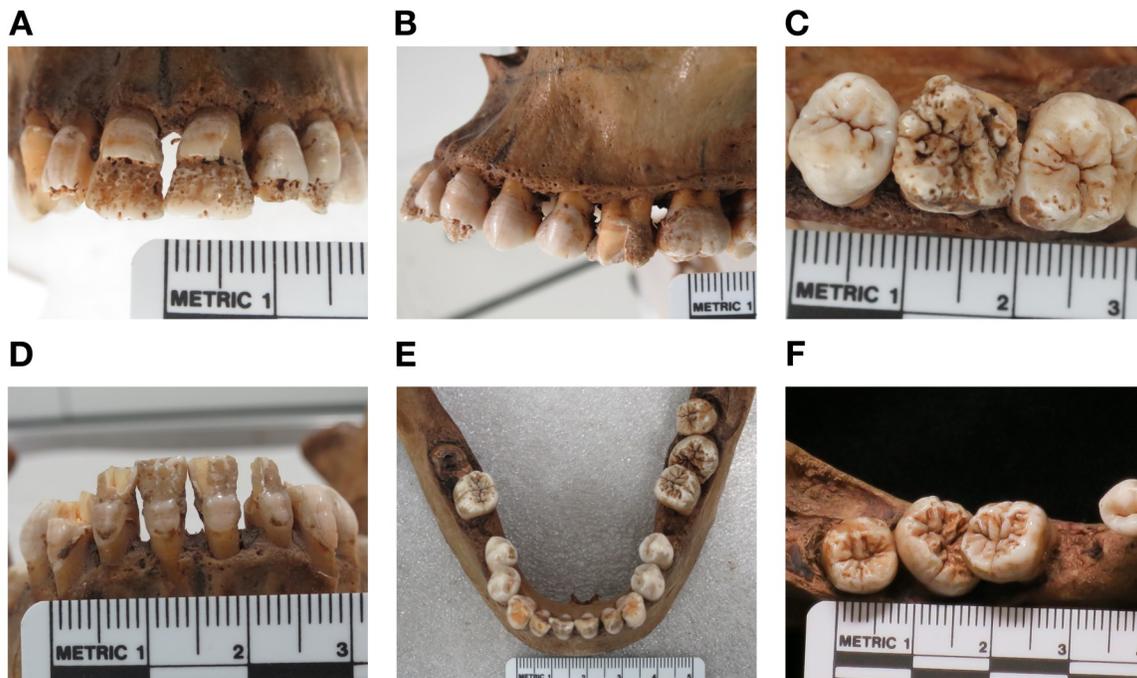


Figure 3. P000707, 26yrs old male. (A) Anterior view of maxilla: Incisal edges of the maxillary central incisors appear healthy with isolated pits. The middle third of the crown demonstrates progressively severe enamel hypoplasia. Similar enamel hypoplasia is evident on the lateral incisors and canines. (B) Lateral view of the left side of maxilla: The lateral incisor and canine display enamel defects similar to the central incisors. (C) Occlusal view of upper right first permanent molar, note unusual configuration of enamel on the occlusal surface. Two thirds of the occlusal surfaces of the first permanent molars are severely hypoplastic, although some normal groove patterns are preserved. (D) Anterior view of the mandible: Two thirds of all incisor and canines crowns are affected by severe hypoplastic defects. (e) Occlusal view of mandible, note both first molars are missing. (F) Close up of supernumerary fourth molar. Note crenulation on occlusal surfaces of other molars.

the left side (Ioannou & Henneberg, 2016). It is smaller in size in comparison to the other molars and has normal molar morphology (Fig. 3F). P000707 demonstrates dental signs that are suggestive of mercuric treatments.

Terry Collection P000679 (Fig. 4) is an African American female, who died of tuberculosis at 33 years of age in St. Louis, Missouri in 1928. Previous evaluation by researchers and curators identified the dental anomalies and considered them to be the product of congenital syphilis and this was noted in the Smithsonian pathology files. The maxillary dentition is complete, except for the left third molar. It is unclear whether the absence of this tooth was due to agenesis or antemortem tooth loss. The maxillary central incisors have narrowed incisal edges with rounded corners. Located at the midcrown on the labial surface are hypoplastic defects that consist of an approximately oval-shaped area of thinner enamel, which is surrounded by pitting that extends distally to the one-third of the crown from the incisal edge (Fig. 4A). Shoveling is apparent on the lingual aspects, as is one linear hypoplastic line on the cervical third of the crowns (Fig. 4B). The lateral incisors appear peg like

in shape with round mesial and distal edges. A couple of isolated pits are evident on the right lateral incisor. One hypoplastic line runs at the same level on both lateral incisors on the labial aspect. The left canine has isolated pits on the tip of the crown. Pits and grooves are present on the lingual aspect of the canines. Pitting is on the occlusal surface and lingual aspect of the first premolars. The right second premolar has a deep groove on the lingual surface. Maxillary first molars have occlusal surfaces that are reduced in size and have abnormal enamel formation (Fig. 4C). There is a demarcation between diseased and healthy enamel by pitting hypoplasia (Fig. 4D). The second molars and third right molar have normal morphology.

The mandibular dentition is represented by a full set of anterior teeth from the left first premolar to the right first premolar. The right third molar and the left second molar are present. All other posterior teeth were lost antemortem as indicated by complete alveolar remodeling (Fig. 4E). The incisors are marked by multiple notches on their incisal edges. Shallow indistinct furrows are present about one-third the length of the crown (Fig. 4F). Isolated pits are present on the lateral incisors. Part of the enamel on the labial

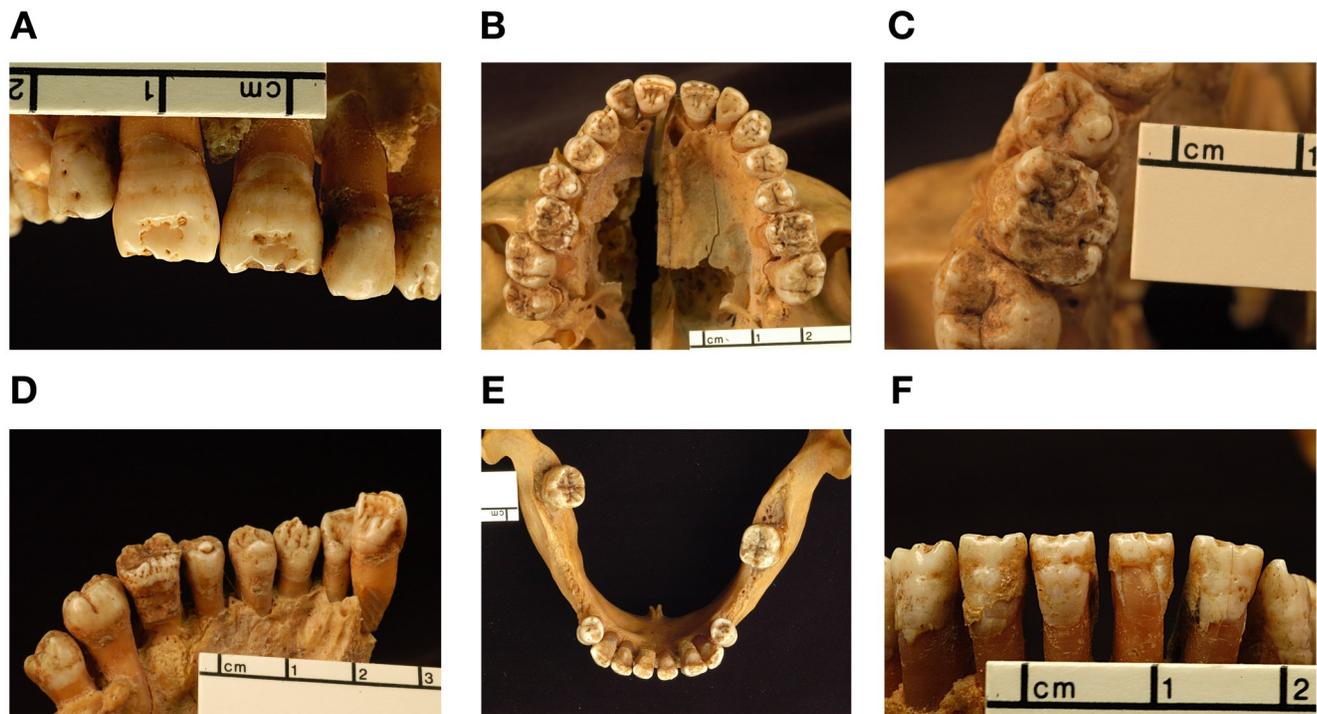


Figure 4. P000679, 33yrs old female. (A) Hypoplastic defects on labial surface of central incisors. Those that are in the incisal third of the crown are large and oval in shape and are centrally located with small-scattered pits. Some other teeth also display pitting. (B) Occlusal view of maxilla: occlusal surfaces of first permanent molars have abnormal formation of the enamel. (C) Close up of upper right first molar. (D) Palatine view of the right maxillary dentition: Note demarcation between diseased and healthy enamel in the first permanent molar. (E) Occlusal view of mandible. (F) Anterior view of mandible: Incisors are marked by multiple notches on their incisal edges while shallow indistinct furrows are present about one-third the height of the crown.

surface of the left central incisor has broken off post-mortem. The first premolars have isolated pits on their surfaces. All other remaining mandibular teeth have normal morphology. The dental defects in P000679 are comparable to Hutchinson's dental observations for CS and suggestive of mercurial teeth morphology.

Terry Collection P000161 (Fig. 5) is an African American female who was approximately 45 years of age at the time of death and added to the skeletal collection in 1925. No cause of death is recorded in the morgue records. Previous evaluation by researchers and curators identified the dental anomalies and considered them to be the product of congenital syphilis and this was noted in the Smithsonian pathology files. All maxillary teeth are present, except the right second premolar and the left first molar. The incisal margins of the central and lateral incisors are notched. The labial surfaces of crowns of anterior teeth have malformed enamel, featuring irregular pitting and a deep furrow located about one-third of the crown height proximal to the incisal edge (Fig. 5A). A second furrow appears on the left central incisor on the cervical third of the crown. The furrows of the anterior teeth appear approximately at the same level. Some enamel was lost postmortem on the cervical

third of the right central incisor and parts of the mesial aspect of the left central incisor. Numerous dark colored pits run horizontally along the middle third of the crown of the central incisors and the incisal third of the lateral incisors and tip of canines. (Fig. 5A). Similar pitting and linear hypoplastic defects occur on the lingual surfaces of these teeth (Fig. 5B). The morphology of the premolars and other molars still present appears normal. A fragment of the occlusal surface of the right first permanent molar is marked by irregular enamel and pitting. A large carious lesion is present in the disto-lingual area of the right first permanent molar, while an interproximal carious lesion is evident towards the mesio-lingual end of the crown. The left first molar has been lost most likely due to dental caries. The alveolar bone has not healed completely, so it is possible the loss occurred shortly before death. The morphology of both second molars and third molars appears normal. On the palate anteriorly on the right side there is a circular bony depression surrounded by elevated bone. There is a large perforation on the right side of the palate. There is also some pitting in the palate that is more apparent near the right first permanent molar.

The mandibular dentition consists of the left and right lateral incisors, canines, first and second premo-

lars, second molars and the left third molar. The central incisors were lost post mortem, while both first molars and the right third molar were lost ante-mortem. The alveoli for both first molars are completely remodeled, but the alveolus for the left has been less remodeled than the right. The third right molar alveolus is healed. Similar to the maxillary dentition, severe linear and pitted enamel hypoplastic defects are present on the lateral incisors and canines (Fig. 5C). The multiple hypoplastic lines run along at the same level of the crown of these teeth on both labial and lingual surfaces (Fig. 5C & 5D). The tops of the crowns of the first premolars appear hypoplastic. Pitting and two small carious lesions are present on the occlusal surface of the left first premolar. The crowns of both second premolars appear normal. The abnormalities seen in the dentition of P000161 are consistent with Hutchinson's description of patients with CS and possibly some features suggestive of mercury effects.

Mercury testing using pXRF

An exploratory, qualitative analysis using a portable x-ray fluorescence analyser (pXRF) was performed to

see if any of the individuals above might have mercury or other chemical elements possibly related to treatment for CS and the cause of the dental abnormalities. The analysis was conducted using a Bruker Tracer III-V handheld analyser on portions of hypoplastic enamel on the central and lateral incisors for all of the individuals, except individual P00011R, which lacked central incisors - instead, a lateral incisor and canine were tested. The analysis was conducted with settings optimized for mercury (0.001" Cu, 0.001" Ti, 0.012" Al filter at 40 keV/16 micro amps for 300 seconds, without vacuum). Bone testing was done on the femur of the same individuals to test for contamination if high readings of any particular elements were found. No mercury was detected. The lack of mercury in these individuals most likely can be attributed to amounts of mercury that may be too minute for the instrument's detection capabilities (see Zuckerman, 2016:50 for discussion on mercury detection with pXRF).

Differential Diagnosis

Diseases that interfere with odontogenesis and amelogenesis are considered for a differential diagnosis.

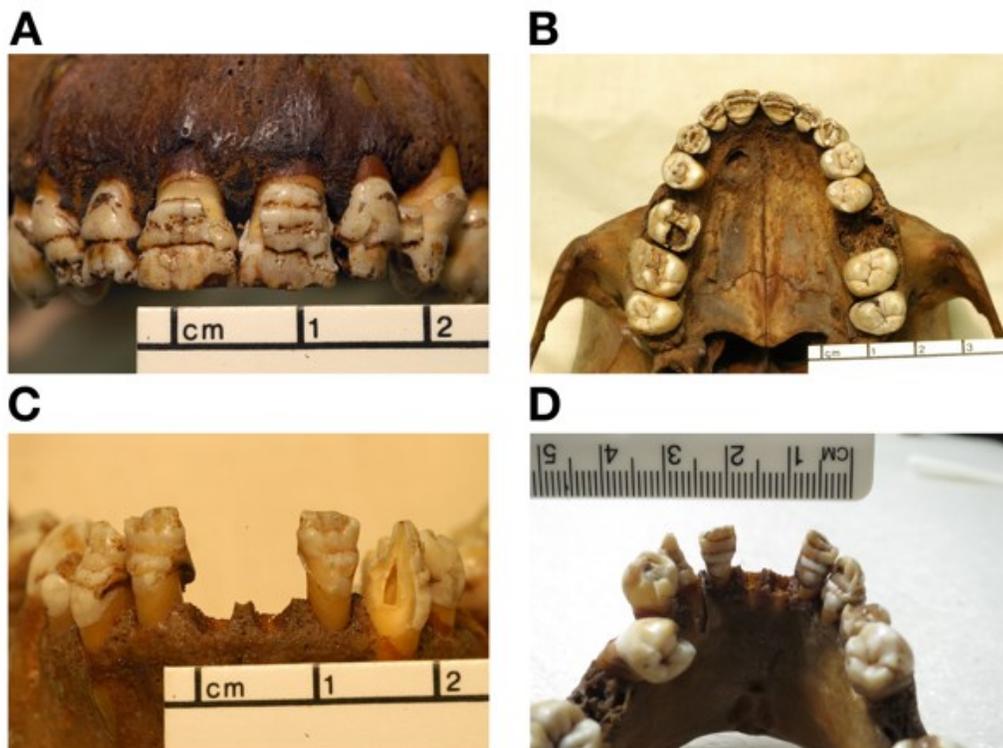


Figure 5. P000161, 45yrs old female. (A) Severe hypoplastic enamel of the maxillary incisors and canines. Incisal thirds of the central and lateral incisors' and canines' crowns are hypoplastic with deep furrows. Dark colored pits run horizontally across the crowns. (B) Occlusal view of maxilla: Linear and pitting hypoplasia noted on the lingual surface of anterior teeth. (C) Anterior view of mandible: Severe linear and pitted enamel hypoplasia on the lateral incisors and canines. (D) Lingual view of mandible: Pitted and linear enamel hypoplasia evident on lateral incisors and canines corresponds to that on labial surface.

These include tuberculosis, leprosy, amelogenesis imperfecta, rickets and fluorosis, as well as elements that have been used as treatments or are known to affect tooth development such as mercury, arsenic, lead, bismuth, and cadmium.

Tuberculosis is a chronic disease that predominately affects the ribs, vertebrae, and the large joints of the body. In adult onset of tuberculosis, there would be no effect on the dentition. In cases of childhood tuberculosis, the most common dental abnormalities are associated with developmental stress - linear enamel hypoplasia (Dabernat and Crubézy, 2010; Bedić et al., 2015); carious lesions (Formicola et al., 1987; Hlavenková et al., 2015); and decreased enamel thickness (Formicola et al., 1987). Since dental signs observed in childhood tuberculosis do not resemble the dental abnormalities or the severity observed in the five cases, tuberculosis is not likely and would be ruled out as a differential diagnosis.

Leprosy is a chronic disease that affects the skin and peripheral nervous system with skeletal loss by resorption in the latter stages of the disease. It is a slow and progressive disease, signs of the disease can start to develop from six months to 30 years (World Health Organization, 2012). Dental abnormalities that have been reported in skeletal cases with evidence of leprosy include linear enamel hypoplasia (Boldsen, 2005) (which might be correlated to possible frailty in the individuals, rather than leprosy itself), and constriction of the roots of the upper permanent central incisors (leprogenic odontodysplasia) (Roffey and Tucker, 2012) that might be related to the resorption of the alveolus rather than development effects of dental formation (Roberts 2011). These observations are not common or diagnostic of the disease. If a child were to be infected with leprosy, since its macroscopic expression would be long-term, it is assumed that the disease would not severely affect dental development, possibly only producing linear enamel hypoplasias from insults to development. It is unlikely that there would be the severity of dental pathology similar to those in the described cases here. Since leprosy is predominately an adult disease, if in children it would not have the severe effects as seen in CS, therefore, leprosy is ruled out as a differential diagnosis.

Amelogenesis imperfecta (AI) is a hereditary condition characterized by enamel defects. Phenotypic expression of the condition is caused by a disturbance in ameloblasts secretions producing hypoplasia, hypocalcification, hypomaturation and hypomaturational-hypoplasia with taurodontism (Gadhia et al., 2012; Prasad et al., 2016). Amelogenesis imperfecta also manifests in enamel discoloration, enamel pitting, and thin enamel (Kar et al., 2012; Gerdolle et al., 2015; Rogers et al., 2016). The prevalence of AI varies

between populations from 43:10,000 in Turkey to 1.25:10,000 in Israel (Gadhia et al., 2012). Amelogenesis imperfecta is an unlikely differential diagnosis for the described cases since AI tends to affect amelogenesis in most all or all teeth – this is unlike congenital syphilis where only specific teeth are affected.

Rickets is a disorder caused by either a lack of vitamin D or phosphorus. These metabolic deficiencies affect tooth mineralization and bone development. Rickets may cause some non-severe linear or pitting-type enamel hypoplasia and in cases discoloration and enamel opacities (Zambrano et al., 2003; Davit-Beal et al., 2014). Like AI, rickets more uniformly affects the teeth. Therefore, with the severity of hypoplastic defects described and the specific tooth involvement, this is not consistent with rickets and their differential diagnosis can be ruled out.

Consumption of large amounts of fluoride can lead to fluorosis, and specifically in developing dentition will cause disturbance of amelogenesis. Enamel will appear discolored (yellow to dark brown), demonstrate white opaque patches or lines, or pitted or mottled hypoplasia (Sherwood, 2010; Muñoz et al., 2013). Similar to AI and rickets, fluorosis does not affect selected teeth, and its hypoplastic effects are less severe than those described in the five cases presented here. Thus, the diagnosis of fluorosis is unlikely.

Mercury was used for medicinal purposes throughout the United States to treat syphilis and congenital syphilis (Cole et al., 1929; United States. Public Health Service. Division of Venereal Diseases, 1930). Mercury was administered in various forms but was most commonly injected intramuscularly or rubbed onto the skin. Treatments containing mercury ranged from one and a half to fourteen grams of solution or ointment (Cole et al., 1929; Cole 1933). Since some of the malformations observed in P000707, P000679 and P000161 could be suggestive of the mercurial or syphilitic-mercuric category set by Hutchinson (1878) and Moon (1884), it is possible that mercury might have caused the dental malformations. There is no proof that any of these individuals may have had treatments and the one clinically diagnosed case (P00011R), was diagnosed at an age that would have excluded the severe effects of dental malformation if mercury were administered after her diagnosis.

Arsenic was also used to treat syphilis/congenital syphilis; however, its effects on enamel development in children with congenital syphilis are limited. Arsenical poisoning has been found to cause tooth sensitivity and tooth abrasion in children (Sunny, 2013), but nothing in the way of severity of the anomalies caused by mercury. Thus, the possibility of arsenic poisoning or treatment is an unlikely differential di-

agnosis.

Bismuth was introduced later than mercury and arsenic, and was used in conjunction with these to treat syphilis and congenital syphilis. Bismuth was noted to cause pigmentation of gums and the enamel, most frequently seen on the labial surfaces of the lower and upper central incisors and in prolonged acute cases, loosening of the teeth (McCarthy and Dexter 1935; Dean, 1943). The common factor observed in bismuth poisoning is that the cervical portion of the incisors was the most constant location for pigmentation (McCarthy and Dexter 1935; Dean, 1943). We see none of this pigmentation, and these individuals would have been too young to have received bismuth treatments, thus, excluding this as a differential diagnosis.

Lead was considered a possible cause in dental development, but previous studies have not found lead to cause enamel abnormalities. High levels of lead only result in a decrease in microhardness of enamel (Gerlach et al., 2002; Youravong et al., 2005) coupled with increases in abrasion and discoloration (Gil et al., 1996). Normal enamel morphology has been observed in cases where high levels of lead were present (Gerlach et al., 2002; Youravong et al., 2005).

Cadmium, although not used to treat syphilis or congenital syphilis, is known to accumulate in enamel; however, its effects on enamel development are limited in the literature. Wilson and Deeds (1939) noted that cadmium toxicity caused bleached white enamel discoloration. Since that is not observed in the discussed individuals, cadmium is unlikely diagnosis.

DISCUSSION AND CONCLUSIONS

Syphilis was a disease that caused serious problems in the United States during the late 19th and early 20th centuries, with various measures taken to control its spread (Lancet, 1930; Lancet, 1937a; Lancet, 1917; Prebble, 1938; Deporte, 1941). While various programs and legislations were initiated, treatments (including mercury) were of primary importance to reduce prevalence rates (Lancet, 1921; Lancet, 1937a; Lancet, 1939). Even though mercury was known to produce side effects, similarly to other chemotherapies (arsenic and bismuth), it was still considered the most effective, being used on its own or in combination with other pharmaceuticals (Lancet, 1937b). However, the healing nature of mercury has also been called into question due to non-systematic recording of treatments and outcomes in the 19th century, as well as misdiagnosis of the decades-long quiescence of the disease as “cured” (Zuckerman, 2016).

Individual P00011R was diagnosed in life with congenital syphilis. The only detectable manifestations of this diagnosed condition are visible in her teeth. While some of her teeth are missing, those that

are present, especially the first permanent molars, are highly consistent with the anomalous condition found in cases of congenital syphilis. The dome-shaped and reduced occlusal surface of her first permanent molars is obviously a consequence of developmental disruption caused by congenital syphilis. They resemble those described by Moon (1884), but due to developmental variability, are not identical to the description.

While congenital syphilis was diagnosed and recorded only in this one individual, the other four individuals display dental changes that fit the broad range of changes described by Hutchinson (1859, 1863, 1878, 1887, 1888), and Moon (1877, 1884). Individual P219398 demonstrates tooth morphology that fits the syphilitic category described Hutchinson. The right central incisor displays a crescentic groove towards the incisal edge. Hutchinson (1863) describes that once this thin enamel has broken off, the characteristic notch is present.

The hypoplastic lesions in the dentition of individuals P000707 and P000161 are of significant severity. In P000707, enamel malformations in the maxillary central incisors begin approximately 2mm from the incisal edge and a normal groove pattern is visible on the very occlusal surface of the first permanent molars, indicating malformation in amelogenesis in the first months of the infant’s life. The lateral incisors and canines demonstrate similar enamel defects but are located at different crown heights that correspond to the differences in the timing of formation of these teeth. Crown development of first permanent molars begins perinatally, permanent central incisors begin to form at approximately 3-4 months of age, lateral incisors at approximately 10-12 months and canines at six months (Nelson & Ash, 2010). The crown of first molars is completed at about 2.5-3 years of age, both incisors at approximately 4-5 years of age, and at about 6-7 years of age for canines (Nelson & Ash, 2010). Judging from the position of hypoplastic defects (reflecting the mercurial category features by Hutchinson) these changes would occur at about 2.0-2.5 years of age.

The pathological changes in the dentition of individual P000161 follow similar interpretation for development and hypoplastic events similarly to individual P000707. However, hypoplastic defects are positioned somewhat earlier in the individual’s life and ceased later than in individual P000707. The severe enamel abnormalities observed in individual P000161 are changes that are more similar to the examples of the mercurial category as described by Hutchinson. But as presented above, no record of this treatment can be attributed to this individual.

Individual P000679 has enamel defects of the maxillary central incisors that are much like the mercurial

category described by Hutchinson. Whatever disturbances caused the anomalous formations of the teeth would have to have started not long after birth or from treatment to the mother - the abnormal enamel occurs much closer to the incisal margin than that seen in either individual P000707 or P000161. But again, there is no record of this treatment attributable to this individual.

In skeletal collections when medical information is not available, paleopathologists make differential diagnoses from the skeletal/dental evidence using the knowledge available at that time. During the turn of the last century and into the 20th century R. Terry, D.S. Lamb, A. Hrdlicka, T.D. Stewart and J.L. Angel made diagnoses of pathological conditions and anomalies on the anatomical and archaeological remains using their familiarity with the pathological understanding from their medical experience, and their knowledge of medical treatment for various diseases. For the individuals studied here, notations of the dental and skeletal observations related to or attributable to "treponemal disease" were made in the Smithsonian records from these scientists based on their observations and knowledge of the disease. In these records, differential diagnoses were often not listed, and thus in some cases, the labeling of a disease may have been from the observations, not from the clinical record of cause of death. From what has been observed in this study, these individuals encompass a range of variation in the dental abnormalities that have occurred in syphilitic patients. The findings of this study provide examples of this range of manifestations, discussing the basis for the malformations, and provide additional insight into identifying CS in future studies.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Rhonda Coolidge for her analysis and report using the pXRF. The instrument was made available by the Smithsonian Anthropology Repatriation Osteology Laboratory. We also acknowledge the monumental effort of Martin Coolidge in acquiring the Death Certificates for the majority of the Terry Collection individuals - which allowed for determination of diagnosed congenital syphilis in P00011R. The first author would like to acknowledge the Australian Government Research Training Program Scholarship.

LITERATURE CITED

- Bedić, Ž., Vyroubal, V., Tkalčec, T., Šlaus, M. (2015). A case of childhood tuberculosis from modern period burial from Crkvari, Northern Croatia. *Podravina: Journal for Multidisciplinary Research*, 14, 64-72.
- Boldsen, J. L. (2005). Leprosy and Mortality in the Medieval Danish Village of Tirup. *American Journal of Physical Anthropology*, 126, 159-168.
- Chargin, L., Saunders H. C. (1939). New York Academy of Medicine, section of dermatology and syphilis. *Archives of Dermatology and Syphilology*, 39, 175-189.
- Chopping, A. (1899). Notes of 84 cases of syphilis treated by the intravenous injection of cyanide of mercury. *Lancet*, 153, 432-437.
- Cole, H.N., Gammel, J., Schreiber, N.E., Sollmann, T. (1929). Mercuric salicylate: A study of its excretion in the treatment of syphilis. *Archives of Dermatology and Syphilology*, 19, 125-130.
- Cole, H. N., De Wolf, H. F., Schreiber, N. E., Sollmann, T., Van Cleve, J. (1933). Mercurial inunctions in the treatment of syphilis: Excretion of mercury following the use of mild mercurous chloride inunctions; mode of absorption of mercury from skin. *Archives of Dermatology and Syphilology*, 27, 1-11.
- Conrad, A. H., McCann, C. H. (1922). XXVI. Results in the treatment of Wassermann-fast syphilis by intravenous mercuric chlorid. *Archives of Dermatology and Syphilology*, 6, 50-54.
- Dabernat, H., Crubézy, E. (2010). Multiple bone tuberculosis in a Child from Predynastic Upper Egypt (3200 BC). *International Journal of Osteoarchaeology*, 20, 719-730.
- Davit-Béal, T., Gabay, J., Antonioli, P., Masle-Farquhar, J., Wolikow, M. (2014). Dental complications of rickets in early childhood: case report on 2 young girls (Case study). *Pediatrics*, 133, e1077-1081.
- Dean, M.R. (1943). Oral Manifestations of Bismuth Therapy in the Treatment of Syphilis. *The Journal of the American Dental Association*, 30, 651 - 657.
- Deporte, J.V. (1941). Premarital and prenatal tests or syphilis. *Lancet*, 238, 59.
- Eller, J.J., Maloney, E.R. (1929). New York Academy of Medicine, section on dermatology and syphilis. *Archives of Dermatology and Syphilology*, 19, 125-130.
- Formicola, V., Milanese, Q., Scarsini, C. (1987). Evidence of spinal tuberculosis at the beginning of the fourth millennium BC from Arene Candide Cave (Liguria, Italy). *American Journal of Physical Anthropology*, 72, 1-6.
- Fournier, A. (1886). *La syphilis héréditaire tardive*. Paris: G. Masson.
- French, H.C. (1909). The treatment of syphilis by intramuscular injection of insoluble salts of mercury as contrasted with the inunction method: A critical rejoinder. *Lancet*, 174, 920-924.
- Gadhia, K., McDonald, S., Arkutu, N., Malik, K. (2012). Amelogenesis imperfecta: an introduction. *British Dental Journal*, 212, 377-379.
- Gerdolle, D., Mortier, E., Richard, A., Vailati, F.

- (2015). Full-mouth adhesive rehabilitation in a case of amelogenesis imperfecta: a 5-year follow-up case report. *International Journal of Esthetic Dentistry*, 10, 12-31.
- Gerlach, R.F., Cury, J.A., Krug, F.J., Line, S.R.P. (2002). Effect of lead on dental enamel formation. *Toxicology*, 175, 27-34.
- Gil, F., Facio, A., Villanueva, E., Pérez, M.L., Tojo, R., Gil, A. (1996). The association of tooth lead content with dental health factors. *Science of the Total Environment*, 192, 183-191.
- Hare. (1858). University College Hospital: Congenital syphilis in an infant a few weeks old. *Lancet*, 72, 172-172.
- Hillson, S., Grigson, C., Bond, S. (1998). Dental defects of congenital syphilis. *American Journal of Physical Anthropology*, 107, 25-40.
- Hlavenková, L., Teasdale, M. D., Gábor, O., Nagy, G., Beňuš, R., Marcsik, A., Pinhasi, R., Hajduh, T. (2015). Childhood Bone tuberculosis from Roman Pecs, Hungary. *HOMO - Journal of Comparative Human Biology*, 66, 27-37.
- Hutchinson, J. (1859). *Transaction of the Pathological Society of London. Including the report of the proceedings for the session 1858-9*. London: J.W Roche.
- Hutchinson, J. (1863). *A clinical memoir on certain diseases of the eye and ear, consequent of inherited syphilis: with an appended chapter of commentaries on the transmission of syphilis from parent to offspring, and its more remote consequences*. London: John Churchill.
- Hutchinson, J. (1878). *Illustrations of clinical surgery consisting of plates, photographs, woodcuts, diagrams etc. Illustrating surgical diseases, symptoms and accidents, also operative and other methods of treatment, with descriptive letterpress*. London: J. & A. Churchill.
- Hutchinson, J. (1887). *Syphilis*. London: Cassell & Company, Limited.
- Hutchinson, J. (1888). *Illustrations of clinical surgery consisting of plates, photographs, woodcuts, diagrams etc: illustration surgical diseases, symptoms and accidents, also operative and other methods of treatment, with descriptive letterpress*. London: J. & A. Churchill.
- Ioannou, S., Henneberg, M., Henneberg, R.J., Anson, T. (2015). Diagnosis of Mercurial Teeth in a Possible Case of Congenital Syphilis and Tuberculosis in a 19th Century Child Skeleton. *Journal of Anthropology*, 2015, 1-11.
- Ioannou, S., Sassani, S., Henneberg, M., Henneberg, R.J. (2016). Diagnosing congenital syphilis using Hutchinson's method: Differentiating between syphilitic, mercurial, and syphilitic-mercurial dental defects. *American Journal of Physical Anthropology*, 159, 617-629.
- Ioannou, S., Henneberg, M. (2016). A Rare Case of Congenital Syphilis and a Supernumerary Fourth Molar in an Early 20th Century African American Woman. *Dental Anthropology*, 29, 41-47.
- Kar, S.K., Tripathi, A., Singh, S.V. (2012). Full mouth rehabilitation of hypomaturation type amelogenesis imperfecta: A clinical report. *Journal of Oral Biology Craniofacial Research*, 2, 213-216.
- Lancet. (1917). The control of venereal diseases. *Lancet*, 189, 772-773.
- Lancet. (1921). Venereal disease in U.S.A. *Lancet*, 198, 863.
- Lancet. (1930). United States of America. *Lancet*, 215, 987-988.
- Lancet. (1937a). Venereal disease in the U.S.A: (From an occasional correspondent). *Lancet*, 229, 466-467.
- Lancet. (1937b). Treatment of syphilis. *Lancet*, 230, 759-760.
- Lancet. (1939). United States of America: (From an occasional correspondent). *Lancet*, 233, 1226-1227.
- Lancet. (1940). United States of America. *Lancet*, 236, 592.
- Lee, H. (1878). Note of the use of calomel vapour bath. *Lancet*, 111, 193-193.
- Lipski, J., Przyłipiak, S. (1959). W sprawie patomorfologii uzebie nia w kile wrodzonej. *Pol Tyg Lek*, 14, 524-528.
- McCarthy, F.P., Dexter Jr, S.O. (1935). Oral Manifestations of Bismuth. *New England Journal of Medicine*, 213, 345-353.
- Miller, J. (1858). Administration of mercury in syphilis: (Note from Professor Miller). *Lancet*, 71, 349-350.
- Moon, H. (1877). On irregular and defective tooth development. In: *Transactions of the Odontological Society of Great Britain vol. IX-New Series*. London: Wyman & Sons.
- Moon, H. (1884). Dental surgery. In: T Bryant, (eds). *A manual for the practice of surgery*. London: J & A Churchill.
- Muñoz, M.A., Arana-Gordillo, L.A., Gomes, G.M., Gomes, O.M., Bombarda, N.H., Reis, A., Loguercio, A.D. (2013). Alternative esthetic management of fluorosis and hypoplasia stains: blending effect obtained with resin infiltration techniques. *Journal of Esthetic and Restorative Dentistry*, 25, 32-39.
- Nakashima, A.K., Rolfs, R.T., Flock, M.L., Kilmarx, P., Greenspan, J.R., Greenspan, J.R. (1996). Epidemiology of Syphilis in the United States, 1941-1993. *Sexually Transmitted Diseases*, 23, 16-23.
- Nelson, S.J., Ash, M.M. (2010). *Wheeler's dental anatomy, physiology and occlusion*. St Louis, MI: Saunders Elsevier.
- Prasad, M.K., Laouina, S., El Alloussi, M., Dollfus, H., Bloch-Zupan, A. (2016). Amelogenesis Imperfec-

- ta: 1 Family, 2 Phenotypes, and 2 Mutated Genes. *Journal of Dental Research*, 95, 1457-1463.
- Prebble, E.E. (1938). Observations of venereal disease in the United States of America. *Lancet*, 232, 1037-1040.
- Roberts, C. (2011). The Bioarchaeology of Leprosy and Tuberculosis. In S. C. Agarwal and B. A. Glencross (Eds), *Social Bioarchaeology* (pp. 252-282). Oxford: Wiley-Blackwell.
- Roffey, S., Tucker, K. (2012). A contextual study of the medieval hospital and cemetery of St Mary Magdalen, Winchester, England. *International Journal of Paleopathology*, 2, 170-180.
- Rogers, H.G., Yesudian, G., Rodd, H.D. (2016). Unusual extrinsic staining following microabrasion in a girl with amelogenesis imperfecta. *European Archives of Paediatric Dentistry*, 17, 271-275.
- Scheer, M., Fraser J. F. (1930). New York Academy of Medicine, section of dermatology. *Archives of Dermatology and Syphilology*, 22, 520-529.
- Sherwood, I.A. (2010). Fluorosis varied treatment options. *Journal of Conservative Dentistry*, 13, 47-53.
- Smith, S.T. (1844). On the treatment of secondary syphilis by mercury. *Lancet*, 43, 556.
- Sunny, S.D., Israt, B., Saha, A.K., Dithi, A.B., Illius, F. (2013). Oral health of the arsenic exposed and non-exposed children in Bangladesh. *City Dental College Journal*, 10, 5-8.
- Švejda, J. (1952). Zmeny na zubech pri kongenitalni syfilis. *Cesk Stomatology*, 52, 321-341.
- United States. Public Health Service. Division of Venereal Diseases. (1930). *Congenital syphilis : abstracts secured in the compilation of "Venereal disease information" and on file in the Division of venereal diseases ; Compilation No .2, (Rev. June, 1930) ; issued by the United States Public Health Service for the use in its cooperative work with the state health departments / Taliaferro Clark, assistant surgeon general, chief, Division of venereal diseases. Washington, DC: United States Government Printing Office.*
- Warner, F. (1881). East London hospital for children: Cases of congenial syphilis. *Lancet*, 117, 173-174
- Wakerlin, G.E. (1934). Colloidal mercury sulphide in the treatment of syphilis. *Archives of Dermatology and Syphilology*, 30, 49-58.
- Weatherill, T. (1833). Extraordinary ravages of syphilis and mercury on the human countenance. *Lancet*, 20, 357-359.
- Wilson, R.H., Deeds, F. (1939). Experimental chronic cadmium poisoning. *Science*, 90, 498.
- World Health Organization. (2012). *Leprosy: fact sheet no. 101*. World Health Organization, Geneva, Switzerland. <http://www.who.int/mediacentre/factsheets/fs101/en/>. Viewed 3 June, 2017.
- Youravong, N., Chongsuvivatwong, V., Teanpaisan, R., Geater, A.F., Dietz, W., Dahlén, G., Norén, J.G. (2005). Morphology of enamel in primary teeth from children in Thailand exposed to environmental lead. *Science of the Total Environment*, 348, 73-81.
- Zambrano, M., Nikitakis, N.G., Sanchez-Quevedo, M.C., Sauk, J.J., Sedano, H., Rivera, H. (2003). Oral and dental manifestations of vitamin D-dependent rickets type I: Report of a pediatric case. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 95, 705-709.
- Zuckerman, M. (2016). More harm than healing? Investigating the latrogenic effects of mercury treatment of acquired syphilis in post-Medieval London. *Open Archaeology*, 2, 42-55.