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Strontium and Geolocation, the Pathway to Identification for Deceased Undocumented Mexican Border-Crossers: A Preliminary Report*

ABSTRACT: Much of the difficulty associated with identifying and repatriating deceased undocumented border-crossers stems from an inability to narrow down the search area to more probable options. Analysis of the isotopic variation in the tooth enamel of modern Mexican populations is currently underway at the University of California Santa Cruz. Using Thermo Ionization Mass Spectrometry, the pilot research analyzed strontium isotopes located in the donated permanent teeth of Mexican-born individuals of known origin from four states. The preliminary results reveal the formation of three distinctly significant regions in the data set. Using the technology outlined here, a map documenting the isotopic variation in modern Mexican tooth enamel is being complied to use for cross comparison with deceased border crossers of unknown origin.

KEYWORDS: forensic sciences, immigrants, border deaths, isotopes, strontium, repatriation

Identification and repatriation of deceased undocumented border crossers is a problem encountered with increasing frequency by forensic scientists working in border communities. The Mexico–US border has long been a popular gateway of undocumented entry, and has consequently been the site of a number of crossing related deaths. Threats of terrorism in the United States have encouraged the formation of regulatory nation state polices targeting increased border security (1). One of the current U.S. policies, the Gatekeeper Complex, has systematically amplified control on popular border crossing avenues, redirecting undocumented migrational flows to more rural desert crossing points and increasing border deaths (1). Studies estimate that approximately seven-hundred men, women, and children die each year on U.S. soil while crossing the border between Mexico and the United States (2). Of these, as many as one-third are never identified. Mexico, a country with a long history of US-focused migration and the largest contributor of immigrants, lacks a well developed and extensive database system of identification for missing persons. Although concerted efforts to identify individuals are being made, these efforts are hampered by a nation-wide search strategy in a country lacking the appropriate tools. One significant improvement would be the ability to identify the region of origin of the deceased and narrowing the search to this area. Studies analyzing stable isotopes derived from human teeth show that such data can monitor patterns of human migration and determine human region of origin (3–8). This report describes research currently underway at the University of California Santa Cruz, utilizing strontium isotopic signatures in human tooth enamel to determine region of origin for deceased undocumented Mexican border crossers.

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Strontium in particular is chosen to track migration and region of origin as it is a geographically distinct isotope, and readily integrated into the hard tissues of the body. Absorption of strontium occurs through the mucosa of the small intestine (9). Once absorbed, strontium incorporates into hard tissues via calcium substation within the crystal matrix (9). For the average adult, cortical bone remodels every 10–15 years, therefore the strontium values in cortical bone reflect a 15-year history of incorporation (9). Conversely, tooth enamel incorporates strontium into its lattice only during the period of enamel formation, which terminates during childhood (9,10). Enamel of permanent teeth reflects the geochemistry of childhood residence and, unlike bone, does not go through significant remodeling or diagenesis (8,11–13). This makes tooth enamel an excellent proxy for region of origin.

Strontium values in hard tissues are a function of dietary intake and locality (5,6,9). In archaeological populations the strontium values of teeth can be referenced to a faunal or environmental baseline to verify relationship (5–7). However, isotopic values of modern material are confounded by the modern diet. Incorporation of packaged foods can skew hard tissue values away from local signals. To obtain a more realistic representation of the population this study utilizes modern human teeth of known origin as the baseline comparison for unknown samples.

Materials and Methods

Materials

This preliminary study utilized 19 human teeth donated from Mexican born individuals. Prior to donation all subjects provided informed written consent for the donation of their tooth in compliance with human subjects guidelines. Table 1 summarizes the tooth type and available demographic information of each individual donor. The teeth chosen for the study were removed for dental or orthodontic reasons and maintained at least 80% of their exterior enamel. Each tooth represented one sample and was prepared under clean lab conditions to isolate the strontium in the enamel for

TABLE 1—*Donor information.*

No.	δ^{87}SrRatio	Birth place	Rancho	Age	Sex	Tooth no.
J1	0.7054	Jalisco	Cocula	44	M	19
J6	0.7056	Jalisco	U	49	M	31
J4	0.7053	Jalisco	Camichines	18	M	28
J5	0.7054	Jalisco	Los Parajes	29	F	15
J2A	0.7051	Jalisco	U	54	F	11
J2B	0.7051	Jalisco	U	54	F	12
J2C	0.7050	Jalisco	U	54	F	13
J3	0.7053	Jalisco	Del Varro	37	F	3
J8	0.7055	Jalisco	Sanicolas	36	M	18
J7	0.7054	Jalisco	San Juan De la Montana	64	M	31
G3	0.7052	Guanajuato	U	57	U	31
G1	0.7052	Guanajuato	Aguatibiampio de Penjamo	26	F	31
G2	0.7051	Guanajuato	Moreleon	60	F	3
M2	0.7044	Michoacan	Zacateca	71	F	20
M1	0.7048	Michoacan	Quiroga	34	M	14
D2	0.7064	DF	U	32	F	15
D1	0.7063	DF	U	28	M	31
D3	0.7062	DF	U	55	F	15
J9*	0.7061	Jalisco	U	27	F	31

U, unknown; DF, Mexico City.
*This individual was born in Jalisco and subsequently moved to Mexico city at the age of 1 year.

analysis. This study utilized bulk enamel sampling; during each step care was taken to ensure sample homogeneity.

Enamel Separation and Preparation

The freshly extracted teeth were placed in a 95% ethanol solution for transport and storage. Each tooth was sonicated for 15 min in MiliQ water, cleaned with a sterile test tube brush and air dried over night. The enamel was manually separated from the dentine using a Dremel™ fitted with a dental drill. Following separation, the enamel chunks went through controlled acid etching in 0.5 N HCL for 10–20 sec after which they were rinsed with DI water and dried overnight. The dried chunks were crushed into a fine powder with an agate mortar and pestle. Each sample was weighed into CLEAN microcentrifuge tubes, labeled and left to soak in a solution of 0.04 mL of 0.1 N acetic acid/1 mg sample for 30 min and then promptly rinsed with DI water. The acetic acid/DI rinse was repeated twice to insure cleanliness. Following the final acetic acid/DI rinse the liquid was suctioned off and samples were rinsed with fresh DI water and centrifuged for 5 min, this step was repeated five times. The freshly cleaned samples were placed in the freezer overnight following which they were freeze-dried for 48 h.

Strontium Extraction and Sample Loading

The freeze-dried sample was weighed in 100 mg increments and put through nitric/Hydrofluoric acid digestion procedure. After the digestion was completed the dried samples were liquefied with 5 mL 5 M nitric acid. Teflon Pb columns were used for Ca/Sr separation. The columns were loaded with 30 μL strontium spec resin and the samples were run through the columns. The samples were loaded and rinsed utilizing a 15-step cycle. During steps one and two 0.2 μL of sample were loaded onto the column following which each sample was rinsed with 200 μL 5 M HNO_3 six times. When the sixth acid wash was completed each sample was washed with 200 μL MilliQ five times and this run-off was collected into CLEAN Teflon and labeled. Each labeled sample was evaporated to complete dryness and loaded onto outgassed Re filaments. Each filament was loaded with 1 μL H_3PO_4, 1 μL TA, and 2 μL sample prepared according to standard filament loading procedure. Each prepared filament was loaded onto a CLEAN turret and run on the (TIMS) Thermo Ionization mass spectrometer. Samples representing the same tooth were loaded on multiple filaments and run through 10 times of replication to ensure reproducibility, and sample reliability. Every turret batch contained a minimum of two NBS 987 standards. The Sr/Ca separation methodology was calibrated for the Keck TIMS utilizing OES.

Instrumentation

The samples for this study were analyzed within the W.M. Keck laboratory with the Keck thermo ionization mass spectrometer a fully-automated, nine- Faraday collector VG Sector 54 equipped with a WARP filter and an ion counting Daly. This instrument is typically used for Rb–Sr, Sm–Nd, Pb, U, Th, Ra and Ca isotope measurements and maintains a standard deviation for the accepted ratio for strontium standards of ±0.000022.

Statistical Analysis

A standard one-way ANOVA was performed on the nineteen strontium ratios utilizing Microsoft Excel statistical package.

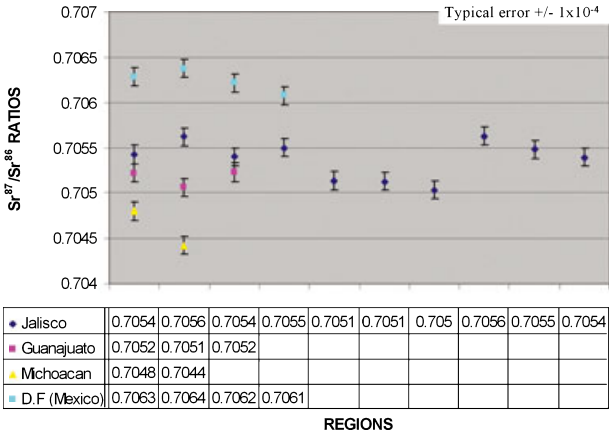
Notation

The strontium values reported here are in delta units. Delta units measure deviation in isotopic ratio from a particular standard and are expressed in terms of parts per thousand. '*R*' is the isotope ratio and 'std' is the internally recognized standard. A δ-value that is negative indicates that the sample is depleted in the heavier isotope relative to the internally recognized standard, while one that is positive indicates that the sample is enriched relative to the standard. There is no internally recognized standard for strontium; the values are presented as ratios relative to an identified lab standard such as NBS 987.

$$\delta = \left(\frac{R_{\text{sample}}}{R_{\text{std}}} - 1\right) \times 1000\%$$

Results and Discussion

The preliminary research analyzed nineteen human teeth from four states: four from Mexico City, two from Michoacan, three from Guanajato and nine from Jalisco. The samples chosen for the study came from regions known to be large contributors of undocumented migrants. The preliminary results (Fig. 1) reveal the formation of three significant and distinct regions in the data set (ANOVA, $p < 0.00000191$, $F = 31.08$, $F_{\text{crit}} = 3.34$). Region 1 encompasses samples from Mexico City and maintains an average value of δ^{87}Sr 0.70626 ± 0.000153. Region 2 encompassed samples from both Jalisco and Guanajuato. The samples from region 2 had a high degree of overlap with an average value of δ^{87}Sr 0.70531585 ± 0.00020755. Region 3 encompassed samples from Michoacan with an average value of δ^{87}Sr 0.7046 ± 0.00028. Figure 2 plots the values over their geographical origins. The difference between the three regions can be attributed to the variation in the intrinsic level of Sr in the local geologic environment. The large differences seen in the coastal versus inland areas are to be anticipated as the coastal areas typically represent areas of geologically younger (<1–10 mya) formations with $^{87}Sr/^{86}Sr$ ratios below 0.7060 (14). While the differences between each region may seem



Jalisco	0.7054	0.7056	0.7054	0.7055	0.7051	0.7051	0.705	0.7056	0.7055	0.7054
Guanajuato	0.7052	0.7051	0.7052							
Michoacan	0.7048	0.7044								
D.F (Mexico)	0.7063	0.7064	0.7062	0.7061						

FIG. 1—*Data table.*

FIG. 2—*Geographical regions.*

small it is noteworthy to point out that these ratios are similar in a quantitative sense but not so isotopically. The differences seen here are large from an instrumental standpoint the Keck TIMS maintains a precision rate of ±0.00002 for strontium. The concern then for this analysis lies in two areas: sample size and the proposed effect of packaged foods on ratios.

The use of isotopic analysis to determine region of origin is not new to the discipline of anthropology but historically been focused on archeological populations (4,6,7,15,16). While the study foundation is based upon the same principles discussed by the mentioned workers the overall concerns for this analysis are somewhat different avoiding issues of sample contamination via diagenesis and approximating potential problems because of the introduction of packaged foods. When dealing with archaeological populations, workers have taken faunal samples (both archaeological and modern) as well as geological samples as baseline comparative (3,7,8). With modern populations this model is less successful and analysis must then be directed to within population variation to determine a statically acceptable baseline. Such variation represents the differences present within a population originating from the same political area, for example, individuals originating from the same state or the same village. Analyzing isotopic ratios in this manner helps to account for the cultural aspects of a particular area and people and their affinity towards certain local and packaged foods. This is not to suggest that boundaries assigned through political means will maintain unique and individual geochemical signature but rather, from a cultural standpoint these political accumulation of people provide a logical plateau from which to being the analysis. In fact, as this analysis points out, with the formation of region 2, which encompass individuals from both Jalisco and Guanajuato geochemical signature can span multiple political boundaries. In this case, the key to successful determination of geochemical boundaries is a large and evenly spread regional sample base, the incorporation of multiple lines of isotopic evidence and statistical analysis.

For this study, the analysis focused on a population variation approach. Tooth samples came with region of origin information on each donor. The samples were categorized by region, run as region blocks and then plotted and statically analyzed. While this type of analysis appears successful in this preliminary, study sample size is a concern. With a study based on a population variation, the larger and more random the sample size the higher the probability that an accurate picture of the population will be generated. More over, Burton (3), which analyzed Ba and Sr to determine geographic origin in archaeological populations illustrates that a lack of geochemical contrast between two sample sets does not indicate the same geographic origin, but merely that the chose variable is equivocal. Given these concerns what can be and should be gleaned from this analysis is that is has the potential for differentiating geographic origins from human tooth enamel. The future of the project will include not only a larger sample size for each state (approximately $n = 30$/state) but also the inclusion of isotopic measurements of oxygen, nitrogen and carbon and the inclusion of dentine. These additional lines of evidence, which have proven useful for studies of human mobility in archaeological populations may further elucidate and individualize regions of origin for the modern population of concern.

Conclusions

This project demonstrates a real potential to identify region of origin in modern Mexican individuals using human tooth enamel. Although not a positive identification, region of origin is a critical first step in the identification and repatriation process of deceased undocumented border crossers. While this preliminary effort is focused on mapping variation in Mexican populations, I hope to extend this technology into south and Central America to offer a more inclusive repatriation tool. Currently, the project is focusing on expanding sample size and verifying values against newly identified formerly unknown individuals.

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