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Forensic medicine: Age written in teeth by nuclear bomb tests

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Establishing the age of individuals is an important step in identification and a frequent challenge in forensic medicine. This can be done with high precision up to adolescence by analysis of dentition, but establishing the age of adults has remained difficult. Here we show that measuring ^{14}C from nuclear bomb tests in tooth enamel provides a sensitive way to establish when a person was born.

^{14}C levels in the atmosphere have remained relatively stable until 1955-63 when above ground nuclear bomb tests caused a dramatic increase[1,2]. Even though the detonations were conducted at few locations, the elevated ^{14}C levels in the atmosphere rapidly equalized around the globe. After the test ban treaty in 1963, the ^{14}C levels have dropped exponentially, not primarily because of radioactive decay (half-life 5730 years), but by diffusion from the atmosphere (Fig 1a)[3]. Atmospheric ^{14}C reacts with oxygen to form CO_2, which is incorporated into plants by photosynthesis. By eating plants, and animals

that live off plants, the ^{14}C concentration in the human body closely parallels that in the atmosphere at any given time[4,5].

The enamel of individual teeth is formed at distinct, well-characterized time points during childhood[6]. After being laid down, there is no turnover of enamel, and the ^{14}C concentration should thus reflect the levels in the atmosphere at the time of enamel formation. Enamel contains 0.4% carbon. We have measured ^{14}C levels in tooth enamel (see supplement for methods) and related it to the known concentration in the atmosphere over time to establish the time of tooth formation. This date was then related to the known age at enamel deposition of individual teeth[6] to establish the year of birth of the person (see examples in Fig. 1a). We find that this provides a remarkably precise method for age determination (R^2=0.99, Fig. 1b). The average deviation from the respective correct value for all measurements was +0.6 years, and the average error for individual measurements was 1.6±1.3 years (SD). This represents a substantially higher precision compared with previously available methods[7].

The last enamel is formed for wisdom teeth at thirteen years of age and for individuals born before 1943 (13 years before the onset of the nuclear bomb tests), the method is limited to concluding birth before this year, although with a high degree of certainty (100% correct in our analysis, n=4). If there is an ambiguity as to whether a person was born before or after the period of nuclear bomb tests, it is necessary to analyze two teeth formed at different ages to distinguish whether the values should be related to the rising or falling part of the ^{14}C curve (see case indicated in green in Fig. 1a).

The sensitivity of the method is mainly determined by the interindividual variation in tooth formation and the precision of the ^{14}C measurement. The degree of interindividual

variation differs between teeth, and by selecting teeth with the least variation the sensitivity would likely be higher. In this regard, the precision of the ^{14}C measurement can be improved by analyzing several teeth from the same individual. The technique for ^{14}C analysis is rapidly becoming increasingly sensitive, suggesting that although the nuclear bomb tests were conducted several decades ago this method may allow precise age determination for a long time to come. Accelerator mass spectrometry for ^{14}C analysis has become more accessible and inexpensive, making age determination with the described method no more complicated or expensive than other methods used in the forensic routine casework.

References

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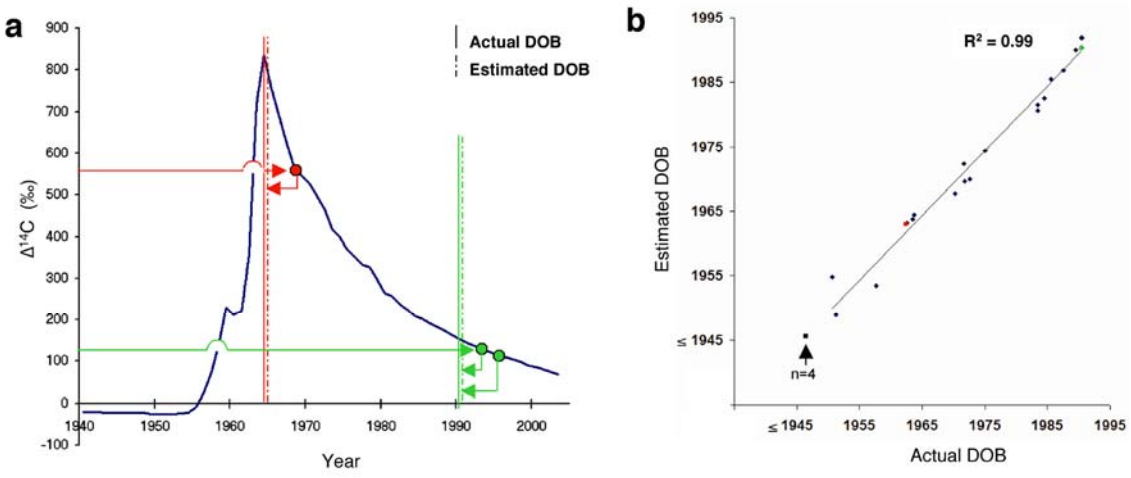
Figure legend

Figure 1 **a** Nuclear bomb tests in 1955-1963 produced large amounts of ^{14}C (blue line), which thereafter have declined exponentially. To estimate the date of birth (DOB) of individuals, the measured ^{14}C concentration in tooth enamel was plotted on to the curve of atmospheric levels to establish the year of enamel synthesis (arrow pointing to the right). The known age of enamel formation for individual teeth was then subtracted from the obtained year to estimate DOB (arrow pointing to the left, with the estimated DOB indicated by a dotted line). Two representative cases are shown in different colors. For the case depicted in green, two teeth were analyzed. The actual DOBs are indicated by solid lines. **b** The relationship between estimated and actual DOB. Each mark corresponds to one individual, with the exception of the one at ≤1945 which represents four individuals. The cases depicted in a are indicated by their respective color in b.

Figure 1


a
Actual DOB
Estimated DOB
Δ14C (‰)
900
800
700
600
500
400
300
200
100
0
-100
1940
1950
1960
1970
1980
1990
2000
Year
b
R² = 0.99
Estimated DOB
1995
1985
1975
1965
1955
≤ 1945
n=4
≤ 1945
1955
1965
1975
1985
1995
Actual DOB

Supplemental material

Methods

Enamel preparation

A total of 33 teeth from 24 individuals were analyzed. The crown of the tooth was cut away from the root at the level of the cervical line. The crown was then immersed in 10N NaOH at room temperature for several hours, before being placed in a water-bath sonicator overnight (Branson 150). The temperature of the water in the sonicator bath warms up gradually over time, to a maximum temperature of 70^0 C. Every 24 hrs the NaOH was replaced and the soft non-enamel structures etched away using blunt dissection. The enamel was then washed three times with DDH_2O, re-submersed in 10N NaOH, and placed in the sonicator. This procedure was repeated every day for 7-12 days (until all dentin and soft structures are stripped from the enamel). The enamel was then rinsed several times in DDH_2O and then dried at 65^0 C overnight. The enamel was weighed and kept sealed in a glass tube until pre-treated for AMS analysis.

Accelerator mass spectrometry

Enamel samples were pretreated in 0.25N HCl for 10 minutes, rinsed 3 times with DDH_2O and placed on a heating block at 95^0 C to dry overnight. Enamel splits were hydrolyzed to CO_2 in individual reaction chambers, evacuated, heated and acidified with orthophosphoric acid at 90^0 C. The evolved CO_2 was purified, trapped, and reduced to graphite in the presence of iron catalyst in individual reactors (Vogel et al., 1987). Large

CO_2 samples (> 500 μg) were split and $\delta^{13}C$ was measured by stable isotope ratio mass spectrometry. Graphite targets were measured at the Center for Accelerator Mass Spectrometry at Lawrence-Livermore National Laboratory.

We used a $\delta^{13}C$ correction of –15 +/-2 for samples that were too small to obtain a CO_2 split. Corrections for background contamination introduced during AMS sample preparation were made following the procedures of Brown and Southon (1997). All ^{14}C data are reported as decay corrected $\Delta^{14}C$ following the dominant convention of Stuiver and Polach (1977). This convention established for reporting radiocarbon data in chronological and geophysical studies was not developed to deal with post-bomb data, but it is the most common pending the adoption of a standard nomenclature for post-bomb data (Reimer, et al., 2004).

References to supplement

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