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Dietary Variability among a Sample of United States Soldiers during the War of 1812

ABSTRACT

The stable carbon and nitrogen isotope ratios of human bone collagen have been used to determine the diet of a sample of United States soldiers who died during the siege of Fort Erie in the War of 1812. Controls were enacted during the analysis to discriminate between well-preserved and contaminated bone. Results from a sample of 15 individuals, recruited from diverse regions of the northeastern United States, indicate that the diet of this population was quite varied. Statistical analysis was used to explore the relationship between diet and skeletal pathologies. There were no significant differences in means between the individuals exhibiting skeletal pathologies and those not exhibiting skeletal pathologies, suggesting the pathologies are more likely tied to the physical hardships endured in these men's civilian or military lives as opposed to their civilian or military diets.

Introduction

Human burials were discovered during the construction of a new housing subdivision in the town of Fort Erie, Canada, during the spring of 1987 (Thomas and Williamson 1991). Construction was immediately halted, and the consulting archaeology firm Archaeological Services Inc. was hired to excavate the Snake Hill site before building resumed. The excavation yielded 28 primary inhumations, an ox burial, and three medical waste pits (Thomas and Williamson 1991). The burials were documented in the field, exhumed, and transferred to the Archaeological Services Inc. laboratories and the Royal Ontario Museum for analysis. The physical examination combined with the artifacts recovered at the site indicated these were U.S. soldiers who had died in 1814 during the British siege of Fort Erie at the end of the War of 1812.

U.S. forces occupied the area around Fort Erie, Canada during the summer and fall of 1814 (Figure 1). The U.S. military campaign in this region began when Brigadier General Winfield Scott's army crossed the Niagara River into Upper Canada and seized the fort on 3 July (Whitehorne 1991). After capturing Fort Erie, the U.S. army marched northward, engaging and defeating the British in the Battle of Chippewa on 5 July. A battered British army retreated north with the U.S. army in pursuit. The two forces clashed again at the battle of Lundy's Lane on 25 July 1814, where the U.S. army was defeated and forced to retreat southward to Fort Erie. The British pursued and initiated

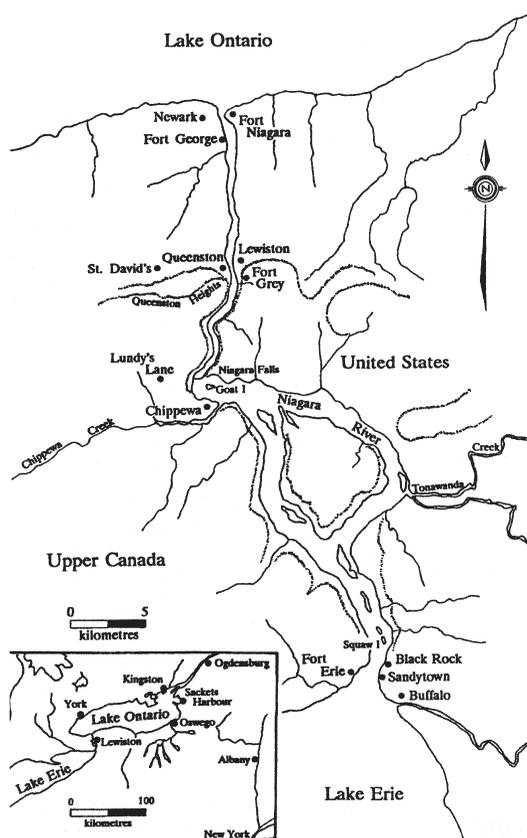


FIGURE 1. The Niagara Frontier in 1814. (Pfeiffer and Williamson 1991.)

a siege of the fort in August. The siege was ultimately unsuccessful and an exhausted British army retreated back to the Chippewa River in September. The U.S. troops continued to occupy Fort Erie in October before abandoning the position in November. The U.S. invasion of Upper Canada resulted in the loss of 2,400 British and 1,800 U.S. soldiers.

The Snake Hill site is located along the shores of Lake Erie, a few hundred meters away from Fort Erie and was the location for Captain Nathan Towson’s battery during the British siege. On August 15th, British troops attacked the Snake Hill location and were repelled by Towson’s battery and the troops of the 21st infantry. The attack resulted in the loss of 1,000 British and 90 U.S. soldiers (Whitehorne 1991). A field hospital was set up in the Snake Hill area to handle the wounded. The 28 individuals recovered from Snake Hill were not casualties of the August 15th battle. They were patients of the field hospital that was set up as a result of the British attack, soldiers who were either wounded or had died as a result of minor skirmishes, British bombardments, or disease after the battle (Litt et al. 1993). They had been transported to the nearby Snake Hill field hospital for treatment. If treatment failed, they were quickly buried in individual or mass graves.

Bone samples of 15 males were retained by Susan Pfeiffer after the repatriation and reburial

of the men of Snake Hill. Extracted collagen from the bone samples was used in laboratory analysis that measured the stable carbon and nitrogen isotopic ratios to explore dietary differences among individuals. A series of controls were enacted to confirm the validity of the laboratory results and the preservation of the sample. The $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of the 15 soldiers were varied and reflect a diverse population recruited from different regions of the northeastern United States. In addition to analyzing the diet of these individuals, statistical analyses were used to find possible differences in diet between those that had and those that did not have evidence of skeletal disease, which was documented by a previous physical analysis of the remains conducted by Douglas Owsley and colleagues (1991).

The Snake Hill Soldiers

The men recovered from the graves at Snake Hill were part of Brigadier General Scott’s army, which included troops from the 5th Pennsylvania Volunteers, the New York militia, and Native American soldiers. Table 1 presents the age estimates of the soldiers, determined by Pfeiffer (1991), and their statures, determined by Shelley Saunders (1991). The average age of males in the sample was 25 years and the average stature was 5 ft. 7 in.

TABLE 1
AGE, HEIGHT, AND EVIDENCE OF PATHOLOGY IN THE SNAKE HILL POPULATION

Burial	Age	Height (ft. and in.)	Periostitis	Ectocranial Porosis	Osteophytosis of the Spine	Depressions
4	28–32	5' 8"	—	—	—	+
5	19–21	5' 4"	—	—	—	+
6	14–16	N/A	—	—	—	—
7	36–38	5' 7"	+	—	+	+
8	19–21	5' 7"	—	—	—	—
10	37–39	5' 6"	—	+	+	—
12	21–23	6' 1"	+	—	—	—
14	34–40	5' 9"	—	—	+	+
16	17–19	6' 1"	—	—	—	+
21	16–18	5' 10"	—	+	—	—
24	27–30	5' 6"	+	—	—	+
26	28–30	5' 7"	—	—	—	+
27	21–23	5' 4"	—	+	—	—
28	18–20	5' 6"	+	—	—	+
29	25+	5' 8"	—	—	—	—

Military recruits from this period were generally either laborers or farmers in their civilian lives (Owsley et al. 1991). While individuals were accustomed to hard physical labor, the life of the soldier was both mentally and physically stressful. The siege of Fort Erie was particularly demanding, as individuals were expected to perform a variety of tasks around the clock under the constant pressure of British bombardment. The work schedule led many soldiers to request certificates of disability for rheumatism, hernias, and hemorrhoids (Whitehorne 1988). The episodic availability of food contributed to the stress. Accessibility to supplies limited the diet of the individual soldiers during the siege campaign. As the siege progressed, rations were limited to salt pork and hard bread with sporadic supplements of vegetables, liquor, and vinegar (Whitehorne 1988). Soldiers could purchase a limited selection of vegetables, prepared foods, and meat from local civilians, but the prices were highly inflated (Whitehorne 1991). The inadequate nutrition, close living conditions, and poor sanitation experienced by soldiers led to periodic outbreaks of typhus, diarrhea, and dysentery, further weakening an already physically stressed population (Whitehorne 1991).

Table 1 documents the physical and nutritional strain of military and civilian life that likely contributed to the skeletal pathologies associated with this sample. Examination of the remains indicated the presence of periostitis of the tibia, fibula, thoracic vertebrae, and frontal bones in 26.67% of the sample (n=15) (Owsley et al. 1991). Previous paleopathological research was unable to determine the time of onset of the bone inflammation for these individuals, making it impossible to label this pathology as occupational (Owsley et al. 1991).

Periostitis is a nonspecific inflammatory response of the bone at the site of a trauma or infection, exhibited by abnormal bone formation on the cortical surfaces. Periostitis can be caused by multiple factors, including infection, trauma, or nutritional deficiencies (Ortner 2003). Nutritional deficiencies and infections can also interact to produce periostitis. In North America, the transition to agriculture, where maize was the primary staple, often resulted in a documented increase in infections that can lead to periostitis (Roberts and Manchester 2005). In populations with vitamin C deficiencies, individ-

uals have reduced abilities to combat infections, absorb iron, and form bodily tissues, especially collagen, which can also lead to periostitis (Roberts and Manchester 2005).

In addition to bone inflammation, there is the presence of ectocranial porosis, expressed as mild pitting around the bregma, the sagittal suture, and squama of the occipital, in 20.00% of the sample (n=15) (Owsley et al. 1991). Ectocranial porosis is often associated with vitamin C and D deficiencies (scurvy and rickets) (Roberts and Manchester 2005). The presence of porous lesions in this sample is believed to be associated with nutritional deficiencies (Owsley et al. 1991). The pathologies were mild and did not exhibit the more pronounced changes associated with cribra orbitalia or porotic hyperstosis, which are associated with anemia caused by malnutrition, chronic blood loss, parasitic infestation, or an increased pathogen load (Owsley et al. 1991; Lewis and Roberts 1997).

The sample also displayed skeletal markers of osteoarthritis of the joint surfaces and osteophytosis of the spine. The occurrence of osteoarthritis of the joint surfaces was low, rarely polyarticular. The level of degenerative change was mild in most cases and largely found on the joint surfaces of the long bones and the pelvis (Owsley et al. 1991). Osteophytosis of the spine, which results in bony outgrowths from the margins of the vertebral body, was more common, with 20.00% of the sample exhibiting these skeletal markers on the thoracic and lumbar vertebrae, as seen in Table 1 (n=15) (Owsley et al. 1991). Like periostitis, the presence of osteoarthritis and osteophytosis is nonspecific, with 80% of cases classified as idiopathic (Aufderheide and Rodriguez-Martin 1998). Both disease and physical trauma (such as occupational stress), however, can lead to degenerative joint disease. It was impossible to determine the ultimate cause of the presence of osteoarthritis and osteophytosis in the Snake Hill population.

The most common skeletal pathologies were Schmorl's depressions of the spine, which were found in 53.33% of the sample (n=15) (Owsley et al. 1991). Schmorl's depressions are lesions in the vertebrae that are the result of both everyday stresses and traumatic injuries (Schmorl and Junghanns 1971). Fifty percent of the individuals exhibiting Schmorl's depressions of the spine

have six or more depressions located on their thoracic and lumbar vertebrae, areas of greatest biomechanical stress (n=15) (Owsley et al. 1991). Occurrences of Schmorl's depressions in this sample are likely associated with the occupational stresses this population endured.

Stable Isotopes and Diet

Isotopes are atoms of one element that differ in the number of neutrons present in their nuclei and, therefore, have the same atomic number but have a different atomic mass. Both carbon and nitrogen have a dominant light isotope, ^{12}C and ^{14}N , and an infrequent, heavier isotope, ^{13}C and ^{15}N (Barrie and Prosser 1996). Carbon and nitrogen isotopic ratios can be measured on a mass spectrometer and are expressed as delta values (δ), which are reported as per mil (‰), or parts per thousand relative to the international standard. The formula is:

$$\delta = 1000 \times (R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}}$$

R_{sample} and R_{standard} are the ratios of the heavy to the light isotope, measured for both the sample and the standard (Barrie and Prosser 1996). The standard is set to 0.00‰. A negative δ means the sample has less of the heavy isotope relative to the standard, whereas a positive δ value means the sample has more of the heavy isotope relative to the standard (Benson et al. 2006).

The application of stable isotopic analyses in the field of anthropology was made possible by early research conducted by plant physiologists and geochemists. Studies found that terrestrial plants are divided into three discrete groups, C_3 , C_4 , and CAM, based upon their photosynthetic pathway (Smith 1972). The environment each terrestrial plant type prefers is unique. The majority of plants consumed by humans are C_3 plants, including cultivated crops such as wheat, rice, beans, tubers, and nuts. C_3 plants favor shaded and moist high latitude and high altitude environments (Ambrose 1990). C_4 plants grow best in sunny, hot, and dry habitats. The C_4 plants comprise about 15.00% of plant species and include human cultivated crops such as maize, amaranth, millet, sugarcane, and marine plants (Pate 1994; Benson et al. 2006). CAM plants are succulents that grow

in arid environments and include plants such as yucca, agave, pineapple, and the prickly pear. The ecosystems necessary to foster CAM growth are limited. The majority of terrestrial plants consumed by humans are either C_3 or C_4 plants.

All plants fix atmospheric CO_2 during photosynthesis. The isotopic composition of a plant depends on the photosynthetic pathway the plant uses to incorporate carbon, nitrogen, oxygen, and hydrogen (Benson et al. 2006). The enzyme used to fix CO_2 differs for each photosynthetic pathway. C_3 plants use the enzyme ribulose biphosphate carboxylase, C_4 plants use phosphoenol pyruvate carboxylase, and CAM plants can use either of these enzymes depending on the environmental cues present (DeNiro 1987). Moreover, during the initial photosynthetic step, the C_3 and C_4 pathways convert CO_2 into a molecule with a different number of carbon atoms. C_3 plants produce a molecule with three carbon atoms and C_4 plants produce a molecule with four carbon atoms (Calvin and Benson 1948; Hatch and Slack 1966).

In addition to the fixation of CO_2 , each of the photosynthetic pathways undergoes isotopic fractionation during photosynthesis. Isotopic fractionation is a change in the isotopic ratios of the product of a reaction relative to the isotopic ratios of the reactants (Nier and Gulbransen 1939). Isotopic quantification of terrestrial plants revealed that C_3 and C_4 plants fractionate stable carbon isotopes in unique ratios (Park and Epstein 1961; Smith and Epstein 1971; O'Leary 1981, 1988). The ratio of ^{13}C to ^{12}C of a sample is measured on a mass spectrometer and expressed relative to a universal standard, the shell of a marine fossil *Belemnitella americana* recovered from the Pee Dee formation in South Carolina. The formula is as follows:

$$\delta^{13}\text{C}_{(\text{PDB})} = \left\{ \left[\frac{^{13}\text{C}/^{12}\text{C}_{\text{sample}}}{^{13}\text{C}/^{12}\text{C}_{\text{PDB}}} \right] - 1 \right\} \times 1000\%$$

C_3 and C_4 plants have nonoverlapping carbon isotopic values. C_3 plants have $\delta^{13}\text{C}$ values that range from -35.00% to -20.00% , and C_4 plants exhibit a range of -16.00% to -7.00% (Deines 1980; O'Leary 1981; Ehleringer 1989). CAM plants can mimic C_3 or C_4 values, depending on the photosynthetic pathway they

utilize; however, they are rare and need only be considered in archaeological research conducted in arid conditions, such as desert regions.

Nitrogen is a second element whose isotopic ratios have been used to differentiate between plant types. Plants absorb and utilize nitrogen from the biosphere. Nitrogen has two stable isotopes, ^{15}N and ^{14}N , that undergo fractionation in plant tissues. The ratio of ^{15}N to ^{14}N in a sample is measured on a mass spectrometer and expressed as a $\delta^{15}\text{N}$ value relative to a universal standard, atmospheric air. The formula is:

$$\delta^{15}\text{N}_{(\text{AIR})} = \left\{ \left[\frac{^{15}\text{N}/^{14}\text{N}_{\text{sample}}}{^{15}\text{N}/^{14}\text{N}_{\text{AIR}}} \right] - 1 \right\} \times 1000\text{‰}$$

The $\delta^{15}\text{N}$ concentration of a plant is dependent on the source of nitrogen. Terrestrial plants acquire nitrogen from atmospheric precipitation, the bacterial decomposition of organic material, and bacterial N_2 fixation. Marine environments acquire nitrogen from the atmosphere, bacteria, and blue green algae. Plants in marine environments exhibit distinctly enriched $\delta^{15}\text{N}$ values relative to their terrestrial counterparts, resulting in discrete $\delta^{15}\text{N}$ ranges for the two. Terrestrial plants have a $\delta^{15}\text{N}$ range of 1.90‰ to 10.00‰, whereas marine plants have a $\delta^{15}\text{N}$ range of 11.70‰ to 22.90‰ (Schoeninger and DeNiro 1984).

Stable carbon and nitrogen isotopic research spread into the field of archaeology in the late 1970s. Archaeologists used the results of isotope analyses to measure the contribution of foods, having different isotopic compositions, to the diets of individuals (Guixé et al. 2006). Early stable carbon isotope analyses of human remains recovered from prehistoric sites, for example, allowed anthropologists to document the onset and spread of maize agriculture in the Americas (Vogel and van der Merwe 1977; Bender et al. 1981). Maize is a C_4 plant with $\delta^{13}\text{C}$ values in the range of -16.00‰ to -7.00‰ (Deines 1980; O'Leary 1981; Ehleringer 1989) while the majority of the plants, in regions where maize grows, are C_3 plants with $\delta^{13}\text{C}$ values in the range -35.00‰ to -20.00‰ (Deines 1980; O'Leary 1981; Ehleringer 1989). The nonoverlapping isotopic ratios allowed researchers to differentiate among isotopic signatures in human bone.

As the use of carbon isotope analysis spread in archaeology, carbon isotope analyses began

to be used to differentiate between marine and terrestrial protein sources in human diets. Fish and marine mammals have $\delta^{13}\text{C}$ values that are 6.00‰ less negative, when compared to animals that feed on C_3 plants, and 7.00‰ more negative, when compared to animals that feed on C_4 plants (Schoeninger and DeNiro 1984; Larsen et al. 1992). Therefore, in areas where C_4 plants are not being consumed, it is possible to detect the human consumption of marine foods (Chisholm et al. 1982; Schoeninger and DeNiro 1983; Larsen et al. 1992).

Nitrogen isotopic ratios also provide information about human diet and subsistence patterns in archaeological contexts. Early nitrogen studies determined the relative contribution of legumes to the diet (DeNiro and Epstein 1981). Legumes have $\delta^{15}\text{N}$ values around 1.00‰ while nonlegumes have values around 9.00‰ (DeNiro 1987; Papathanasiou 2003). $\delta^{15}\text{N}$ values have also been used to discern overall contributions of marine versus terrestrial foods to the diet of past peoples (Schoeninger and DeNiro 1983, 1984). Marine foods have $\delta^{15}\text{N}$ values of 1.90‰ to 10.00‰, and terrestrial foods have values of 11.70‰ to 22.90‰ (Schoeninger and DeNiro 1984; Pate 1994).

Finally, $\delta^{15}\text{N}$ values have allowed researchers to reconstruct the proportion of animal foods consumed by past populations (Ambrose and DeNiro 1986). ^{15}N amasses along the food chain. Each trophic level has a stepwise increase of 2.00‰ to 4.00‰ (Papathanasiou 2003). A mammal's bone collagen is therefore enriched in ^{15}N over the source of protein being consumed, and, consequently, $\delta^{15}\text{N}$ values are 2.00‰ to 4.00‰ higher than expected (Richards et al. 2006). If baseline herbivore and carnivore $\delta^{15}\text{N}$ values are known for an archaeological site, it is possible to use these values to determine whether the human diet was obtained mainly from plant sources (herbivore $\delta^{15}\text{N}$ values), animal sources (carnivore $\delta^{15}\text{N}$ values), or a mixture of the two ($\delta^{15}\text{N}$ values in the middle) (Richards et al. 2006).

The incorporation of stable isotopic research in the field of archaeology is possible because an animal's tissues reflect the isotopic ratios of the foods they consume. The isotopic composition of an animal's bone collagen is directly related to its diet as elements freed by digestion are incorporated into the collagen of that

animal. Controlled animal feeding experiments have shown, however, that the $\delta^{13}\text{C}$ values of bone collagen, which is a protein, are biased towards the protein fraction of an animal's diet (Krueger and Sullivan 1984; Ambrose and Norr 1992; Tieszen and Fagre 1993), with 19% of the carbon atoms in bone collagen coming from essential amino acids that have to be obtained from dietary protein (Klepinger and Mintel 1986; Ambrose 1993). Since dietary animal protein contains all of the essential amino acids, it will likely make a much larger contribution to collagen synthesis than plant protein (Harrison and Katzenberg 2003). The dietary analysis of collagen must be conducted carefully as collagen $\delta^{13}\text{C}$ values can over-represent the dietary importance of ^{13}C foods enriched in protein (such as marine foods) and under-represent ^{13}C foods low in protein (such as maize) (Harrison and Katzenberg 2003).

Another source of potential interpretation error is the isotopic ratios derived from bone collagen and the timeframe these collagen samples represent. Bone collagen comprises more than 90% of the organic matrix of bones and teeth and is less metabolically active than soft tissues (Schoeninger 1995). Therefore, collagen tends to reflect the average isotopic composition of an individual's dietary protein intake over a period of 10 or more years (White and Schwarcz 1994; Privat and O'Connell 2002; Prowse et al. 2005). Normally, human bone is one of the last tissues affected by short-term dietary changes because its cell turnover is slow when compared to soft tissues, such as nails and hair. In times of nutritional stress, however, the stable isotopic ratios of human hair and pathological bone samples have the capacity to record these events (Katzenberg and Lovell 1999; Fuller et al. 2004, 2005). Specifically, $\delta^{15}\text{N}$ values are enriched in animals undergoing nutritional stress due to the recycling of tissue proteins (Hobson et al. 1993; Katzenberg and Lovell 1999). The majority of isotopic ratios will be based on long-term diet; in times of nutritional stress, however, the isotopic ratios can reflect short-term dietary changes in the $\delta^{15}\text{N}$ values.

Analytical Methods

Collagen was extracted in 2003 from the sample of 15 individuals recovered from the

Snake Hill site in Ontario, Canada, using a modified version of the Judith Sealy method (Sealy and van der Merwe 1986) of collagen extraction. The bone samples were cleaned of visible contaminants with a scalpel, rinsed in distilled/deionized water, and dried. The bone was ground into small fragments using a stainless steel mortar and pestle. The mortar and pestle were thoroughly cleaned with a bleach solution between samples. After grinding, 1.50 gm. samples of each of the 15 individuals were placed into 15.00 ml tubes.

The fifteen samples were demineralized in 0.10 M (molar) hydrochloric acid at room temperature. The hydrochloric acid removes carbonates, phosphates, acid soluble substances, and fulvic acids (Ambrose 1990). The acid solution was changed daily, and the samples were placed on a laboratory tube rocker to allow for even distribution of the aqueous solution. Sample appearance was checked daily for translucence, an indication of demineralization. The average acid soak lasted five days. At the end of the demineralization process, the samples were placed in a 0.10 M sodium hydroxide wash for 24 hours. The sodium hydroxide removes humic acids and most of the lipids present in the bone (Ambrose 1990). After the sodium hydroxide was removed, the samples were washed in distilled and deionized water for five days. Each sample was freeze-dried after the five-day water rinse. The carbon and nitrogen isotopic ratios were measured on a Carlo Erba 1500 elemental analyzer attached to a Finnigan MAT Delta plus XL Mass Spectrometer through a ConFlo III continuous flow interfacer (measured at Oregon State University in the College of Oceanic and Atmospheric Sciences).

C/N Ratios

Postdepositional contamination and diagenesis, or postdepositional modification, of human bone is a common problem. A series of methods was used to screen samples prior to data interpretation. The atomic ratio of carbon to nitrogen in collagen is one method for identifying the presence of noncollagenous residues and diagenesis in bone collagen (DeNiro 1985). Collagen extracted from modern animals has a C/N ratio of around 3.20 (Ambrose 1990; Pate 1998; Hutchinson and Norr 2006). The range

of acceptable C/N ratios for preserved animal and human remains is between 2.60 and 3.60 (Schoeninger 1989; Richards et al. 2002; Tuross 2002; Hutchinson and Norr 2006). Samples that fall outside of this range tend to have uncharacteristically high $\delta^{15}\text{N}$ levels and somewhat abnormal $\delta^{13}\text{C}$ levels (White and Schwarz 1994). The C/N ratios for the 15 samples are listed in Table 2. All 15 of the samples exhibited C/N ratios that fell within the range of 2.60 and 3.40. The average C/N ratio for the group was 2.80 ($n=15$, $sd=0.40$).

Collagen, Carbon, and Nitrogen Concentrations

The weight percentage of collagen and the carbon and nitrogen concentrations in bone also provide information regarding sample integrity (Table 2). Modern human bone collagen concentrations range from 0.10% to 22.20% by weight (Ambrose 1990; Collins et al. 2002). The transition between well-preserved and diagenetically altered human bone samples occurs around the range of 1.20% to 1.80% (Ambrose 1990; Privat and O'Connell 2002; Papathanasiou 2003). Samples exhibiting collagen concentrations below 1.80% tend to be poorly preserved and are coupled with atypical C/N ratios, indicating the presence of noncollagenous residues. All 15 of the samples studied exhibited acceptable

collagen concentrations. The average collagen concentration was 19.00% ($sd=0.02$).

Table 2 expresses carbon and nitrogen concentrations of the bone collagen as weight %C and weight %N. Modern animal bones have carbon concentrations of 15.30%–47.00% by weight and nitrogen concentrations of 5.50%–17.30% (Ambrose 1990; Richards et al. 2000; Privat and O'Connell 2002). Carbon and nitrogen concentrations that drop below 6.60% and 1.90% respectively, by weight, tend to exhibit low collagen concentrations and low C/N ratios, indicating poor preservation (Ambrose and Norr 1992; Richards et al. 2000; Privat and O'Connell 2002). All 15 samples exhibit carbon and nitrogen concentrations well within the expected range. The average carbon concentration value for the studied population is 41.99% ($sd=3.42$) and the average nitrogen concentration value is 15.15% ($sd=1.29$).

Infrared Spectra

Infrared spectroscopy is an independent means for differentiating between well-preserved and diagenetically altered bones prior to analysis (DeNiro and Wiener 1988; Liden et al. 1995; Michel et al. 2006). Infrared spectra for collagen extracted from unaltered bone include three strong absorption peaks: a proline peak at 1453 cm^{-1} , an amide I peak around 1650 cm^{-1} , and

TABLE 2
STABLE ISOTOPE RESULTS FOR THE SNAKE HILL POPULATION

Burial	Sample no.	Collagen (wt. %)	Nitrogen (wt. %)	Carbon (wt. %)	C:N ratio	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
4	12	19	16.29	44.62	2.74	8.69	-15.01
5	13	17	14.85	41.01	2.76	11.85	-20.16
6	14	22	15.27	41.55	2.72	9.56	-16.45
7	15	18	15.87	44.57	2.81	10.54	-16.69
8	16	15	15.46	42.07	2.72	10.37	-16.82
10	17	19	12.53	34.80	2.78	9.92	-15.10
12	18	22	11.94	33.73	2.83	10.45	-17.74
14	19	15	16.84	46.26	2.75	10.17	-17.01
16	20	20	15.56	42.75	2.75	9.75	-15.85
21	27	22	15.40	42.22	2.74	9.11	-18.05
24	21	18	15.37	44.20	2.88	10.20	-17.31
26	26	17	15.43	43.01	2.79	9.19	-18.87
27	22	17	15.93	43.59	2.74	11.70	-15.45
28	23	20	15.40	42.38	2.75	10.77	-13.87
29	28	21	15.78	43.65	2.77	11.16	-13.57

an amide II peak around 1540 cm^{-1} (DeNiro and Weiner 1988). Well-preserved samples also exhibit an adsorption peak at 1050 cm^{-1} , and poorly preserved collagen samples exhibit a dominant absorption peak at 1100 cm^{-1} (DeNiro and Weiner 1988).

The infrared spectra of the samples were measured on a benchtop Midac infrared spectrometer employing Grams 32 software ($n=15$). Bone samples were ground in a mortar and pestle with potassium bromide. The ground material was pressed into pellets and placed into the spectrometer for infrared analysis. The spectrum of the potassium bromide was subtracted from the collagen spectrum by a computer. The Snake Hill population displayed strong absorption peaks at 1650, 1540, and 1453, in addition to a strong adsorption peak at 1050, indicating that these samples are well preserved.

Results and Discussion

A previous stable isotopic analysis of the Snake Hill sample, conducted in 1991 by M. Anne Katzenberg, used the DeNiro and Epstein (1978) method of collagen extraction ($n=29$). This collagen extraction method required the bone to be dissolved in 1 molar hydrochloric acid, soaked in a weak sodium hydroxide solution, and then hydrolyzed in slightly acidic hot water before being freeze-dried and analyzed by mass spectrometry (Katzenberg 1991). The primary objective of this study was a stable isotopic analysis of a sample of soldiers from the War of 1812 and an exploration of the relationship between diet and pathology in this population. A secondary goal of the present analysis was to determine if differing methodologies and a 12-year gap in mass spectrometer technology (1991–2003) produced similar stable isotopic ratios (Richards et al. 2003).

Katzenberg's 1991 stable isotope analysis yielded a mean $\delta^{13}\text{C}$ value of -15.80‰ ($sd=1.3$), overlapping with and nearly identical to $\delta^{13}\text{C}$ mean value of -16.07‰ ($sd=1.87$) of this analysis (Katzenberg 1991). Katzenberg does not provide a mean $\delta^{15}\text{N}$ value but does state that the main cluster of $\delta^{15}\text{N}$ values range between 9.60‰ and 11.80‰ (Katzenberg 1991). The mean $\delta^{15}\text{N}$ value of this analysis was 10.20‰ ($sd=0.89$), falling within Katzenberg's main cluster of $\delta^{15}\text{N}$ values. The Michael DeNiro and

Samuel Epstein (1978) and Judith Sealy and Nikolaas van der Merwe (1986) methods have yielded overlapping results, reinforcing the validity of both methodologies of collagen extraction. Furthermore, this analysis conducted a series of controls (C/N ratios, collagen, carbon, and nitrogen concentrations, and infrared spectra analysis) to guarantee the absence of postdepositional contamination and modification, thus ensuring the validity of the stable isotopic ratios.

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of this analysis are represented in Figure 2. The average $\delta^{13}\text{C}$ value for the sample was -16.07‰ ($sd=1.87$). The majority of the sample exhibits stable carbon isotopic ratios that are indicative of the consumption of both C_3 and C_4 plants. However, Burial 5 has a $\delta^{13}\text{C}$ value of -20.16‰ , a value clearly within the -35.00‰ to -20.00‰ range of C_3 plant consumers. Burials 4, 10, 16, 27, 28, and 29 have $\delta^{13}\text{C}$ values that fall within the -16.00‰ to -7.00‰ range of C_4 plant consumers (Deines 1980; O'Leary 1981; Ehleringer 1989).

The observed dietary heterogeneity is expected, as human bone collagen reflects the average isotopic composition of an individual's dietary protein intake over a period of 10 or more years (White and Schwarcz 1994; Privat and O'Connell 2002; Prowse et al. 2005). The United States Army consisted primarily of militia who were recruited from Pennsylvania and New York a few months prior to the Fort Erie

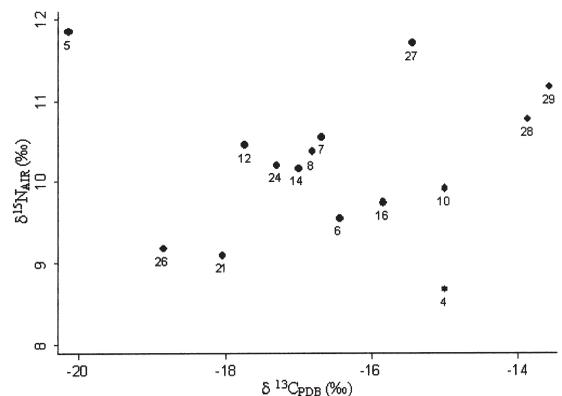


FIGURE 2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the Snake Hill soldiers. $\delta^{15}\text{N}$ values from 1‰ to 9‰ are terrestrial plants and 11.7‰ to 22.9‰ values are marine plants. $\delta^{13}\text{C}$ values -35‰ to -20‰ are C_3 plants and -16‰ to -7‰ are C_4 plants. (Graph by authors, 2005.)

campaign (Whitehorne 1991). Their civilian, regional diets were diverse. Plant staples from these regions, which these individuals and their livestock consumed, included wheat and rice (C_3 plants) or maize (a C_4 plant) (Katzenberg 1991). The range of $\delta^{13}C$ values is likely a reflection of the regional, long-term diet of each man and not the short-term diet they shared as soldiers.

While the $\delta^{15}N$ values were less variable than the $\delta^{13}C$ measures, these values are indicative of dietary diversity. The mean $\delta^{15}N$ value was 10.20‰ (sd=0.89). The $\delta^{15}N$ values of burials 5 and 27 lay within the 11.70‰ to 22.90‰ range of marine consumers (Schoeninger and DeNiro 1984; Pate 1994). Individuals 4, 6, 10, 16, 21, and 26 have $\delta^{15}N$ values that lay within the 1.90‰ to 10.00‰ range of terrestrial consumers (Schoeninger and DeNiro 1984). The remaining members of the Snake Hill population had a mixed diet of marine and terrestrial foods. It is unlikely that nutritional stress altered observed $\delta^{15}N$ values, as this analysis used normal, non-pathological bone samples. Hence, the $\delta^{15}N$ and $\delta^{13}C$ values indicate that the diets of these men were as diverse as their geographic origins.

In addition to determining the contribution of C_3 , C_4 , marine, and terrestrial foods to the diet of the sample series via carbon and nitrogen isotopic analysis, statistical analyses explored the relationship between diet and the presence or absence of paleopathologies. This population was under great physical duress during the siege of Fort Erie in 1814. Physical strain or occupational stresses may have been the cause of several of the observed skeletal afflictions; however, the availability of food choices during the siege or during civilian life may have also contributed to the formation of pathological lesions. The previously conducted paleopathological study documents the presence/absence of periostitis and ectocranial porosis in the Snake Hill population (Owsley et al. 1991), two skeletal pathologies that can result from nutritional deficiencies.

Student t-tests were used to determine whether $\delta^{13}C$ and $\delta^{15}N$ means of the sample exhibiting periostitis and ectocranial porosis were significantly different from the means of the sample that did not exhibit pathologies. There were no significant differences in means between those individuals with pathologies and those without

pathologies. It is important to note that despite the small sample size ($n=15$), t-tests can be conducted. The small sample size, however, affects the precision of the estimates, or how close the estimator is expected to be to the true value of the parameter.

The diversity of each individual's background, their short-term military service, the chronic nature of pathology, and a small sample size made it impossible to find statistically significant differences in the means of individuals with varied diets and the concomitant presence/absence of skeletal pathologies. Prospective research using larger, more homogenous populations from the War of 1812, however, could reveal existing correlations between pathology and diet, allowing researchers to answer important questions regarding the diet, health, and status of individuals living in this historic period. Future research should also be conducted on the influence of nutritional stress on stable isotopic ratios in nonpathological, human bone samples. Preliminary studies have demonstrated that $\delta^{15}N$ values are enriched by 2.00‰ in individuals undergoing nutritional stress due to the recycling of tissue proteins in pathological segments of bone (Hobson et al. 1993; Katzenberg and Lovell 1999). The results of new analyses on nonpathological bone samples could have important implications for the interpretation of $\delta^{15}N$ values for any population undergoing nutritional stress.

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