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Investigating individual migration life histories: An isotopic case study from 17th to 18th century Nouvelle France

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Abstract

Objectives: This isotopic study explores the mobility patterns of a growing urban population from Notre Dame's Catholic cemetery (1691–1796), located in Montreal (Canada). The site offers a unique opportunity to investigate early colonial settlement in Nouvelle France through individual life patterns.

Materials and methods: Stable oxygen isotopic compositions ($\delta^{18}O$) were measured on the enamel of 32 individuals from the Notre Dame collection. Premolars and third molars were selected, as they reflected the $\delta^{18}O$ of the drinking water during childhood (2.5–5.5 years) and pre-adulthood (9.5–15.5 years). Firstly, premolars from three children (4–8 years of age) allowed us to provide a mean $\delta^{18}O$ for the water consumed locally (22.7 ± 1.0 ‰ vs. VSMOW). Then, our $\delta^{18}O$ were compared with published data from various geographical regions in North America (Eastern Canada and the United States) and Europe (France and the British Isles) to highlight mobility patterns of each individual.

Results: Forty-eight percent of our sample (14 out of 29 individuals) did not reflect any long-distance mobility, as all their $\delta^{18}O$ reflected Montreal's variation during their lifetime. The remaining (15 out of 29 individuals) experienced mobility within ($n = 8$) and outside ($n = 7$) North America and at different phases of their life (five at pre-adulthood, six at adulthood and four during both phases). Their migration patterns were analyzed according to age, sex, diet and possible ancestry in order to propose some "biographies."

Discussion: This study highlights high population diversity in early colonial Montreal. Historians wrote that the city was growing, not only with the arrival of Europeans (e.g., young male workers, sailors), but also other groups (e.g., Indigenous people, slaves from North America). Additional analyses (e.g., ancient DNA) will be needed to explore further this phenomenon.

KEYWORDS
carbonate, enamel, stable oxygen isotopes

1 | INTRODUCTION

Historical records are helpful as they provide general contextual information on past populations (e.g., origin, occupation, cause of death). When dealing with unknown skeletons excavated from a historic cemetery, a direct bioarchaeological approach is needed to provide supplementary biographical information on an individual (e.g., age, sex, origin, health, diet, migration patterns). Isotopic analyses allow us to address questions regarding individuals' environments and behavior, as continental and regional movement is a topic frequently

addressed in bioarchaeology (e.g., Makarewicz & Sealy, 2015, Britton, 2017, Britton & Guitry, 2020). Here, Canada's 17th–18th century Montreal population is of great interest as it was the result of numerous events including multiple Trans-Atlantic migrations (in addition to various intra-continental ones), but also natural immigrants' demographic growth, who to some extent admixed with Indigenous people (B-Hardy, 2015; Charbonneau, 1990; Dechêne, 1974). The city was founded in 1642 by the *Société de Notre-Dame de Montréal pour la conversion des sauvages de la Nouvelle-France* (Society Notre Dame of Montreal for the conversion of the Savages in New France). Their objective was to create a missionary station where "Indigenous converted to Catholicism and the French colons would live side by side and practice agriculture" (translated from Linteau, 2008, p. 20). Yet it rapidly turned into a colony oriented towards the fur trade, and due to its location, it was soon considered as the "gateway to the West" (Linteau, 2008, p. 34). Hence, from its foundation, the city was a crossroad for individuals from disparate backgrounds and diverse migration life histories.

1.1 | The historical context: European migration processes in early colonial Montreal

In 1642, 50 people (mostly men, but also a few families) erected a fortified village on the island of Montreal. In 1652, the population was still so small that the *Sieur de Maisonneuve* returned to France to encourage people to settle in Nouvelle France. Subsequently, 200 individuals, mostly men, but also some families and single women, immigrated to the colony (with two spikes in 1653 [$n = 95$] and later in 1659 [$n = 91$]; Dechêne, 1974; Linteau, 2008). They worked as indentured servants, laborers or servicemen, and some later decided to stay after the termination of their contracts and to marry. Yet, the colonial population remained stagnant due to a large imbalance of men versus women, the former representing 163 % of the latter in the first census of 1666 (Dechêne, 1974, p. 98). The situation did change with the arrival of 764 *Filles du Roy* in Nouvelle France between 1663 and 1673 (Landry, 2013). In total, Dechêne (1974) recorded 178 women, who emigrated from France and married in Montreal, between 1646 and 1715 (p. 77). Consequently, the urban population that listed 659 inhabitants in 1666, doubled in 15 years (1681: $N = 1388$) and almost increased six-fold by 1715 ($N = 4200$; Dechêne, 1974, p. 101; Table 1). The composition of the population also changed drastically in terms of immigrants versus locally born individuals. After 1680, colonial settlement policies ceased, as France considered that the effort of peopling the colony had been accomplished (Naud, 1997, p. 28). In 1666, 56 % of the inhabitants were immigrants. By 1681, 66 % of the colonial population was locally born and this proportion increased to 85–90 % by 1715 (Dechêne, 1974, p. 98).

TABLE 1 Compiled demographic data about immigrants and locally born people in Montreal between 1666 and 1715

Year of census	Population	Immigrants	Locally born
1666	*659*	*386*	*273*
1681	1389	501	888
1715	*4200*	*420–630*	*3570–3780*

Note: Numbers in italics are approximations based on proportions estimated by Dechêne (1974, p. 98).

Therefore, the initial founding group of 17th century immigrants contributed mostly to the growth of the colonial population, a fact that is supported by both genetic and genealogical data (Gagnon & Heyer 2001; Roy-Gagnon et al., 2011). Historical records indicated that French-speaking colonists made up to 97 % of the first wave of European immigrants. They originated mostly from regions such as the Parisian Basin and Poitou-Charentes, as well as, three major cities, Paris, La Rochelle and Rouen (Dechêne, 1974, p. 95; Charbonneau, 1990; Desjardins, 1990, p. 72; Naud, 1997, p. 54). However, these data must be interpreted with caution, as many historians have noted that the boarding points registered were often confused with the place of origin of an individual (Charbonneau, 1990, p. 52; Poussou et al., 1998; Carpin, 2001). Consequently, the registered origin might not reflect the true picture and those from the rural areas might have been systematically under-estimated.

1.2 | Exploring migration patterns through oxygen stable isotopes

All bioarchaeological studies on migration using oxygen stable isotopes are based on the following principle observed by Dansgaard (1964): as the $\delta^{18}O$ of precipitation water vary according to latitude, longitude, and altitude, they can highlight the geographical variation of groundwater (its isotopic composition). More precisely, during the hydrologic cycle, some fractionation between ^{18}O and ^{16}O occurs, from evaporation to condensation and precipitation, with ^{18}O being preferentially retained in the liquid phase. These isotopic values that are geographically specific, are then integrated into human tissue during their synthesis, mainly through the process of drinking water (Longinelli, 1984). Although they cannot provide unique signatures, higher $\delta^{18}O$ will tend to reflect a warmer climate and/or more coastal region, and lower $\delta^{18}O$, tend to reflect a cooler climate and/or more continental region and/or higher altitude.

On a practical level, $\delta^{18}O$ can be analyzed from either the phosphate ($\delta^{18}O_P$) or carbonate ($\delta^{18}O_C$) phase of bone or tooth enamel hydroxyapatite. Both provide the same information ($\delta^{18}O$), yet, with an offset from one another corrected (with associated error) by conversion formulas (as developed by Chenery et al., 2012). Phosphate analysis has a few advantages over carbonate: it is abundant in the chemical structure of the hydroxyapatite crystals (Ca_{10} $[PO_4]_6$ $[OH]_2$) and is less subject to post-depositional alteration (Kohn & Cerling, 2002). Contrary, the carbonate phase is found under a substitute form, in small proportion (5 %) and the C—O link is weaker (Chenery et al., 2012). However, the pre-treatment to obtain carbonate $\delta^{18}O_C$ is less labor intensive and the resultant $CaCO_3$ provides both $\delta^{18}O_C$ and $\delta^{13}C$ data. Stable carbon isotope values ($\delta^{13}C$) in enamel carbonate can reflect the consumption during childhood of

various plants using photosynthetic cycle C_3 (most plants in temperate/cool climate, mean: −28.0 ‰) or C_4 (maize in North America, mean: −13.0 ‰) and marine resources (range: −24.0 to −19.0 ‰; Fry, 2006: 42). Notably $\delta^{13}C$ data is of great bioarchaeological interest as it reflects the life history of the individual with migratory and dietary indicators.

Bioarchaeological studies explore migration patterns with $\delta^{18}O$ data using mainly dental remains (as suggested by Koch et al., 1997). In fact, bone $\delta^{18}O$ analyses are problematic because of the nature of bone tissue that is highly porous and is susceptible to contamination from ground water and microbes. In contrast, tooth enamel has a non-porous structure, which makes it extremely resistant to mechanical erosion and contamination (Kohn & Cerling, 2002). In addition, contrary to human bones that remodel throughout life and represent a mean of the last years of an individual's life, tooth enamel is formed during growth and stays unchanged. Thus, this material allows the recovery of the mean $\delta^{18}O$ of the water (or precipitation water of the environment) that was drank during a relatively short period—from childhood to early adulthood. As a result, tooth enamel is often chosen by bioarchaeologists to explore individual "biographies," as it has a greater potential to capture past geographical shifts.

For colonial Eastern Canada, several bioarchaeological studies have explored migration patterns using oxygen stable isotopes (Blyth, 2003; Caron, 2013; Ellerbrok, 2014; Emery et al., 2017; Munkittrick et al., 2019; Schwarcz et al., 1991). The first study (Schwarcz et al., 1991) used $\delta^{18}O_P$ to assess the origins of soldiers ($n = 6$) that were recovered west of Old Fort Erie, in Ontario and dated to the War of 1812. They compared their isotopic data to values from Southwestern Ontario ($n = 2$, $\delta^{18}O_C$ of 21.2 ‰) and Antietam Battlefield, Maryland, USA ($n = 1$, $\delta^{18}O_C$ of 22.2 ‰). They concluded that they could not identify the origins, yet the small range of values suggested that the soldiers lived in a similar environment during their lives. Blyth (2003) analyzed another collection (Smith's Knoll, Stoney Creek, *n = 34)* dated to the same military event in Ontario. She found that $\delta^{18}O_P$ variations reflected various origins in her sample, although it was not possible to distinguish between North America and Great Britain. This last collection was recently re-analyzed by Emery et al. (2017, $n = 20$). By combining $^{87}Sr/^{86}Sr$ and $\delta^{18}O_C$ data with historical records on the origins or place of the soldiers' recruitment, these authors concluded that five men were probably born in North America (one possibly originating from Lower Canada, mean $\delta^{18}O_C$: 22.5 ‰; four from the United States, mean $\delta^{18}O_C$: 24.3 ± 0.4 ‰) and four originated from the British Isles (mean $\delta^{18}O_C$: 25.4 ± 0.4 ‰).

In Nova Scotia, Ellerbrok (2014) analyzed the $^{87}Sr/^{86}Sr$ and $\delta^{18}O_C$ of 33 individuals from an 18th century mass burial at the Louisbourg Fortress. Based on data from local fauna (rat, hare, beaver, fox; mean $\delta^{18}O_C$: 23.3 ± 1.4 ‰) and precipitation water, she concluded that 16 out of the 33 individuals would have been locally born. French origins were suspected for non-locals, as the site was part of France's North American defensive strategy. Ellerbrok (2014) also suggested a New England origin, as soldiers from this region occupied the fort in 1745 and died there during wintertime. Munkittrick et al. (2019) have undertaken a similar exercise on individuals buried at the Southside Cemetery in St. John's, Newfoundland ($n = 21$). The burials were associated with the St. John's Naval Hospital, which used the cemetery between ca. 1750 and 1825. These authors compared their $\delta^{18}O_C$ with those obtained from six contemporaneous civilians from the St. Paul's Anglican Church cemetery (Harbor Grace, Newfoundland, 1764–1820; mean $\delta^{18}O_C$: 23.6 ± 0.3 ‰). They found that every individual from the Southside Cemetery (except one), showed $\delta^{18}O_C$ statistically different from the local population, indicating they were not long term residents in the region. Yet, although most have $\delta^{18}O$ within values expected for the British Isles (24.3–27.1 ‰, compared to converted $\delta^{18}O$ phosphate values of Evans et al., 2012: 24.8–27.9 ‰), the dietary variability can probably be explained by geographic origins outside of the British Isles.

Closer to Montreal and for a contemporaneous period, Caron (2013) obtained $\delta^{18}O_C$ for 34 burials from St Matthew's Protestant cemetery in Quebec City (1771–1860). As he compared the $^{87}Sr/^{86}Sr$ and $\delta^{18}O_C$ obtained from the sampled water with the data compiled from the literature (Brettell et al., 2012; Evans et al., 2012; Schroeder et al., 2009), he concluded that 65 % of the sample appeared to be of foreign origin, mostly from the British Isles. Caron (2013) mentioned also that his isotopic results were supported by historical data reporting the arrival of a multitude of English-speaking migrants after the British Conquest in 1760 (Hare et al., 1987; Henripin & Martin, 1991).

In order to investigate the possible geographical origins of "non-local" individuals, six bioarchaeological studies including isotopic data have been selected for North America (France et al., 2014) and Europe (Bataille et al., 2021; Colleter et al., 2021; Daux et al., 2005; Millard et al., 2020; Trickett, 2018). Table 2 summarizes these $\delta^{18}O_C$ data, in addition to the ones obtained from three studies from Eastern Canada (Emery et al., 2017; Munkittrick et al., 2019; Schwarcz et al., 1991). Within Eastern Canada, $\delta^{18}O_C$ tends to increase along a regional gradient, ranging from lowest values in inland areas (Southwest Ontario, 21.2 ‰, Schwarcz et al., 1991) up to highest ones in coastal areas (Newfoundland, 23.6 ± 0.3 ‰, Munkittrick et al., 2019) (see Figure 1). Similarly, within North America, $\delta^{18}O_C$ increases, as both latitude decreases and temperature increases (northern region mean: 24.5 ± 1.5 ‰; southern region mean: 25.5 ± 1.5 ‰; France et al., 2014). However, Europeans sites seem to provide a range of variation ($\delta^{18}O_C$: 24.4–34.8 ‰; Daux et al., 2005; Mays et al., 2011; Emery et al., 2017; Trickett, 2018; Millard et al., 2020, Bataille et al., 2021, Colleter et al., 2021) that is not very different from North America ($\delta^{18}O_C$: 20.4–29.7 ‰; France et al., 2014), as all these values overlap. These isotopic similarities between two continents imply that, when using only $\delta^{18}O_C$, interpretations about past mobility in a transatlantic context must remain very cautious. Nevertheless, the $\delta^{18}O_C$ remains a useful tool to explore origins and mobility within one continent and even between continents, especially when both historical and osteological data are available for colonial cemeteries.

In Eastern Canada, the isotopic studies explored largely the mid-18th to mid-19th century period, and thus there is no isotopic data

TABLE 2 Comparative data on $\delta^{18}O$ compiled from nine publications for North America and Europe

Site information (date A.D.)	Authors	n	$\bar{x} \pm 1\sigma$ (‰)	Range min; max (‰)
North America				
Eastern Canada				
Quebec city (1950–2000)	Daux et al., 2005	5	23.7 ± 0.5	23.0; 24.2
Southwestern Ontario (date unknown)	Schwarcz et al., 1991	2	21.2 ± 0.0[a]	21.2
Lower-Canada-born soldier buried in Stoney Creek, Ontario (1812)	Emery et al., 2017	1	22.5	
St. Paul's Anglican Church, Harbor Grace, Newfoundland (1764–1820)	Munkittrick et al., 2019	6	23.6 ± 0.3	23.2; 24.1
United States				
Seven sites, individuals of northern origin (18th and 19th C.)	France et al., 2014	98	24.5 ± 1.5	20.4; 29.7
United States-born soldiers buried in Stoney Creek, Ontario, Canada (1812)	Emery et al., 2017	5	24.3 ± 0.4	23.8; 24.7
Five sites with individuals of southern origin (18th and 19th C.)	France et al., 2014	28	25.5 ± 1.5	22.2; 27.7
Europe				
France				
Lorraine (1950–2000)	Daux et al., 2005	6	25.6 ± 0.5 [a]	25.1; 26.1
Lorraine (16th-18th C.)	Daux et al., 2005	24	26.4 ± 0.7 [a]	25.2; 28.0
Rennes, Brittany (1491)	Colleter et al., 2021	10	27.8 ± 3.7	24.4; 34.8
Brittany (17th C.)	Bataille et al., 2021	2	27.3 ± 0.7	26.8, 27.8
British Isles				
British-born soldiers buried in Stoney Creek, Ontario, Canada (1812)	Emery et al., 2017	5	25.4 ± 0.4	25.1; 25.9
Officer from the Franklin Expedition, 1845	Mays et al., 2011	1	25.7[a]	
Chelsea, London (18th-19th C.)	Trickett, 2018	24	26.3 ± 0.6 [a]	25.1; 27.7
Coventry, West Midlands (18th-19th C.)	Trickett, 2018	10	25.5 ± 0.4[a]	25.0; 26.1
Scottish soldiers captured at Battle of Dunbar (1650)	Millard et al., 2020	9	27.1 ± 1.1 [a]	25.0; 28.1

[a]$\delta^{18}O$ phosphate ($\delta^{18}Op$) were here transformed to $\delta^{18}O$ carbonate ($\delta^{18}Oc$) following Chenery et al. (2012) formula: $\delta^{18}Oc = (\delta^{18}Op + 9.6849)/1.0322)$. This procedure was done to be able to compare the data with our present study.

for the mid-17th to mid-18th century. In addition, archeological reference dataset for $\delta^{18}O$ are scarce for historical Northeastern North America; only Schwarcz et al. (1991) and Munkittrick et al. (2019) analyzed individuals of known origin to create "control groups" of local variation. Furthermore, except for the work of Mays et al. (2011), Ellerbrok (2014), Emery et al. (2017) and Millard et al. (2020), none of the studies mentioned in Table 2 attempted to focus on individual migration behavior to produce life histories. Thus, the main objective of the present isotopic study is to reconstruct the biographies of a few burials from Notre-Dame's Catholic cemetery through migration patterns, as the latter can potentially document this missing period. The analyses of the stable oxygen composition of the enamel carbonate ($\delta^{18}O_C$) obtained from both premolar (Pm) and third molar (M3) tooth enamel of individuals will allow the investigation of their location during early childhood and young adulthood. Since the Notre-Dame cemetery opened 11 years after the end of the main migration waves, we considered the $\delta^{18}O_C$ obtained from the children under 10 years of age and the individuals of possible Indigenous or mixed ancestry within the sample to indicate the local variation, and thus, will be used as a "control group" for $\delta^{18}O$ in Montreal and Northeastern North America. Therefore, several possible migration patterns will be proposed based on these local data and comparative $\delta^{18}O_C$ data compiled from the literature. These mobility patterns will be also compared to previous data on dental morphology (B-Hardy, 2015; B-Hardy et al., 2005), ancient DNA (Harding et al., 2020) and diet (Vigeant, 2012; Vigeant et al., 2017) when available, to propose short "biographies" on an individual level.

2 | MATERIALS

The dental sample was taken from Notre Dame's skeletal collection. This site located in the center of Montreal's old city corresponded to the burial ground associated with the first Catholic parish church built in 1672 (Arkéos, 2008, p. 7). The cemetery opened just a few years after the end of the first wave of immigration, around 1680

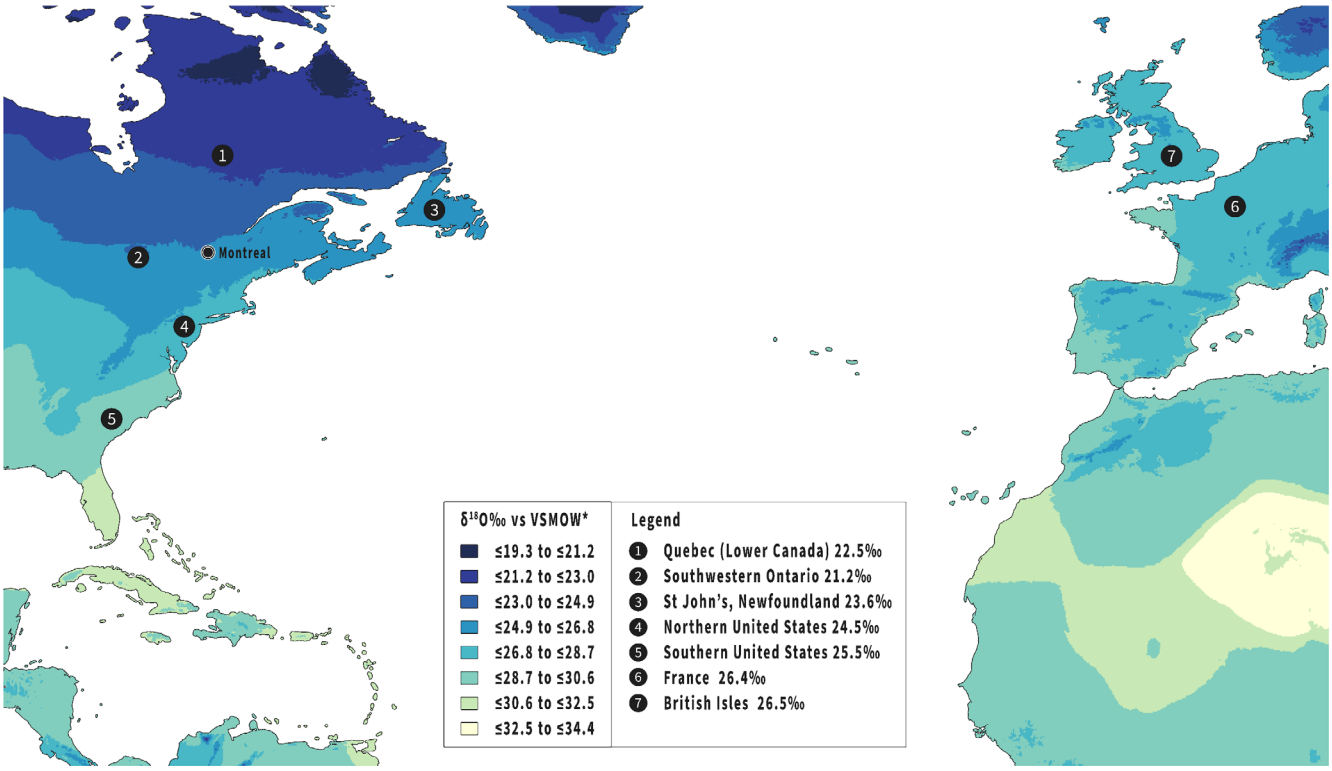

FIGURE 1 Geographical distribution of key comparative $\delta^{18}O_{CARBONATE}$ data used for Montreal. Sources: (1) Emery et al. (2017); (2) Schwarcz et al. (1991); (3) Munkittrick et al. (2019); (4 and 5) France et al. (2014); (6) Daux et al. (2005), Bataille et al. (2021), Colleter et al. (2021); (7) Trickett (2018). Map created with Global and Regional Precipitation values from Waterisotopes.org (https://wateriso.utah.edu/waterisotopes/pages/data_access/ArcGrids.html) based on OIPC v3.2 database values from Bowen and Revenaugh (2003) and Bowen et al. (2005) papers. Map was modified using ArcGis Pro 2.7. $^{*}\delta^{18}O$ values were transformed into tooth values using Chenery et al. (2012). Waterisotopes.org: Accessed 13 March 2021. Query: Country = Global, Type = Mean Annual $\delta^{18}O$ data

(Naud, 1997, p. 28). In 1691, a burial ground was opened on the southern side of the church (Arkéos, 2008, p. 8). In 1796, as public health regulations improved, burials were banned within the city's walls. Thus, Notre Dame's cemetery was closed and a new cemetery (Saint-Antoine, 1799–1854) was opened outside the city walls.

Considering that Notre Dame's skeletal collection often presented fragmented and commingled remains, the dental sample was carefully selected to include only well-associated teeth. Sex and age for adults were determined by using various methods (see Vigeant et al., 2017), and age-at-death for subadults was estimated following Scheuer and Black (2007). Crown formation age phases for the permanent teeth were estimated according to AlQahtani et al. (2010).

Since a bias in the $\delta^{18}O$ can be introduced with breastfeeding bringing about a 0.5 ‰ increase (Wright & Schwarcz, 1998), only teeth whose crowns had been formed after weaning were selected. The study by Gutierrez (2018, $n = 29$) carried out on the same collection indicated that weaning was completed by 2 years of age. Since permanent premolars crown formation starts after 2.5 years of age (AlQahtani et al., 2010), they were selected. Third molars were included as their $\delta^{18}O_C$ reflects a later period in life (2.5–6.5 years of age for both first and second Pm; and 9.5–15.5 years of age for M3) (AlQahtani et al., 2010). All children that provided a premolar ($n = 3$), as well as, all individuals having both a premolar (Pm) and a third molar (M3; $n = 29$) were sampled.

The 32 teeth selected for the study belonged to 9 juveniles and 23 adults (Table 3). Sex could only be determined for 22 individuals. The sample was also subdivided into six age categories:

1. children 4–8 years old ($n = 3$);
2. pre-adults 12–17 years old ($n = 6$);
3. young adults 18–25 years old ($n = 9$);
4. mature adults 26–40 years old ($n = 7$);
5. adults >41 years old ($n = 6$); and
6. adults of unknown age ($n = 1$).

Prior biodistance analysis of the dental morphology of Notre Dame's sample provided some information on the possible genetic origin of nine individuals (B-Hardy, 2015; see Table A1). B-Hardy (2015), who used 18 traits from the ASUDAS protocol (Turner et al., 1991) suggested that: (i) seven individuals (three pre-adults, four adults) were possibly of Indigenous or mixed ancestry, as they displayed several dental traits commonly observed in both Indigenous (e.g., interruption groove on upper second incisor, 5-cusps on second upper molar, shovel and double shovel incisors) and European (e.g., 2-rooted on lower canine, Carabelli's trait on upper first molar)

TABLE 3 Summary of age-at-death and sex information for the 32 individuals under study from Notre-Dame's cemetery

Broad age categories	Number of individuals			
	Females	Males	Undetermined sex	Total
Children (∼3–8 years)			3	3
Pre-adults (∼12–17 years)		2	4	6
Young adults (∼18–25 years)	3	4	2	9
Mature adults (∼26–40 years)	5	2		7
Adults aged > ∼41 years	3	3		6
Undetermined adult age category			1	1
Total	11	11	10	32

populations; and ii) two others appeared to be most probably of European ancestry. Harding et al. (2020), who analyzed historic human remains from Quebec to test a new method combining genetics and genealogy, also confirmed the sex (male) and origin (Europe) for one mature individual (11D-S1; see Table A1). Paleodietary data from bone collagen were also available for all individuals of the sample under study except for one child (12 W-S11 [a]; Vigeant, 2012; Vigeant et al., 2017).

3 | METHODS

Paleochemical analyses were conducted at the Stable Isotopes Laboratory of the Geotop Research Center (Université du Québec à Montréal, Canada).

Six teeth were pre-treated as a test. Enamel powder (bulk samples from the whole crown surface) was submerged in 2 % NaOCl solution for 48 hours, then in 0.1M acetic acid solutions for 4 h (as suggested in Garvie-Lok et al., 2004). In one sample the treated $\delta^{18}O_C$ gave lower value while the other five values were higher (0.3–1.6 ‰ difference) than untreated samples. These variations in $\delta^{18}O$ resulting from carbonate pretreatment methods have been frequently reported in the literature (Crowley & Wheatley, 2014; Garvie-Lok et al., 2004; Koch et al., 1997; Pellegrini & Snoeck, 2016). Since tooth enamel hydroxyapatite is less susceptible to alteration (Kohn & Cerling, 2002), this procedure was omitted (as in Pellegrini et al., 2011; Chenery et al., 2012).

Therefore, the $\delta^{18}O$ tooth enamel carbonate was unacidified prior to analysis. However, to reduce soil contamination, the surface layer of the enamel (lingual or buccal) was removed with a rotary tool. Then, sampling was carried out by drilling the surface of the pre-cleaned tooth crown, in order to obtain enamel powder. A single sample was taken from the entire tooth surface to reduce annual and seasonal variation, and in order to compare similar samples. Apart from the duplication induced by the testing of the acid treatment on six samples, the analyses were not duplicated.

Finally, a total of 1.2 mg of tooth enamel powder was weighted for isotope analysis, which was done using an Isoprime^{MC} isotope ratio mass spectrometer in double injection mode coupled with a Multicarb^{MC} system. All isotopic values are expressed in the δ notation and reported in "permil" (‰) versus VSMOW scale for $\delta^{18}O$ (measured vs. VPDB and converted to VSMOW according to Brand et al. (2014) and versus VPDB on the NBS19-LSVEC scale for $\delta^{13}C$, with ±0.05 ‰ uncertainty (1σ) as (example for oxygen):

$$\delta\left(^{\frac{18}{16}}O\right)(\text{in}‰) = \left[\frac{N\left(^{18}O\right)_p \Big/ N\left(^{16}O\right)_p}{N\left(^{18}E\right)_{std} \Big/ N\left(^{16}E\right)_{std}}\right] - 1.$$

where $N_p(^{18}O)$ and $N_p(^{16}O)$ are the abundances of the two isotopes ^{18}O and ^{16}O of oxygen in specimen P, and equivalent parameters follow for the international measurement standard, "std" (Coplen, 2011). As described in Brand et al. (2014), we have simplified the notation to $\delta^{18}O$ and $\delta^{13}C$.

Preservation of the enamel carbonate was analyzed with attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) using an Agilent 4500a portable instrument equipped with a single-bounce diamond ATR. Approximately 1 mg of treated enamel powder was pressed against the clean diamond crystal, and absorbance spectra were collected with a spectral range of 4000–650 cm^{-1}, at 4 cm^{-1} resolution, with 64 co-added scans, and background measurements taken after each sample. The peak measurements were calculated using a measurement system based on absolute peak height following Pothier-Bouchard et al. (2019). The carbonate v_3 peak (C) was defined between 1415 and 1405 cm^{-1}. The phosphate v_3 peak (P) was defined between 1035 and 990 cm^{-1}. Due to distortion from the ATR, these positions are equivalent to peaks measured in KBr spectra at 1415 and 1035 cm^{-1}, respectively. As recommended by France et al. (2020, 13), C/P ratios between 0.08 and 0.2 were considered indicating well-preserved samples.

To assess mobility, the composition of local drinking water had to be determined isotopically. Therefore, data on actual ^{18}O isotopic composition of local water precipitations (Meyzonnat, 2018) and the equations of Evans et al. (2012) were used for this purpose. The $\delta^{18}O_C$ of the three children's premolars from our sample were also used as it was assumed that they would reflect local drinking water (Vigeant, 2012). In addition, the $\delta^{18}O_C$ of Indigenous or mixed ancestry premolars were considered as representative of the drinking water on Northeastern North America, as they were natives of the region.

4 | RESULTS

All $\delta^{18}O_C$, $\delta^{13}C$, and C/P are presented in detail in Table A1. The results are presented below in two sections. The first section addresses the question of the $\delta^{18}O$ of the drinking water in Montreal and other regions of Northeastern North America during the late 17th and 18th centuries. The second section presents the various individual's life histories and migration patterns that have been identified through the $\delta^{18}O_C$ and the $\delta^{13}C$.

4.1 | $\delta^{18}O_C$ of individuals that would have consumed local water (17th-18th century, Montreal/Northeastern North America)

The $\delta^{18}O_C$ obtained from the three children from Notre Dame varied little (range: 22.4–22.9 ‰). This suggests that these children lived in a similar geographical location between the age of 2.5 and 6.5 years, probably Montreal.

One can calculate the $\delta^{18}O_{DW}$ of Montreal's drinking water by using the $\delta^{18}O_C$ of Notre Dame's children's teeth and the following equation ($\delta^{18}O_{DW} = 1.590 \times \delta^{18}O_C - 48.634$; Chenery et al., 2012). A mean of -12.6 ± 0.5 ‰ is thus calculated for drinking water in Montreal during the late 17th and 18th centuries (Table 4). This value is in the low range of modern variation based on the data collected for local groundwater (Meyzonnat, 2018: range from -10 to -12.5 ‰) and for surface water from Eastern Canada and New England between 2007 and 2013 (-9.4 ‰, ±2.6 at 1σ, Timsic & Patterson 2014: Table 2). As a gradient of 0.4–0.8 ‰ by Celsius degree has been measured in Northeastern America (see review in Timsic & Patterson 2014, p. 602), these differences in "local" drinking water $\delta^{18}O$ could reflect the colder climate of the period (Little Ice Age, from 1375 to 1890 in North America Brönnimann et al., 2018, Moore et al., 2001).

Yet, the calculation of $\delta^{18}O_C$ to $\delta^{18}O_{DW}$ increases the uncertainty of these values, from 0.05 to 1.00 ‰ through the propagation of uncertainties of the measured data and the scientific equation (Chenery et al., 2012). Consequently, it seems better to use the $\delta^{18}O_C$ of Notre Dame's children as a valid proxy for the $\delta^{18}O_{DW}$. It is argued that this methodological procedure using the untransformed $\delta^{18}O_C$ ‰ versus VSMOW of children's teeth from the sample as a proxy to assess past drinking water in Montreal is more cautious approach than to apply the equations mentioned above and to compare these with the values for modern ground water.

For interpretative purposes, it is argued that the mean annual isotopic composition of individuals who drank local water was within 1 ‰ variation of the mean $\delta^{18}O_C$ for those children (22.7 ‰). This 2 ‰ range was selected for the following three reasons:

1. it represents the range of variation of groundwater in the region (see above);
2. it represents the average range of teeth phosphate $\delta^{18}O_P$ reported in different localities (e.g., White et al., 2002, p. 219) including Quebec (Daux et al., 2005, Table 1); and
3. it is slightly larger than the reported $\delta^{18}O$ spread reported using modern hair for the nearby greater Toronto area (Mant et al., 2016, Table 2).

This interpretative procedure is reinforced by the $\delta^{18}O_C$ obtained from premolars of five individuals of possible Indigenous or mixed ancestry who fall within the Montreal's variation (22.1–23.1 ‰, Table 4). In addition, two other individuals of possible Indigenous or mixed ancestry (one pre-adult (11G-S1) and one young adult male (12DD-S5)) display slightly higher $\delta^{18}O_C$ values (24.3 ‰ and 24.2 ‰ for Pm respectively), suggesting that these values represent other North American regions (more southern and/or coastal than Montreal).

These data allow us to narrow down the isotopic definition of the drinking water $\delta^{18}O_C$ of the "Montreal area" (21.7–23.7 ‰) within Canada. These results concur with comparative bioarchaeological data obtained from nearby contemporaneous sites (Table 2). For example, Emery et al. (2017) determined a Lower Canada origin for a soldier buried at Smith's Knoll showing a $\delta^{18}O_C$ of 22.5 ‰. In Southwestern Ontario, Schwarcz et al. (1991) obtained slightly lower $\delta^{18}O_C$ (21.2 ‰, $n = 2$), which reflect its continental setting. In coastal Eastern Canada (Newfoundland), Munkittrick et al. (2019) obtained $\delta^{18}O_C$ ranging from 23.2 to 24.1 ‰ (St Paul's Anglican Church cemetery, Harbor Grace, Newfoundland). As other North American ([pre-] United States) and European (France and the British Isles) sites have overlapping $\delta^{18}O_C$ values (>24.4 ‰), it does not allow us to assign a clear origin for individuals with high $\delta^{18}O_C$. Nevertheless, historical records (e.g., Desjardins, 1990) suggest that French immigrants are more likely to be encountered in our sample.

TABLE 4 Estimation of the $\delta^{18}O$ values of drinking water from Montreal and other North American locations using the $\delta^{18}O_{CARBONATE}$ values of premolars from 10 Notre Dame's individuals

Skeleton code	$\delta^{18}O_C$ ‰ versus VSMOW	Calculation to $\delta^{18}O_{DW}$ from Chenery et al. (2012) with 2σ of uncertainty
Children		
12BB-S13	22.4	−13.1 (±1.00)
12 W-S11(a)	22.7	−12.6 (±1.00)
12EE-2	22.9	−12.2 (±1.00)
Average values	22.7 (±0.3)	−12.6 (±1.00)
Individuals of possible indigenous or mixed ancestry according to dental biodistance analysis (B-Hardy, 2015)		
12AA-S10	22.1	
12CC-S3	22.5	
4K-S3	22.7	
12EE-S5	22.8	
9B1-S3	23.1	
12DD-S5	24.2	
11G-S1	24.3	

Still, according to the comparative data (Table 2) and our $\delta^{18}O_C$ results obtained from the children and (pre-)adults of possible Indigenous or mixed ancestry from Notre Dame, the geographical origins of the individuals can be divided into the following three categories:

1. Northeastern North America ($\delta^{18}O_C$ < 24.4 ‰);
2. more specifically within Northeastern North America, the Montreal area in Canada ($\delta^{18}O_C$ range: 21.7–23.7 ‰); and
3. various locations corresponding to a warmer climate and/or more coastal area than Northeastern North America ($\delta^{18}O_C$ ≥ 24.4 ‰).

4.2 | Migration patterns for Notre-Dame

As the $\delta^{18}O_C$ obtained from both the premolars and the third molars are individually compared to one another, it allowed us to follow mobility patterns during two different life phases. These variations indicated events that occurred during childhood (2.5–6.5 years of age) for the Pm and during adolescence and into early adulthood (9.5–15.5 years of age) for the M3. Figure 2 plots the individuals' $\delta^{18}O_C$ for both teeth in relation to the variation observed for Montreal area and Northeastern North America reported above. The 20 individuals within the ±1 ‰ oblique lines are considered to have experienced regional change in their place of residence before adulthood. They represent 69 % of our sample (20 out of 29). The nine remaining individuals have a difference of $\delta^{18}O_C$ between their Pm and M3 ($\Delta\ \delta^{18}O_{C\ PM\text{-}M3}$, see Table A1) ranging between 1.4 and 2.7 ‰, and this implies mobility towards a region with a colder climate.

Overall, three main scenarios of mobility patterns are apparent:

1. vertically under the label "Childhood in Northeastern North America," individuals who spent their childhood in Northeastern North America (including the Montreal area);
2. horizontally along the label "Between 10 to 16 years of age in Northeastern North America," individuals who lived in Northeastern North America (and the Montreal region) between the ages of 9.5 and 15.5 years; and

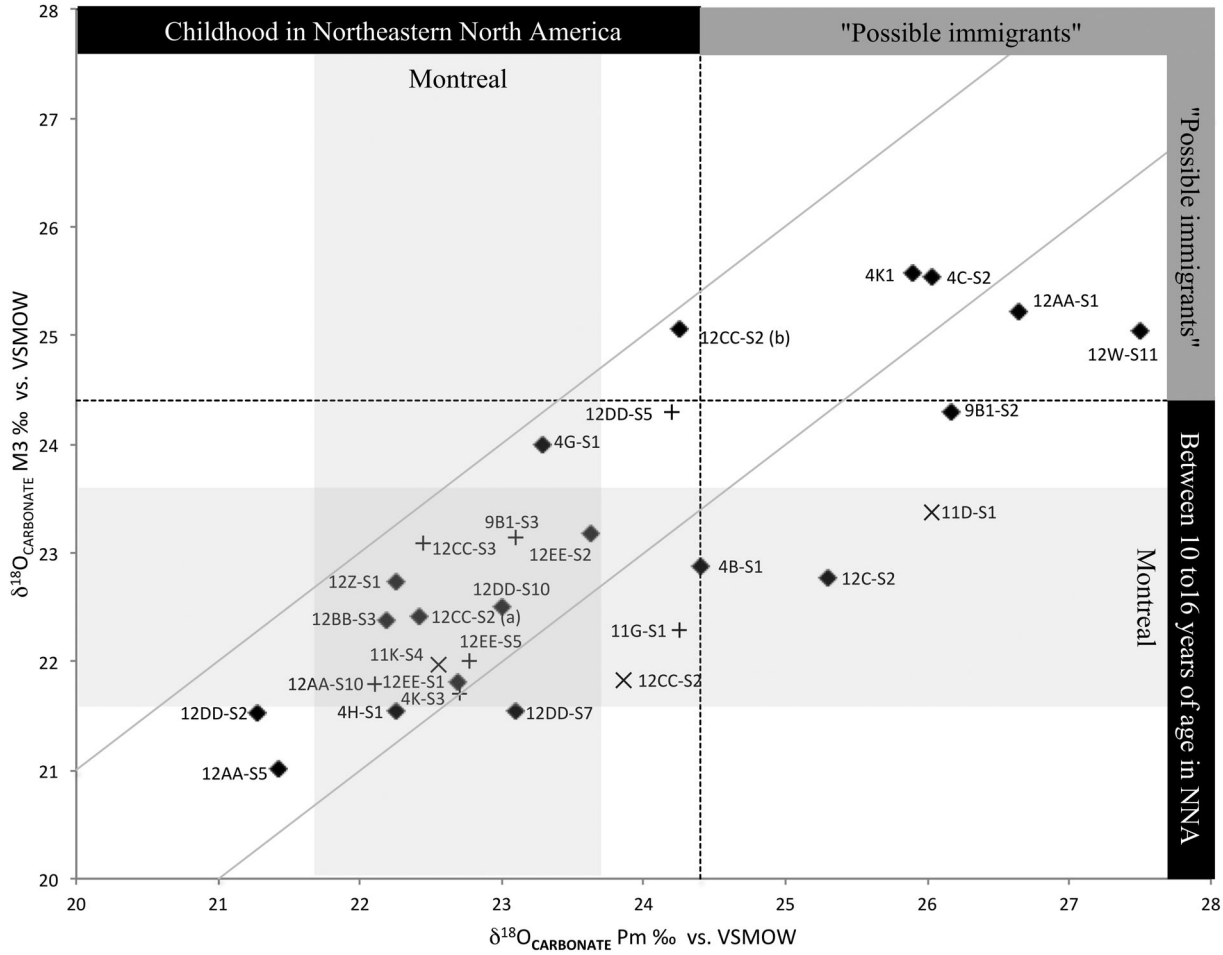

FIGURE 2 $\delta^{18}O_{CARBONATE}$ from premolars (Pm) plotted against $\delta^{18}O$ obtained from third molar (M3). Individuals of possible indigenous or mixed ancestry are represented by a + sign, while those of European origin are represented by a x sign, the diamonds represent the individuals of unknown ancestry. Horizontal and vertical lines correspond to $\delta^{18}O$ associated to North America. The oblique lines encompass $\delta^{18}O$ for the two tooth types varying less than ±1 ‰ indicating no migration between childhood (2.5–6.5 years of age) and adolescence/early adulthood (9.5–15.5 years of age)

TABLE 5 Migration patterns based on place of residence before adulthood, age-at-death and sex

Region[a] of residence before		Age-at-death								
		12–17 years		18–25 years			26–40 years		>41 years		Adult	N
2–6 years	10–16 years	Males	Sex?	Females	Males	Sex?	Females	Males	Females	Males	Sex?	
MTL	MTL	**12CC-S3**	**4K-S3** *11K-S4* 12CC-S2(a)	**12AA-S10** **12EE-S5**	12Z-S1	12DD-S10	**9B1-S3** 12EE-S2	12EE-S1		12BB-S3		12
	NNA			12DD-S7					4H-S1 4G-S1			3
NNA	NNA				**12DD-S5**				12AA-S5		12DD-S2	3
	MTL	**11G-S1**					12CC-S2					3
	WC					12CC-S2(b)						1
WC	WC				4 K1		12AA-S1			4C-S2		4
	NNA				12W-S11(b)		9B1-S2					1
	MTL		12C-S2					4B-S1		11D-S1		2

Note: Skeleton codes in bold belong to seven individuals of possible indigenous or mixed ancestry and the ones in italic to three individuals of European ancestry (B-Hardy, 2015; Harding et al., 2020). All shaded skeleton codes correspond to individuals that experienced long-distance mobility within North America (light gray) and outside the latter (dark gray). Underlined skeleton codes correspond to the 16 possible biographies proposed in the discussion.

[a]MTL = Montreal region; NNA = Northeastern North America (various locations); WC = warmer climate and/or more coastal than Montreal (various locations).

3. finally, the "possible immigrants" located in the upper-right corner of the graph, who spent their youth in a region with a warm (and/or more coastal) climate possibly outside of Northeastern North America (e.g., (pre-) United States and Europe).

Twenty-one individuals (72 % of the sample) displayed $\delta^{18}O_C$ premolar lower than 24.4 **‰** and fall under the label "Childhood in Northeastern North America" (Figure 2). Fifteen of these individuals (52 % of the sample) would have lived in the Montreal region during their childhood, including five of the seven individuals, possibly of Indigenous or mixed ancestry. Of that number, 12 "Montrealers" possibly did not leave the region as their $\delta^{18}O$ range between 21.7 and 23.7 ‰. Yet, this does not exclude mobility from the city. Still, of the three individuals (4G-S1, 4H-S1 and 12DD-S7) who showed mobility from the city during pre-adulthood ($\delta^{18}O_{M3}$), two of them (4G-S1, 4H-S1), have $\Delta\ \delta^{18}O_{Pm\text{-}M3}$ less than 1 ‰, which suggest limited mobility. The third individual, 12DD-S7, would have moved towards a region that was more continental or with a colder climate at 10–16 years of age and would have returned later.

Six individuals, who do not fall within Montreal's variation (24 % of the sample), reflect mobility within Northeastern North America (see under the label "Northeastern North America" for both phases in Figure 2). They would have migrated to the "Montreal region" at a young age or at adulthood, from elsewhere in Northeastern North America. Two of them (12DD-S2 and 12AA-S5) spent all their youth in a colder or inland region of Northeastern North America (compared to Montreal, see lowest $\delta^{18}O_{PM}$ and $\delta^{18}O_{M3}$; left lower quadrant of Figure 2). The other three originated from a warmer or more coastal region of Northeastern North America as their $\delta^{18}O$ values range between 23.9 and 24.3 ‰. They arrived in Montreal at various ages: either during adolescence ($\delta^{18}O_{M3}$ of 11G-S1 and 12CC-S2 fit within Montreal variation) or later during adulthood ($\delta^{18}O_{M3}$ of 12CC-S2 [b] and 12DD-S5 still fall outside the Montreal variation). Included within this sample, there were two individuals of possible Indigenous or mixed ancestry (11G-S1 and 12DD-S5) according to their dental morphology (B-Hardy, 2015).

Eight individuals (28 % of the sample) do not fall at all under the label "Childhood in Northeastern North America" in Figure 2, as they present the highest $\delta^{18}O_{C\ PM}$ range (24.4–27.5 ‰). They originated from various locations with climates warmer than specifically Northeastern North America (e.g., southern or coastal regions of North America and Europe). They likely left either during early adulthood (9.5–15.5 years of age) or later. For example, in the most upper right section of Figure 2 (where $\delta^{18}O_{C\ PM}$ and $\delta^{18}O_{C\ M3}$ are highest), there are four individuals (4C-S2, 4K1, 12AA-S1, and 12W-S11), who likely immigrated to Montreal, during adulthood (after ~16 years of age). In the same right portion of the graph, there are four other individuals with $\delta^{18}O_{C\ M3}$ lower than 24.4 ‰. They would have immigrated to Northeastern North America at a young age (between 10 and 16 years of age). Individuals 4B-S1, 12C-S2 and 11D-S1 would have arrived in the Montreal region at adolescence. Yet, the fourth individual (9B1-S2) would have moved later to Montreal. Therefore, these eight individuals buried in Notre Dame's cemetery were possibly first-

generation immigrants, as their $\delta^{18}O_{C\ PM}$ (range from 24.4 to 27.5 ‰) indicated growing up elsewhere other than Montreal or Eastern Canada.

In short, out of 29 individuals sampled (children excluded), 14 probably did not experience any long-distance mobility during their lifetime (Table 4). Yet, it implies that 15 individuals (or 52 % of our sample) did experience migration to some extent and at different periods of their life (five at pre-adulthood, six at adulthood and four others during both pre-adulthood and adulthood). Notre Dame's individuals involving different migration patterns are discussed below, as they reflect different possible "life biographies."

5 | DISCUSSION

The comparison of the $\delta^{18}O_C$ obtained from premolars and third molars allowed the identification of residency during early childhood and adolescence, therefore revealing mobility between 2.5 and 15.5 years of age. For this purpose, Table 5 summarizes the mobility scenarios that have been identified (Figure 2). The 29 individuals are assigned to eight scenarios that present all possible scenarios based on the three broad regions defined above, focusing first on the Montreal area and then the wider region (Northeastern North America and various locations of warmer and more coastal climate than Montreal and Eastern Canada). Each individual with their own identification number, estimated age at death and sex, is assigned to one of these eight scenarios.

5.1 | 17th-18th century Montreal: Second-generation immigrants and individuals of Indigenous or mixed ancestry

Despite its small sample size, Notre Dame's population sample already reflects some key aspects of the migration/colonization processes that occurred in Montreal during the late 17th and 18th centuries. At least, 75 % (24 out of 32) of the individuals analyzed were most probably born in Montreal or its surroundings, Upper/Lower Canada (Ontario/Quebec) or Northeastern North America. They correspond to a second or later generation of European immigrants, as well as, individuals of possible Indigenous or mixed ancestry (B-Hardy, 2015; Harding et al., 2020). These results acquiesce with the historical records (Dechêne, 1974; Landry, 1992; Naud, 1997).

The key origin of the colonial diaspora to Montreal was France (97 %), but a few citizens from other European countries such as Great Britain, Ireland and Germany also crossed the Atlantic (Charbonneau, 1990, p. 50; Desjardins, 1990; Naud, 1997, p. 42). Based on the $\delta^{18}O$ obtained for the individuals of possible Indigenous or mixed ancestry in Notre Dame's sample, eight individuals (an adolescent, two young adult males, two mature women, a mature male and two older men) with high $\delta^{18}O_C$ (>24.4 ‰) could be considered as possibly originating from outside Northeastern North America (North America or Europe). These migration patterns, still mostly European in nature, agree with historical information, as this burial ground was opened in 1691; not long after the first major wave of European immigrants (Naud, 1997).

At first, most of the colonists were single males (as they were less expensive to transport than whole families), which resulted in an imbalance in female vs. male colonists: in 1663 it was of one to six. This discrepancy seems to have been successfully reversed as women and men are equally represented in our sample (six women, six men and four of undetermined sex). Also, due to a high fertility rate (9.5 children per woman, Gauvreau, 1998), two thirds of the European population was locally born by 1681 (Charbonneau, 1977; Dechêne, 1974). This concurs with the proportion of locally born people of European descent in our sample. In Tables 5, 68 % of the sample or 17 out of 25 individuals of possible European ancestry (children included), were probably locally born or from a Northeastern North American origin.

Early colonists were rather dependent on local groups not only for economic reasons, but also for their demographic contribution. Mixed marriages were encouraged in the 17th century (Trudel & D'Allaire, 2004) and population admixture between Colonists and Indigenous people continued throughout the 18th century. Thus, the presence of individuals of possible Indigenous or mixed ancestry in our sample (7 out of 29 individuals) is not unexpected. However, for 19 individuals out of 29, the ancestry was not determined either by morphology (due to insufficient preservation of dental material, B-Hardy, 2015) or because they were not selected for ancient DNA analysis (Harding et al., 2020). Therefore, our figures are probably underestimated (see below). According to historical sources, it is estimated that 59 % of Montreal's population was composed of Indigenous individuals in 1692 (791 out of 1341). This proportion had decreased to 27 % (1177 out of 4409) in the 1716 census (Dechêne, 1974: Table 1).

The presence of seven individuals of possible Indigenous or mixed ancestry in the Montreal sample is intimately related to the city's history. Envisioned during a period of spiritual revival in France, the founding purpose of Ville Marie (renamed Montreal) was to convert Indigenous groups to Catholicism. Yet after arrival, the strategic position of the island provoked a change in attitude towards a more materialistic goal: the fur trade. Strong alliances were forged with the Odawa and other Algonquian Nations, to dissuade them to trade with New Amsterdam (New York, after 1674) and therefore to ensure France's territorial sovereignty of the fur trade (Dechêne, 1974).

5.2 | Investigating individual migration life histories: To and from Montreal

Isotopic analysis interest is in the reconstitution of individuals' environment and behavior. Here, using premolar and third molar we were able to reconstruct possible mobility during youth, and figure migration at adulthood for "foreigners" (as they were buried in Montreal). All the mobility patterns inferred from the isotopic data involved movements of individuals between Montreal region, North America

and probably Europe. In total, 52 % of the sample (15 out of 29) would have experienced migration or mobility, either at pre-adulthood ($n = 5$), adulthood ($n = 6$) or during both stages of life ($n = 4$; shaded areas in Table 5). Individual cases of this sub-sample are highlighted here in the discussion, as they illustrate certain life trajectories in relation to history. Supplemented by data from dental morphology (B-Hardy, 2015), ancient DNA (Harding et al., 2020) and diet (Vigeant, 2012; Vigeant et al., 2017), 16 possible bioarchaeological "biographies" are proposed below (see Table A1).

5.2.1 | Nouvelle France's intendant demanded that no man under the age of 16 be sent to Canada

Although, children were ready to work at a very young age, it appears that at pre-adulthood most of them were still living relatively near their place of birth (since 20 out of 29 individuals or 69 % have a $\delta^{18}O_{C\ Pm\text{-}M3}$ difference of <1 ‰). This concurs with a demand made on the 29th of October 1667, by the First Intendant of Nouvelle France, Jean Talon, to Colbert, then Minister of Finance in France, that "no man under 16 (and over 40) years of age should be sent to Canada, as they were not going to adapt to the country and would cost the King" (translated from Charbonneau & Landry, 1979, p. 34).

Yet, this concern could be reflected in the death of an adolescent (12C-S2), as he would have died upon his arrival in Montreal ($\delta^{18}O_{C\ Pm}$: 25.3 ‰ $\delta^{18}O_{C\ M3}$: 22.8 ‰, Table A1). It was then common practice to recruit children (as young as 10 years of age) among inhabitants of poor houses to become French sailors (Lefrançois, 2007). In fact, the low protein intake of his diet (Vigeant et al., 2017: Table A1) and his premature death may point towards a low status (Lefrançois, 2007, pp. 5–6).

Another individual, 11D-S1 would also have experienced Trans-Atlantic migration at a relatively early age ($\delta^{18}O_{C\ Pm}$: 26.0 and $\delta^{18}O_{C\ M3}$: 23.4, Table A1). The genetic profile of 11D-S1 indicated that he might have been of Basque origin (Harding et al., 2020, p. 655). Furthermore, this young man may have not journeyed alone to the colony as his premolar enamel $\delta^{18}O_C$ is identical to another man (4C-S2, both 26.0 ‰). While 11D-S1 would have migrated to Montreal before 10 years of age, 4C-S2 would have arrived after the formation of his third molar crown (after 16 years of age, Figure 2). In addition, their diets are isotopically similar (Vigeant, 2012, Vigeant et al., 2017) indicating C_3 resources and animal protein intake. A third man (4K1) would have migrated at adulthood from a region with a similar $\delta^{18}O_C$ (25.9 ‰) value. Yet, his diet differs from the two other men, with a higher consumption of marine or C_4 plants resources (Vigeant, 2012, Vigeant et al., 2017). Although it is speculative as only ancient DNA could confirm this hypothesis, these individuals reflect male migration (e.g., contract workers, indentured servants, soldiers) possibly from the same region and—for two of them—the same family, yet at different ages.

Another young adult male 12W-S11(b) experienced different migratory episodes during his lifetime. Interestingly, during each episode, a dietary change occurred. Between childhood and pre-adulthood, his $\delta^{18}O_C$ lowered by 2.5 ‰ ($\delta^{18}O_{C\ Pm}$: 27.5 and $\delta^{18}O_{C\ M3}$: 25.0 ‰), while his $\delta^{13}C$ changed by +2.4 ‰ from a C_3 diet ($\delta^{13}C_{Pm}$: −14.1 ‰) to a diet including more aquatic resources and C_4 plants (e.g., maize in North America or millet in Europe; $\delta^{13}C_{M3}$: −11.7 ‰). During adulthood, his later arrival in Montreal involved another dietary change slightly more towards C_3 resources ($\delta^{13}C_{BoneCarbonate}$ −12.7 ‰, Vigeant, 2012).

These migration life histories show different scenarios that male colonists migrating at a young age could have experienced. But males were not the only ones to have arrived in North America before 16 years of age. 9B1-S2, a mature woman, could have arrived in Northeastern North America at such a young age (Table 5). Although the *Filles du Roy* were sometimes as young as 14 years old (Landry, 2013), it seems most likely that this young woman would have traveled to North America with her family before 10 years of age and moved to Montreal later in life. The woman 12AA-S1 would be a better candidate to have been part of the *Filles du Roy*. Most of these women were daughters of artisans, laborers and servants raised in urban settings, often port cities and rural girls raised on farms, coming from nearly everywhere in France (Runyan, 2010, pp. 19–20). The woman 12AA-S1 could have been from this last group of female migrants. The difference in $\delta^{18}O_C$ between her premolars (26.7 ‰) and third molars (25.2 ‰) indicated that she would have experienced mobility during her youth, possibly within France. She would have arrived in Montreal after ~16 years of age. While these scenarios remain hypothetical, these two first-generation female immigrants died during adulthood (26–40 years).

5.2.2 | Indigenous people in Montreal

Before 1671, European families and Religious Congregations would occasionally adopt Indigenous children for conversion to Catholicism (Trudel & D'Allaire, 2004). In addition, during the first 20 years of the colony, Indigenous people would have settled near the fort (Dechêne, 1974, p. 22). The imperatives for such behavior were multiple: the merchants and the missionaries did enforce a sedentary lifestyle, but war, epidemics and famine would also have pressed some individuals to seek protection from the colony. The first mission was established in the 1660s. Primarily inhabited by converted Oneidas, it quickly expanded with the arrival of Onondagas and Mohawks, bringing with them large contingents of Huron prisoners (Tremblay, 2016).

B-Hardy et al. (2005) compared the diet during childhood of seven individuals of Indigenous or mixed ancestry of the Notre-Dame sample ($\delta^{13}C$ from tooth premolars) with a subsample of the diet of individuals of European ($n = 3$) or unknown origin ($n = 23$). These authors observed that the $\delta^{13}C$ of the individuals ($n = 7$) plotted on both extremes of the isotopic variation (−13.6 to −12.5 ‰, $n = 6$ and −9.0 ‰, $n = 1$). Five individuals living in Montreal during childhood were identified as of possible Indigenous or mixed ancestry by dental morphology. Yet, two individuals (a woman 4H-S1 and a man 4B-S1) that could not be included in B-Hardy's (2015) study have dietary data that may indicate similar ancestry. The $\delta^{13}C_{PM}$ of both 4H-

S1 and 4B-S1 are among the 15 % highest values of the sample (−10.1 and −9.9 ‰ respectively, compared to a mean: −11.7 ± 1.2 ‰, $n = 64$, Vigeant et al. unpublished) indicating a higher C_4 resources intake, as maize, during childhood than the whole sample.

The aged woman (4H-S1) may not have encountered long distance mobility during her lifetime (Δ $\delta^{18}O_{C\ Pm\text{-}M3}$ of 0.7 ‰). However, she still shows a difference in her diet between childhood and pre-adulthood (Δ $\delta^{13}C_{Pm\text{-}M3}$ of −2.4 ‰) indicating a major dietary change towards less C_4 intake at pre-adulthood than during early childhood. The mature man (4B-S1) experienced a similar dietary change (Δ $\delta^{13}C_{Pm\text{-}M3}$ of −2.5 ‰) that was also combined with a change of residence at pre-adulthood ($\delta^{18}O_{C\ PM}$ 24.4 vs. $\delta^{18}O_{C\ M3}$ 22.9 ‰). This suggests that he spent his childhood in an area either southern and/or more coastal than Montreal on the North American territory and moved to Montreal before the age of 10 years old.

5.2.3 | Forced migration of Indigenous and African slaves

Forced migration to or within the American continent during the colonial period is also a reality. Although the northern portion of Nouvelle France did not base its economy on slavery, as it had no plantations, 4185 slaves of Indigenous or African descent were listed from the mid-17th century to 1834 (when slavery was abolished; Trudel & D'Allaire, 2004, p. 90). A large proportion of them lived in Montreal (36.4 %; Trudel & D'Allaire, 2004, p. 96). They were probably buried in various cemeteries (Notre Dame's Parish's Death Archives record the interment of both Indigenous and African slaves). Trudel & D'Allaire (2004, pp. 84, 88–89) reported that most First Nation slaves were drawn from the southern regions (66.9 % of the *Panis* listed came from the Mississippi valley; the French term covered every enslaved Indigenous, as it derived from the *Pawnees* a tribe native from Nebraska and Kansas). The slaves of African descent were transferred along different routes (e.g., New England, Louisiana, West Indies). Two Notre Dame's pre-adult and young adult men, 11G-S1 and 12DD-S5 (of possible Indigenous or mixed ancestry), could have experience some of these unfortunate journeys (Table 5).

The two men are among the lowest $\delta^{13}C_{PM}$ of the whole Notre Dame sample (−12.7 and −13.5 ‰ respectively, compared to a range from −7.9 to −14.1‰, $n = 64$, Vigeant et al. unpublished). These values indicate a diet at childhood that differed from the Notre-Dame diet (B-Hardy et al., 2005; Vigeant et al., 2017). The pre-adult male 11G-S1 would have arrived in Montreal before the age of 10 years old, from a region with a $\delta^{18}O_C$ of 24.3 ‰. He would have died a few years after his arrival in Montreal. His low protein diet (Vigeant, 2012) may indicate that he suffered from malnutrition, possibly prompting his death. The man (12DD-S5) left a region with a similar $\delta^{18}O_C$ (24.3 ‰ for $\delta^{18}O_{M3}$) after 16 years of age. This $\delta^{18}O_C$ is slightly higher than the one measured in Eastern Canada (24.1 ‰ for Newfoundland, Munkittrick et al., 2019), possibly indicating an origin further south, within the (pre-) United States, as the Mississippi Valley. They did not encounter a major change in diet after migrating to Montreal. The men did not survive long after their arrival in Montreal. All died before 25 years of age.

5.2.4 | Mobility in nouvelle France

Many late 17th and 18th century Montrealers originated from various areas of Nouvelle France: they could have been demobilized soldiers choosing to settle or just people moving to other regions (Dechêne, 1974; Naud, 1997). It is estimated that these migrants represented 5 % of the new immigrants arriving after 1680 (Naud, 1997). Yet, they could be over-represented in our sample (5 out of 29 or 17 %). Within North America, mobility occurred mostly from east to west, with Acadians representing up to 40 % of these new migrants (Naud, 1997). In fact, the $\delta^{18}O_C$ of the mature "European" woman 12CC-S2 (23.9 ‰; B-Hardy, 2015) is within the variation measured at the St Paul's cemetery, in Newfoundland by Munkittrick et al. (2019, 23.2–24.1 ‰), suggesting a coastal origin. Yet, her identification as "Acadian" is highly improbable as most of them lived in Quebec City, and at most, Montreal hosted 1 % of these emigrants (Vachon, 2018, p. 96). She would have migrated at a young age (before 16 years of age). The young adult of undetermined sex 12CC-S2(b) would have migrated after 16 years of age from a region with higher $\delta^{18}O_C$, but most probably more southern. His $\delta^{18}O_{C\ PM}$ and $\delta^{18}O_{C\ M3}$ (variation of <1 ‰, from 24.3 to 25.1 ‰, respectively) suggest that his location during childhood and pre-adulthood was probably a southern or more coastal region of North America, before migrating to Montreal during adulthood. Within Canada, two individuals, an aged woman 12AA-S5 and an adult 12DD-S2, experienced mobility from a more continental or northern region, as their $\delta^{18}O_C$ (21.3 and 21.4 ‰) are similar to ones obtained by Schwarcz et al. (1991, 21.2 ‰, $n = 2$) from Southwestern Ontario. They would have moved after 16 years of age to Montreal. Their diet throughout their lifespan was rather similar to other local European groups (Vigeant et al. unpublished). Similarly, a woman (12DD-S7) could have experienced this kind of mobility, towards a more continental or northern region after leaving Montreal during pre-adulthood ($\delta^{18}O_{C\ M3}$ of 21.5 ‰). These migration patterns reflect individual movements within the vast Northeastern American territory.

This sample from the Notre-Dame cemetery, although small, reflects some of the various migration and mobility movements that occurred in North America/Montreal during the late 17th and 18th centuries. Seven individuals may have crossed the Atlantic either at 10 years of age (12C-S2, sailor and possibly 12W-S11 (b)), and at different ages as men migrating from the same region (11D-S1, 4C-S2, 4K1), and as women contributing to the colonial population (9B1-S2, 12AA-S1; see Table A1). The presence in Montreal of Indigenous/mixed ancestry individuals is also highlighted by seven to nine possible cases (4K-S3, 9B1-S3, 11G-S1, 12AA-S10, 12CC-S3, 12DD-S5 12EE-S5, and 4B-S1, 4H-S1). Two of them correspond to young men that may have been brought as slaves from another region of North America (11G-S1 and 12DD-S5). Nonetheless, our data show that the

majority of our sample is composed of possibly second-generation European immigrants (17 out of 32 individuals), who sometimes experienced mobility within Northeastern North America and from Montreal.

6 | CONCLUSIONS

By using the $\delta^{18}O_C$ obtained from children and individuals of possible Indigenous or mixed ancestry, we were able to assess the $\delta^{18}O_C$ of drinking water of the Montreal region during the late 17th and 18th century. This present study provided new bioarchaeological $\delta^{18}O_C$ values for a growing database on Eastern Canada and Northeastern North America. Since most of the $\delta^{18}O_C$ data obtained from the literature on North American and European sites overlap ($\delta^{18}O_C \geq 24.4$ ‰, see Table 2), this procedure still allowed us to investigate past mobility patterns at an individual level.

Despite Notre Dame's small sample size, the broad picture concurs largely with historical sources. The opening of the burial ground (first internment in 1691) coincided with the settling of a newly urban immigrant population (Charbonneau, 1990; Naud, 1997). Either for commercial, demographic or conversion purposes, they formed strong alliances with Indigenous people (although some may have been brought as prisoners or slaves). Nine individuals of possibly Indigenous or mixed ancestry have been identified (representing 31 % of the sample) either by dental morphology (B-Hardy et al., 2005) or through their diet at childhood. The arrival of women from France (between 1646 and 1715) stimulated the growth of the European colonists (Charbonneau, 1977; Landry, 1992). Among 23 individuals of possible European descent, 15 of them (or 65 %) may have been second-generation immigrants in North America.

The comparison of the $\delta^{18}O_C$ obtained from the premolars and the third molars allowed us to compare the early childhood and pre-adulthood periods of these individuals and produce eight mobility scenarios between three broad regions: Montreal, Northeastern North America and regions with a warmer climate. Most of the individuals experienced little mobility before the age of 16 years (20 out of 29 individuals, children not included). Fifteen of them (52 %) moved to Montreal either during pre-adulthood ($n = 5$), adulthood ($n = 6$) or after experiencing mobility during both pre-adulthood and adulthood ($n = 4$). Furthermore, hypothetical biographies were proposed for 16 individuals by combining the $\delta^{18}O_C$ and $\delta^{13}C$ with previous data on dental morphology (B-Hardy, 2015), ancient DNA (Harding et al., 2020) and diet (Vigeant, 2012; Vigeant et al., 2017).

The hypothetical biographies provided by this study still need to be explored further, but it suggests that a rather heterogeneous population originating from various regions and communities populated early colonial Montreal. More comparative data is needed to explore the $\delta^{18}O_C$ variation through time and space, within and beyond the American continent (e.g., Acadia, Louisiana, Western France). In addition, $^{86}Sr/^{87}Sr$ data could possibly help separate overlapping $\delta^{18}O_C$ for the United States and Europe. Although carbon and oxygen isotopes allowed identifying dietary behavior remindful of certain groups, ancient DNA analyses would assign ancestry more precisely.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jacinthe Vigeant: Conceptualization (lead); formal analysis (lead); funding acquisition (lead); methodology (supporting); writing – original draft (lead); writing – review and editing (supporting). **Isabelle Ribot:** Funding acquisition (supporting); supervision (supporting); writing – review and editing (lead). **Jean-François Hélie:** Formal analysis (supporting); methodology (lead); resources (lead); supervision (lead); writing – review and editing (supporting).

DATA AVAILABILITY STATEMENT

The data that supports these findings are included with this article.

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APPENDIX

TABLE A1 Summary of the Notre-Dame's burials with age, sex, dental sample and isotope data

					Premolar (Pm)			Third molar (M3)			Δ Pm-M3		
Skeleton code[a]	Sex[b]	Age group in years	Ancestry[c]	Tooth analyzed[d]	$\delta^{18}O$ ‰ versus VSMOW	$\delta^{13}C$ ‰ versus VPDB	C/P	$\delta^{18}O$ ‰ versus VSMOW	$\delta^{13}C$ ‰ versus VPDB	C/P	$\delta^{18}O$ ‰	$\delta^{13}C$ ‰	Biographical hypotheses[e]
12BB-S13	Und.	6	Und.	Pm2	22.4	−11.6	0.16						Locally born
12W-S11(a)	Und.	4–5	Und.	Pm2	22.7	−11.4	0.14						Locally born
12EE-2	Und.	7–8	Und.	Pm2	22.9	−11.5	0.19						Locally born
4K-S3	Und.	12 to 17	PIMA	Pm2 & M3	22.7	−12.9	n.a	21.7	−13.3	n.a	−1.0	0.4	Locally born
11G-S1	M	12 to 17	PIMA	Pm2 & M3	24.3	−12.7	0.13	22.3	−12.3	0.13	2.0	−0.4	1st generation migrant from NNA with C_3 diet (slave?)
12CC-S3	M	12 to 17	PIMA	Pm2 & M3	22.5	−9.0	0.14	23.1	−10.8	0.14	−0.6	1.8	Locally born
12EE-S5	F	18 to 25	PIMA	Pm2 & M3	22.8	−12.5	n.a	22.0	−11.9	n.a	0.8	−0.6	Locally born
12AA-S10	F	18 to 25	PIMA	Pm2 & M3	22.1	−13.1	0.13	21.8	−11.6	0.11	0.3	−1.5	Locally born
12DD-S5	M	18 to 25	PIMA	Pm2 & M3	24.2	−13.5	0.13	24.3	−12.5	0.15	−0.1	−1.0	1st generation migrant from NNA with C_3 diet (slave?)
9B1-S3	F	26 to 40	PIMA	Pm2 & M3	23.1	−12.8	0.13	23.1	−13.2	n.a	0	0.4	Locally born
11 K-S4	Und.	12 to 17	PE	Pm2 & M3	22.6	−12.7	0.11	22.0	−12.1	0.10	0.6	−0.6	Locally born
12CC-S2	F	26 to 40	PE	Pm2 & M3	23.9	−11.3	0.16	21.8	−12.5	0.12	2.1	1.2	2nd generation European migrant from NNA (warm/coastal)
11D-S1	M	>41	E	Pm1 & M3	26.0	−11.1	0.14	23.4	−12.3	0.12	2.6	1.2	1st generation immigrant from Basque region according to aDNA
12C-S2	Und.	12 to 17	Und.	Pm2 & M3	25.3	−11.0	0.11	22.8	−11.9	0.09	2.5	0.9	1st generation immigrant from Europe (recruited young sailor?)
12CC-S2 (a)	Und.	12 to 17	Und.	Pm2 & M3	22.4	−12.0	0.12	22.4	−11.3	0.10	0	−0.7	Locally born
12DD-S7	F	18 to 25	Und.	Pm2 & M3	23.1	−12.8	0.13	21.5	−11.3	0.12	1.6	−1.5	Locally born. Left Montreal for more northern/continental region
4 K1	M	18 to 25	Und.	Pm2 & M3	25.9	−11.2	0.12	25.6	−11.8	0.13	−0.3	0.6	1st generation immigrant from warmer/coastal region (Europe?)
12 W-S11(b)	M	18 to 25	Und.	Pm2 & M3	27.5	−14.1	0.14	25.0	−11.7	0.14	2.5	−2.4	1st generation immigrant from warmer/coastal region (Europe?) with diet changes
12Z-S1	M	18 to 25	Und.	Pm2 & M3	22.3	−12.1	0.11	22.7	−13.1	0.10	−0.4	1.0	Locally born

TABLE A1 (Continued)

Skeleton code[a]	Sex[b]	Age group in years	Ancestry[c]	Tooth analyzed[d]	Premolar (Pm)			Third molar (M3)			Δ Pm-M3		Biographical hypotheses[e]
					$\delta^{18}O$ ‰ versus VSMOW	$\delta^{13}C$ ‰ versus VPDB	C/P	$\delta^{18}O$ ‰ versus VSMOW	$\delta^{13}C$ ‰ versus VPDB	C/P	$\delta^{18}O$ ‰	$\delta^{13}C$ ‰	
12CC-S2 (b)	Und.	18 to 25	Und.	Pm2 & M3	24.3	−11.0	0.13	25.1	−10.2	0.15	−0.8	−0.8	1st generation migrant from NNA (warmer/coastal)
12DD-S10	Und.	18 to 25	Und.	Pm2 & M3	23.0	−12.3	0.16	22.5	−12.3	0.14	−0.5	0	Locally born
9B1-S2	F	26 to 40	Und.	Pm2 & M3	26.2	−13.1	0.13	24.3	−12.2	0.12	1.9	−0.9	1st generation immigrant from warmer/coastal region (Europe?)
12AA-S1	F	26 to 40	Und.	Pm1 & M3	26.7	−11.9	0.15	25.2	−11.3	0.14	1.5	−0.6	1st generation immigrant from warmer/coastal region (Europe?) *Fille du Roy?*
12EE-S2	F	26 to 40	Und.	Pm2 & M3	23.6	−13.1	0.16	23.2	−11.2	0.14	0.4	−1.9	Locally born
4B-S1	M	26 to 40	Und.	Pm1 & M3	24.4	−9.9	0.10	22.9	−12.4	0.13	1.5	2.5	1st generation migrant from NNA with C_4 diet (Indigenous?)
12EE-S1	M	26 to 40	Und.	Pm2 & M3	22.7	−11.1	0.11	21.8	−12.8	0.13	0.9	1.7	Locally born
4G-S1	F	>41	Und.	Pm1 & M3	23.3	−12.1	0.13	24.0	−12.5	0.11	−0.7	0.4	Locally born
4H-S1	F	>41	Und.	Pm2 & M3	22.3	−10.1	0.09	21.6	−12.3	0.13	0.7	2.2	Locally born (Indigenous?)
12AA-S5	F	>41	Und.	Pm2 & M3	21.4	−12.4	0.12	21.0	−12.8	n.a	0.4	0.4	1st generation migrant from NNA (continental/northern)
4C-S2	M	>41	Und.	Pm2 & M3	26.0	−10.0	0.14	25.5	−12.1	n.a	0.5	2.1	1st generation immigrant from warmer/coastal area (Europe?), (like 11D-S1?)
12BB-S3	M	>41	Und.	Pm1 & M3	22.2	−12.1	0.12	22.4	−12.9	0.15	−0.2	0.8	Locally born
12DD-S2	Und.	Ind.	Und.	Pm2 & M3	21.3	−11.7	0.10	21.5	−11.5	0.10	−0.2	−0.2	1st generation migrant from NNA (continental/northern)

[a]Underlined skeleton codes correspond to the 16 hypothetical biographies involving mobility (or not for 4H-S1) and presented in the discussion;
[b]F = female; M = male; Und. = undetermined sex or age-at-death.
[c]Und. = undetermined ancestry; PIMA: possibly mainly Indigenous or mixed ancestry (Indigenous and European) according to dental biodistance analysis (B-Hardy, 2015); PE = possibly mainly European according to dental biodistance analysis (B-Hardy, 2015); E = mainly of European ancestry confirmed paleogenetically (Harding et al., 2020).
[d]Pm 1 = first permanent premolar; Pm2 = second permanent premolar; M3 = third permanent molar.
[e]NNA = Northeastern North America.