

Dogs as Analogs in Stable Isotope-Based Human Paleodietary Reconstructions: A Review and Considerations for Future Use

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Abstract In contexts where human remains are scarce, poorly preserved, or otherwise unavailable for stable isotope-based paleodietary reconstruction, dog bone collagen as well as other tissues may provide a suitable proxy material for addressing questions relating to human dietary practices. Inferences drawn from applications of this “canine surrogacy approach” (CSA) must be made with caution to ensure the accuracy and transparency of conclusions. This paper shows that CSA applications are essentially analogical inferences which can be divided into two groups that provide specific types of information and may require different levels of substantiation. A framework of three categories of factors is outlined to aid in establishing positive, negative, and neutral elements of comparison of dog and human diets. CSA applications may benefit from explicitly detailing the type and nature of the analogical reasoning employed and from providing a systematic assessment of the degree to which stable isotope values of dogs and humans under comparison are thought to be like, unlike, or of unknown likeness.

Keywords Dogs · Paleodiet · Human proxy · Stable isotopes

Introduction

Reconstructing diet is an important part of archaeological efforts to understand past lifeways. As new questions and complications are addressed, the archaeologist’s toolbox for paleodietary reconstruction becomes diversified. Stable isotope analysis is now included in this toolbox as a well-established technique for reconstructing ancient dietary regimes (Katzenberg 2008). Based on the premise that “you are what you eat” and that different foods can have distinctive isotopic compositions, researchers analyze stable carbon and nitrogen isotope ratios preserved within

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different human tissues to deduce broad trends in human diet. This method of analysis offers an otherwise unobtainable direct evidence of ancient subsistence practices and nutrition. While valuable, the technique is destructive and, for this reason, has led to concerns among various academic, non-academic, and indigenous communities regarding the ethical treatment of ancestrally and scientifically important human remains (Hublin *et al.* 2008; Katzenberg 2001; Walker 2008:25–26).

In response to legislation such as the Native American Graves Protection and Repatriation Act in the USA, archaeologists contending with issues of the inaccessibility of human remains for stable isotope-based paleodietary reconstruction have sought a proxy for human materials. A group of applications here termed the “canine surrogacy approach” (CSA) is one such alternative. This approach analyzes archaeological domesticated dog (*Canis familiaris*) remains in order to offer some indication of their human keepers’ dietary practices (*e.g.*, Cannon *et al.* 1999), the premise being that dogs were likely provisioned with scraps from human meals and feces and thus could have shared an isotopically similar diet with contemporaneous humans.

Indications that stable isotope information from dog remains might provide a surrogate material for their human keepers were first presented in the late 1970s. Based on stable carbon isotope values derived from 12 hair and bone collagen samples from mainly Peruvian dogs, Burleigh and Brothwell (1978) were able to suggest a diet of maize and argued that this isotopic information provides circumstantial evidence that contemporaneous humans had been practicing agriculture. Several publications making similar observations followed in the 1980s (*e.g.*, Katzenberg 1988, 1989; Murray and Schoeninger 1988:164). The first CSA application was published in 1988 by Noe-Nygaard who showed dietary similarities based on stable carbon isotope information from both humans and dogs at inland and coastal sites spanning the Neolithic and Mesolithic in Denmark. These observations she suggested provide a case for the supplementary use of dog remains in stable isotope-based human paleodietary reconstructions. The most often cited and clear early use of the CSA was that conducted by Cannon and colleagues in 1999 (Cannon *et al.* 1999). Outlined in greater depth below, this application showed how stable isotope information from dogs derived from periods in which no human remains are available can allow for the identification of changes in human dietary trends at a coastal marine-oriented hunter-gatherer site in western Canada.

The CSA, in its most basic formulation, is a theory through which dogs can be viewed as a form of dietary analogy for contemporaneous humans. To be clear, an analogy is created by selectively transposing information from a source to a subject “on the basis of comparison that, fully developed, specifies how the terms compared are similar, different, or of unknown likeness.... These dimensions of comparison establish positive, negative and neutral components of analogy” (Wylie 2002:147). Strong analogical inferences take the relevance of each piece of information into account, thus considering some factors as more, or less, important than others. In the context of CSA applications, the terms “subject” and “source” refer to associated humans and dogs, respectively. The measure of comparison is the degree of congruency of their bone collagen stable isotope values. This is further elaborated in later sections.

Unlike more traditional uses of analogy in archaeological interpretation which tend to be ethnographical (see Ascher 1961; Orme 1974; Wylie 2002:136–153), the CSA presents a relatively unique case in which the analogy made is essentially biological. The CSA analogy relies on biochemical and other assumed metabolic similarities, yet is simultaneously influenced by cultural, environmental, and biobehavioral factors. The unusual problems posed by the unique and complex analogical nature of CSA inferences are rarely addressed in the literature (for some examples, see Allitt *et al.* 2008; Cannon *et al.* 1999; Eriksson and Zagorska 2003; Noe-Nygaard 1988; Tankersley and Koster 2009; White 2004). Very little work has been done toward surveying and cohesively summarizing potential issues which might arise during CSA interpretations.

In response to apparent wholesale cautioning of CSA use (*e.g.*, Bocherens *et al.* 2000; Eriksson 2004; Eriksson and Zagorska 2003:160–162), this paper explores the analogical nature of CSA applications and attempts to show why such considerations are necessary for producing more convincing interpretations of ancient human diet. Although dog and human bone collagen stable isotope values generally track one another to varying extents independent of spatial, temporal, or cultural context, there is a need for CSA authors to explicitly consider the different ways in which dogs can be used to provide information on human dietary practices and the factors which can influence human–dog proxy relationships. Examining different CSA applications in terms of their unique analogical context indicates how varying applications provide different kinds of information and, in turn, may require different sets of qualifying considerations. These considerations may be critical when formulating compelling CSA interpretations. A discussion of these and the factors influencing the strengths or weaknesses of CSA inferences follows.

Stable Isotope Theory Background

The interpretation of stable carbon and nitrogen isotope values draws on well-established understandings of stable isotope ecology. Stable carbon isotope ratios ($\delta^{13}\text{C}$) mainly reflect relative proportions of plants with distinctive C3 and C4 photosynthetic pathways contributing to dietary intake either through direct consumption of plant materials or indirectly through animal consumption (Schwarcz and Schoninger 1991). Stable carbon isotope values, however, can also provide evidence of the consumption of foods deriving from marine or freshwater ecosystems (Schwarcz and Schoninger 1991). Stable nitrogen isotope ratios ($\delta^{15}\text{N}$) generally show a stepwise increase of between 3‰ and 5‰ with each ascending trophic level of the food web and are thus, at a basic level, capable of differentiating herbivorous, omnivorous, and carnivorous diets (for review, see Bocherens and Drucker 2003; Hedges and Reynard 2007; Sponheimer *et al.* 2003a). Predominantly marine-derived diets can also be differentiated from terrestrial-focused diets based on $\delta^{15}\text{N}$ values as marine ecosystems can have much longer food chains (Chisholm *et al.* 1982; Schoeninger *et al.* 1983). It is important to note that these general relationships used for interpreting $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values have not been developed from controlled experiments on humans or dogs and that a small degree of uncertainty remains when using the above conventions to assess ancient

diet. For a review of these and other factors which can influence $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, see Katzenberg (2008) and Sealy (2001).

Basic background information on the nature of bone collagen is also necessary for the interpretation of stable isotope values. Research has indicated that stable isotope values of bone collagen primarily reflect the protein component of diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). In addition, bone collagen remodels slowly over a long period of time. While turnover rates vary between bones, individuals, stage of life, and species, it is generally thought that stable isotope values of human bone collagen from a specimen of adult cortical bone may reflect up to or more than 20 years of dietary intake (Geyh 2001; Hedges *et al.* 2007; Wild *et al.* 2000).

Dog–Human Dietary Relationships: A Cross-Contextual Overview

Since early indications that dogs' bone collagen and hair can have $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reflecting human foods (Burleigh and Brothwell 1978; Clutton-Brock and Noe-Nygaard 1990; Katzenberg 1989; Murray and Schoeninger 1988:164; Noe-Nygaard 1988), researchers have increasingly used dog remains to address questions related to human dietary practices (Allitt *et al.* 2008; Barton *et al.* 2009; Black 2003; Cannon *et al.* 1999; Chilton *et al.* 2001; Choy and Richards 2009, 2010; Choy *et al.* 2010; Grier 2006:132–133; Hogue 2002, 2003; Noe-Nygaard 1995:245; Rick *et al.* 2011; Schulting and Richards 2002, 2009; Tankersley and Koster 2009; White *et al.* 2001). In addition to these materials, researchers have also begun to investigate the use of apatite from dog tooth enamel (Allitt *et al.* 2008; Chilton *et al.* 2001; Pechenkina *et al.* 2005; Prowse *et al.* 2004) as well as collagen from tooth dentine (Allen and Craig 2009; Chilton *et al.* 2001; Eriksson and Zagorska 2003:162). Furthermore, expanding investigations of dog materials have included the analysis of additional stable isotope systems such as sulfur and oxygen (*e.g.*, Chilton *et al.* 2001; Nehlich and Richards 2009; Privat *et al.* 2007).

A substantial number of studies including human and dog bone collagen isotope values indicate general similarities (within 2–3‰ of associated human data clusters in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) in various cultural and temporal contexts in many areas of the world (Table 1). To illustrate this, Fig. 1 combines stable isotope data from all studies (known to the author) which included at least five humans and five dogs collected from the same site and general time period. Selection criteria for comparison focused on data deriving from bone collagen for which both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are available. Additionally, due to the variation in $\delta^{15}\text{N}$ values of younger individuals resulting from the weaning effect (*e.g.*, Schurr 1998), only data from adults were included. As very few studies have offered indication of dog ages, this criterion was only applied to human data. To include data representing regions for which fewer paleodietary reconstructions have been conducted, certain selection criteria have been waived on a case-by-case basis (details in Table 2). While these criteria do not provide a strictly random sampling of comparative data, there has been no active selection for studies with particularly similar dog and human data; for this reason, comparisons can be considered relatively unbiased.

It is difficult to quantify human–dog dietary similarities from these comparative data because the dimensions of dog and human associations as well as the methods

Table 1 List of studies including human and dog $\delta^{13}\text{C}$ and/or $\delta^{15}\text{N}$ values indicating general similarities (within 2–3‰ of associated human data clusters in both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) across various cultural and temporal contexts

Region	References
Africa	Mosothwane (2010:132)
Americas	Allitt <i>et al.</i> (2008); Berón <i>et al.</i> (2009); Berry (1992); Burleigh and Brothwell (1978); Cannon <i>et al.</i> (1999); Chilton <i>et al.</i> (2001); Coltrain (2009); Corr <i>et al.</i> (2009); DeBoer and Tykot (2007); Gerry (1993:200, 216, 1997); Gerry and Kruger (1997:201, 202); Hogue (2002, 2003); Guiry (2009); Guiry and Grimes (2010); Katzenberg (1988, 1989, 2006:266); Katzenberg and Kelly (1991:212); Rick <i>et al.</i> (2011); Tankersley and Koster 2009; White (2004); White <i>et al.</i> (1993, 2001, 2004:156, 2006:145)
Asia	Atahan <i>et al.</i> (2011); Barton <i>et al.</i> (2009); Bocherens <i>et al.</i> (2006); Choy and Richards (2009, 2010); Choy <i>et al.</i> (2010); Chu (1994:39); Hollund <i>et al.</i> (2010); Katzenberg <i>et al.</i> (2010:185); Kusaka <i>et al.</i> (2008); Losey <i>et al.</i> (2011); Pechenkina <i>et al.</i> (2005); Webber <i>et al.</i> (2009)
Europe	Bocherens <i>et al.</i> (2007); Bösl <i>et al.</i> (2006); Le Bras-Goude and Clauster (2009); Chenery <i>et al.</i> (2011); Craig <i>et al.</i> (2009); Eriksson <i>et al.</i> (2008); Fischer <i>et al.</i> (2007a, b); Formander <i>et al.</i> (2008); Fuller <i>et al.</i> (2010); Hakenbeck <i>et al.</i> (2010); Hedges <i>et al.</i> (2008); Herrscher and Le Bras-Goude (2010); Honch <i>et al.</i> (2006); Jay and Richards (2006, 2007:174); Jørkov <i>et al.</i> (2010); Keenlyside <i>et al.</i> (2009); Kosiba <i>et al.</i> (2007); Lightfoot <i>et al.</i> (2009); Müldner and Richards (2005, 2007); Murray and Schoeninger (1988:164); Noe-Nygaard (1988, 1995:245); Petrousta and Manolis (2010); Prowse <i>et al.</i> (2004); Redfern <i>et al.</i> (2010); Richards <i>et al.</i> (2003); Schulting and Richards (2000: 57, 2002, 2009); Stevens <i>et al.</i> (2010); Van Strydonck <i>et al.</i> (2009)
Oceania	Allen and Craig (2009); Craig (2007, 2009:225); Jones and Quinn (2009); Valentine <i>et al.</i> (2006)
Studies with disparate values	Borić <i>et al.</i> (2004); Byers <i>et al.</i> (2011); Dürrwächter <i>et al.</i> (2006); Jones and Quinn (2009); Thompson <i>et al.</i> (2005, 2008); Richards <i>et al.</i> (2009)

Studies from all regions indicating more disparate stable isotope values between humans and dogs are also included

for collagen extraction and analysis vary between studies. Nonetheless, Fig. 1 clearly suggests that dog stable isotope values often, to varying extents, track those of their human keepers in many contexts across temporal, cultural, and geographical boundaries. This provides supporting evidence for suggestions that dogs have a food-sharing relationship with humans.

Some researchers have offered qualitative observations to characterize general relationship trends between human and dog bone collagen stable isotope values. Most commonly noted are observations that dog remains may consistently produce lower $\delta^{15}\text{N}$ values (Allitt *et al.* 2008; Cannon *et al.* 1999; Hogue 2003; Katzenberg 2006:266; Katzenberg *et al.* 2010:185; Kusaka *et al.* 2008), of perhaps a trophic level reduction, relative to humans. Hypotheses regarding the impetus for this relationship include trophic level shifts due to human consumption of dog meat (Richards *et al.* 2009), the canid practice of caceaotrophy (Allitt *et al.* 2008; Cannon *et al.* 1999), and possible intrinsic differences between human and dog metabolism and tissue isotope incorporation (Cannon *et al.* 1999; Clutton-Brock and Noe-Nygaard 1990; Jay and Richards 2006). These factors are discussed below. Data

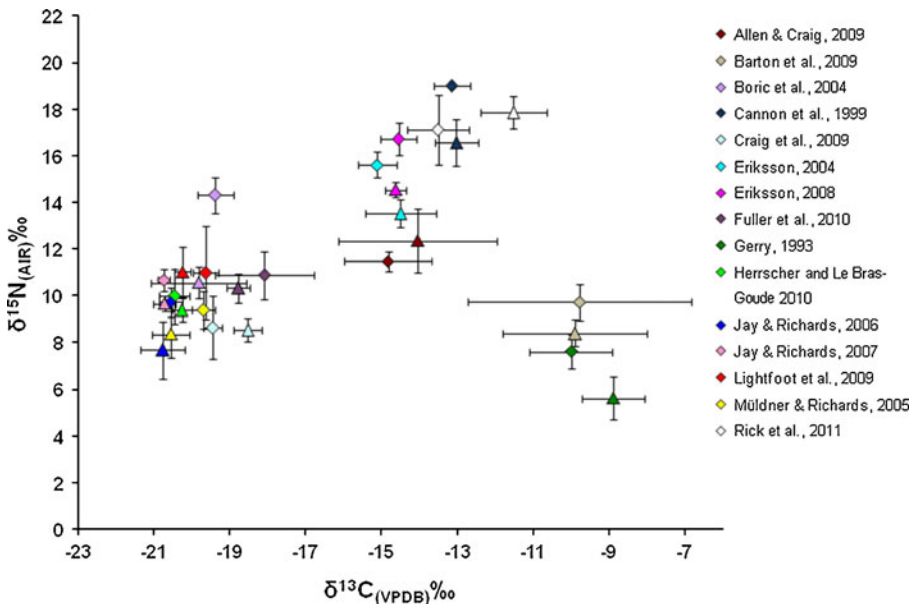


Fig. 1 Human (diamonds) and dog (triangles) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data means color-coded according to source. Error bars show one standard deviation. Table 2 provides background information on each study. Available collagen quality indicators including collagen yield and C/N (Van Klinken 1999) were considered in data selection

compiled in Fig. 1 show an average difference of $-1.16 \pm 1.28\text{‰}$ (1σ , all data) between mean dog and human $\delta^{15}\text{N}$ values, which agrees with the suggestion that dogs often produce $\delta^{15}\text{N}$ values which are lower relative to humans. Despite similar trends between many other studies (see also Bösl *et al.* 2006; Coltrain 2009; Fornander *et al.* 2008; Hollund *et al.* 2010; Jay and Richards 2006; Jørkov *et al.* 2010; Katzenberg 1989; Katzenberg and Kelly 1991:212; Losey *et al.* 2011; Müldner and Richards 2005, 2007; Schulting and Richards 2000:57), Fig. 1 also indicates that under some circumstances, dogs have very close to, or even higher, $\delta^{15}\text{N}$ values relative to their human keepers (see also Le Bras-Goude and Claustre 2009; Lightfoot *et al.* 2009; Lössch *et al.* 2006; Murray and Schoeninger 1988:160; Tankersley and Koster 2009). Trends in offsets between human and dog $\delta^{13}\text{C}$ values have also been commented on (*e.g.*, Lightfoot *et al.* 2009; Rick *et al.* 2011), but have remained less theorized. From Fig. 1, aside from being generally similar and producing an average difference of $0.19 \pm 0.77\text{‰}$ (1σ , all data), there appears to be little consistency in the relative relationship of $\delta^{13}\text{C}$ values between dogs and humans.

A lack of contextual information on the archaeological association between dogs and humans has made it difficult to assess the presence of trends in human and dog dietary similarities between the groups shown in Fig. 1. Table 2 shows the mean stable isotope values for each group of associated dogs and humans, and Fig. 2 shows the difference between their mean values. Considering the points made in “A Categorical Framework for Approaching Comparative Dimensions of CSA Analogies” below, there does not appear to be any trends between groups with differing modes of subsistence or in differing environmental contexts. For instance,

Table 2 Background information on studies contributing human and dog bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data in Fig. 1

Source	Location	Notes	Dog (n)	Human (n)	Dog mean values (%)	Humans mean values (%)	Difference in mean dog and human values
Allen and Craig (2009)	Aitutaki, S. Cook Is.	Some dog values derive from dentine.	11	8	$\delta^{13}\text{C}$ -14.05±2.08 $\delta^{15}\text{N}$ 12.35±1.35	$\delta^{13}\text{C}$ -14.83±1.15 $\delta^{15}\text{N}$ 11.46±0.41	$\delta^{13}\text{C}$ 0.78‰ $\delta^{15}\text{N}$ 0.89‰
Barton <i>et al.</i> (2009)	N.W. China	Dogs included are associated with general phase from which human values are given.	6	6	$\delta^{13}\text{C}$ -9.90±1.91 $\delta^{15}\text{N}$ 8.40±0.57	$\delta^{13}\text{C}$ -9.78±2.96 $\delta^{15}\text{N}$ 9.72±0.79	$\delta^{13}\text{C}$ -0.12‰ $\delta^{15}\text{N}$ -1.32‰
Borić <i>et al.</i> (2004)	Serbia		10	31	$\delta^{13}\text{C}$ -19.82±1.26 $\delta^{15}\text{N}$ 10.56±0.68	$\delta^{13}\text{C}$ -19.38±0.48 $\delta^{15}\text{N}$ 14.31±0.78	$\delta^{13}\text{C}$ -0.43‰ $\delta^{15}\text{N}$ -3.76‰
Cannon <i>et al.</i> (1999)	W. Canada	Human $\delta^{13}\text{C}$ values from Chisholm <i>et al.</i> (1983) and $\delta^{15}\text{N}$ values from unpublished data (Schwarcz <i>et al.</i> , n.d., as per Cannon <i>et al.</i> 1999:404). No standard deviation given	15	13	$\delta^{13}\text{C}$ -13.02±0.56 $\delta^{15}\text{N}$ 16.56±0.67	$\delta^{13}\text{C}$ -13.15±0.47 $\delta^{15}\text{N}$ 19.00	$\delta^{13}\text{C}$ 0.12‰ $\delta^{15}\text{N}$ -2.44‰
Craig <i>et al.</i> (2009)	S. Italy		6	116	$\delta^{13}\text{C}$ -18.52±0.37 $\delta^{15}\text{N}$ 8.53±0.50	$\delta^{13}\text{C}$ -19.44±0.25 $\delta^{15}\text{N}$ 8.65±1.33	$\delta^{13}\text{C}$ 0.92‰ $\delta^{15}\text{N}$ -0.12‰
Eriksson (2004)	Gotland, Sweden		13	20	$\delta^{13}\text{C}$ -14.49±0.93 $\delta^{15}\text{N}$ 13.54±0.60	$\delta^{13}\text{C}$ -15.12±0.51 $\delta^{15}\text{N}$ 15.60±0.55	$\delta^{13}\text{C}$ 0.63‰ $\delta^{15}\text{N}$ -2.06‰
Eriksson, <i>et al.</i> (2008)	Öland, Sweden	Individuals from Kópingsvik shown.	9	15	$\delta^{13}\text{C}$ -14.62±0.28 $\delta^{15}\text{N}$ 14.54±0.32	$\delta^{13}\text{C}$ -14.55±0.46 $\delta^{15}\text{N}$ 16.72±0.71	$\delta^{13}\text{C}$ -0.07‰ $\delta^{15}\text{N}$ -2.18‰
Fuller <i>et al.</i> (2010)	Ibiza, Spain		23	21	$\delta^{13}\text{C}$ -18.78±0.31 $\delta^{15}\text{N}$ 10.33±0.63	$\delta^{13}\text{C}$ -18.09±1.31 $\delta^{15}\text{N}$ 10.88±1.02	$\delta^{13}\text{C}$ -0.70‰ $\delta^{15}\text{N}$ -0.55‰
Gerry (1993)	W. Honduras	Only individuals from Copán shown here. Human data may include very young individuals	9	15	$\delta^{13}\text{C}$ -8.90±0.83 $\delta^{15}\text{N}$ 5.62±0.91	$\delta^{13}\text{C}$ -10.00±1.09 $\delta^{15}\text{N}$ 7.62±0.73	$\delta^{13}\text{C}$ 1.10‰ $\delta^{15}\text{N}$ -2.00‰
Herrscher and Le Bras-Goutte (2010)	S. France	Individuals from Cugnaux shown.	5	8	$\delta^{13}\text{C}$ -20.26±0.27 $\delta^{15}\text{N}$ 9.40±0.51	$\delta^{13}\text{C}$ -20.46±0.41 $\delta^{15}\text{N}$ 9.98±1.19	$\delta^{13}\text{C}$ 0.20‰ $\delta^{15}\text{N}$ -0.58‰
Jay and Richards (2006)	E. UK		6	56	$\delta^{13}\text{C}$ -20.77±0.60 $\delta^{15}\text{N}$ 16.56±0.67	$\delta^{13}\text{C}$ -20.56±0.31 $\delta^{15}\text{N}$ 19.00	$\delta^{13}\text{C}$ -0.20‰ $\delta^{15}\text{N}$ -2.44‰

Table 2 (continued)

Source	Location	Notes	Dog (n)	Human (n)	Dog mean values (%)	Dog mean values	Humans mean values (%)	Difference in mean dog and human values
Jay and Richards (2007)	N.E. UK	Individuals from Broxmouth shown.	5	9	$\delta^{15}\text{N}$ 7.68±1.23 $\delta^{13}\text{C}$ -20.72±0.30	$\delta^{15}\text{N}$ 9.72±0.60 $\delta^{13}\text{C}$ -20.74±0.15	$\delta^{15}\text{N}$ -2.03‰ $\delta^{13}\text{C}$ 0.02‰	
Lightfoot <i>et al.</i> (2009)	S. UK	Individuals from the Roman Period shown.	5	5	$\delta^{15}\text{N}$ 9.66±0.32 $\delta^{13}\text{C}$ -20.24±0.21	$\delta^{15}\text{N}$ 10.67±0.47 $\delta^{13}\text{C}$ -19.64±0.34	$\delta^{15}\text{N}$ -1.01‰ $\delta^{13}\text{C}$ -0.60‰	
Mildner and Richards (2005)	UK	Individuals from the Wharham Percy Site shown. Human data from Richards <i>et al.</i> (2002)	6	28	$\delta^{15}\text{N}$ 11.02±1.07 $\delta^{13}\text{C}$ -20.55±0.50	$\delta^{15}\text{N}$ 10.98±2.01 $\delta^{13}\text{C}$ -19.7±0.30	$\delta^{15}\text{N}$ 0.04‰ $\delta^{13}\text{C}$ -0.85‰	
Riek <i>et al.</i> (2011)	W. US		5	14	$\delta^{15}\text{N}$ 8.37±1.00 $\delta^{13}\text{C}$ -11.52±0.87	$\delta^{15}\text{N}$ 9.40±0.80 $\delta^{13}\text{C}$ -13.51±0.82	$\delta^{15}\text{N}$ -1.03‰ $\delta^{13}\text{C}$ 1.99‰	

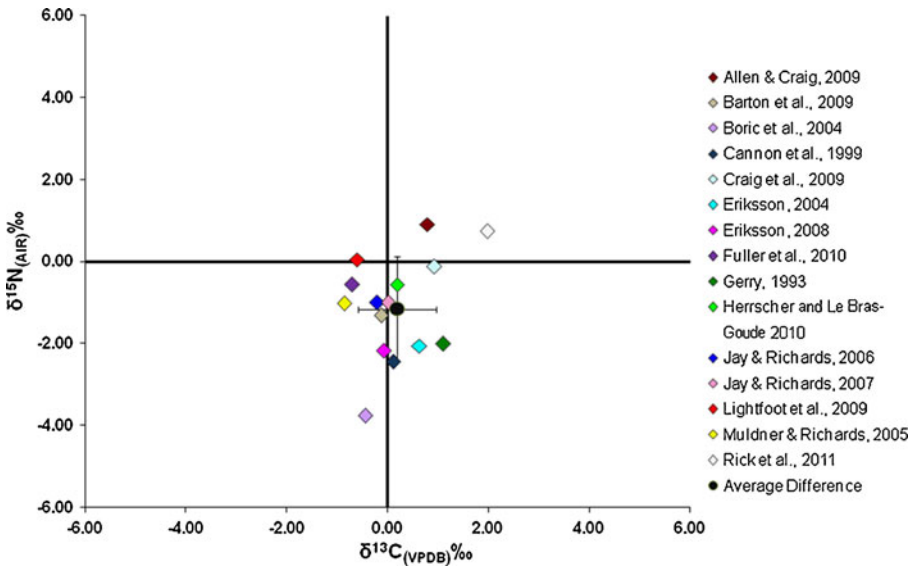


Fig. 2 Humans mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values subtracted from those of associated dogs. Table 2 provides background information on each study. Error bars show one standard deviation

the mean $\delta^{15}\text{N}$ values of dogs from European agricultural contexts may be very close (within 0.25‰) to those of their human keepers (e.g., Craig *et al.* 2009; Lightfoot *et al.* 2009) or more than 2‰ distant (Jay and Richards 2006). The same is evident from dog data deriving from hunter gather contexts. Other influences of factors identified in section “Challenges Pertaining to Cultural Context” such as the relative geographical isolation of a group do not appear to produce any trends in human and dog dietary similarities either. Furthermore, due to the relatively small sample populations of dogs relative to humans in most studies, it is difficult to assess the extent to which human dietary variability is reflected in dogs’ stable isotope values. While standard deviations from mean stable isotope values of some groups of associated dogs and humans show a generally similar spread proportionally between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, others do not. These issues might be remedied if future studies incorporate the analysis of larger quantities of dog materials alongside humans in addition to efforts to outline, as fully as possible, the archaeological associations between dogs and humans.

There has been disagreement in the literature with regards to what constitutes stable isotope value similarities that are “close enough” for dogs to provide credible information on human dietary activities. For example, this is evident in situations where different authors cite data from the same paper (e.g., Katzenberg 1989) as supporting (e.g., Cannon *et al.* 1999; Hogue 2002) or refuting (e.g., Eriksson 2004; Eriksson and Zagorska 2003:162) the argument for human–dog comparability in CSA inferences. While this issue is necessarily subjective, clarification might be offered by considering the type of dietary information being sought. For instance, are dog stable isotope values intended to provide a relatively accurate or rough proxy for human diet, or, are they simply an indication of the presence or absence of certain foods? This issue may be further resolved by explicit and systematic clarification of

probable influences on the faithfulness of dogs' stable isotope values reflecting those of their human keepers. There have been no systematic or cohesive analyses of the ways in which dogs might be used to reflect human diet or the potential for differing dietary influences (although for brief discussions, see Allitt *et al.* 2008; Cannon *et al.* 1999; Eriksson and Zagorska 2003; Noe-Nygaard 1988; Tankersley and Koster 2009; White 2004). By considering the implications of the analogical nature of CSA applications, the following section distinguishes between two common ways in which dog bone collagen stable isotope values have been used to help characterize those of their human keepers. Following this is a categorical framework for considering possible variations in influences on dog diet relative to human diet.

Dogs as Analogs: Common Uses and Interpretive Implications

One way of clarifying issues in the interpretation of stable isotope values from dog remains for the purpose of human dietary reconstruction is to consider the different types of information CSA applications can provide and how this might influence the forms of criticism to which resulting inferences can be subjected. As an analogy, the parameters and credibility of information provided by a CSA inference are determined by the components of its analogical reasoning. This section considers these components to separate distinctive types of CSA application—those which are based on direct analogies and those which are based on indirect analogies.

As outlined above, in the context of CSA applications, the terms “subject” and “source” refer to associated humans and dogs, respectively. The specified terms for comparison are the degree (or expected degree) of congruency shown by their respective bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. The degree of similarity is determined through the positive, negative, and neutral dimensions of comparison considered by researchers claiming that in a given context dogs should, to a certain extent, provide an indication of human dietary activities.

In many applications, the CSA is used as a tool for characterizing human diet and dietary changes over time by bridging gaps in the paleodietary record. A well-known example of this type of CSA application is its use by Cannon and colleagues (1999) to enhance the temporal resolution of the paleodietary record of a human group in northwest coastal British Columbia, Canada. This was accomplished by establishing congruencies between the stable isotope values of contemporaneous dogs and humans present in the archaeological record and then analyzing dog specimens that stratigraphically and temporally flanked those from available humans based on the assumption that dogs in these time periods would also have shared similar stable isotope values. Dog stable isotope values were able to “confirm” trends in changing human diet indicated by zooarchaeological analyses of associated faunal materials. In this type of CSA application, information regarding the source (dogs in the past) is transposed directly on to the archaeologically unavailable subject (their human keepers in the past). This argument is a direct analogical inference requiring consideration of the dimensions of comparison which establish positive, negative, or neutral components of the analogy. An argument for positive aspects supporting the transposition is made in noting that other lines of inquiry corroborate the observed dietary trend and also that the observed difference between $\delta^{15}\text{N}$ values might be

explained by trophic level shifts related to the canine practice of caecaeotrophy (see below). Negative and neutral aspects of the comparison are also suggested when the authors consider the dearth of information on early human–dog social and working relationships in the region as well as a lack of comparative studies detailing possible metabolic differences between human and dog tissue isotope incorporation. In making these considerations and concessions, the authors have clarified the ways in which the dogs in this particular CSA analogy are thought to be like and unlike their human keepers and thus fortified their argument against a variety of criticism relating to their underlying analogical reasoning. Additional possible factors (as discussed in “[A Categorical Framework for Approaching Comparative Dimensions of CSA Analogies](#)”) can be considered in order to further strengthen or weaken this inference.

In other cases, dog stable isotope values are used to identify the relative availability of important foodstuffs within certain archaeological contexts. Several researchers have been able to show the presence and abundance of maize and provide an indication of its relative availability for human consumption in various temporal and cultural contexts as its cultivation and use spread across the precontact Americas (e.g., Allitt *et al.* 2008; Burleigh and Brothwell 1978; Chilton *et al.* 2001; White *et al.* 2001). The success of this form of CSA application is dependent on the isotopic composition and ecology of the environment within which humans and their dogs lived relative to that of major local cultigens or other food sources. More specifically, it has been possible for researchers to identify that dogs had consumed substantial quantities of maize (a C4 plant producing higher $\delta^{13}\text{C}$ values) only because the local natural environment in which the dogs lived was monopolized by C3 plants (which produce lower $\delta^{13}\text{C}$ values). In these cases, the transposition of information is not directly from dog to human, but rather the focus is on evidence of dog diets incorporating foods that demonstrate human dietary activities. These indirect analogies are not necessarily subject to the same kinds of considerations as direct analogies since the subject of the comparison is not complete human diet but rather one aspect of human dietary practices. By shifting the subject of comparison from highly complex aspects of whole human diet to a single component of human dietary activities, which can be determined relative to known isotopic endpoints (O’Leary 1988; Schwarcz and Schoneninger 1991), these applications may require fewer considerations of comparative dimensions which establish positive, negative, or neutral components of the analogy. For this reason, they may be less susceptible to critiques of strengths and weakness of source–subject comparison.

A consideration of the direct or indirect nature of the analogical inferences made by CSA applications may allow for a more systematic assessment of their credibility by providing a structured framework for critically assessing their claims. Explicitly identifying the types of information provided by each kind of application not only clarifies the ways in which dogs are being used as surrogates for human diet but can also facilitate (most importantly in cases of direct analogy) more informed considerations of the degree of congruency between human and dog stable isotope values necessary to provide meaningful indications of human dietary practices. The following section provides a framework for approaching the positive, negative, and neutral comparative dimensions to be considered when contextually assessing the degree of similarity between human and dog stable isotope values in CSA analogies.

A Categorical Framework for Approaching Comparative Dimensions of CSA Analogies

CSA applications make two foundational *a priori* assumptions that specify the ways in which dogs should share similar dietary stable isotope signatures with humans: (a) that dogs had access to human foods through scavenging, handouts, and cacaetrophy (e.g., Cannon *et al.* 1999) and (b) that dogs and humans metabolize and incorporate their food intake in a similar manner such that rates of isotopic fractionation and incorporation into respective tissues are comparable for both (e.g., Jay and Richards 2006; Noe-Nygaard 1988, 1995:262). While there have been some recent ethnoarchaeological indications that humans and dogs isotopically incorporate foods into hair very similarly (Tankersley and Koster 2009; Van der Merwe *et al.* 2000:32), further studies are needed to confirm whether the same is true for bone collagen. Granting these assumptions, there are three categories of factors that might influence the degree to which dog diet isotopically reflects human diet:

1. Inherent *biological* or *behavioral* differences existing between humans and dogs that could alter the expression of dietary isotopic signatures in their respective tissues
2. *Cultural factors* affecting human–dog relationships, thereby contributing to dogs eating or being fed foods with isotopic signatures disproportionate to those of the bulk food constituent of their human keepers' diet
3. *Environmental* stimuli affecting how humans fed and/or cared for their dogs

The relevance, as well as the supportive *versus* undermining nature of these factors, will affect the confidence with which dietary stable isotope information from dog remains can be transposed to archaeologically unavailable associated humans. In Wylie's (2002:147) terms, these factors can be neutral (that is they are unlikely to influence dog diet relative to human diet), negative (they are likely to skew dog diet such that it is less isotopically consistent with human diet), or positive (they are likely to contribute to a convergence of dog and human diet). Following are examples of factors within each category and a discussion of how they might influence the relative strength of analogical inferences with regard to source–subject similarity or difference and their contextual relevance. Consideration of these comparative dimensions can help specify how source and subject are of like, unlike, or unknown likeness, thereby fortifying CSA inferences based on direct analogies, rendering them more transparent and less susceptible to criticism.

Challenges Pertaining to Dog Behavior and Biology

Regardless of whether or not dogs may have eaten a diet isotopically similar to their human keepers, biologically and behaviorally, they are different from humans, and it is possible that related factors may cause stable isotope values from similar foods to be expressed slightly differently by each. The following issues represent the potential sources of error in CSA arguments with respect to the foundational assumption that dogs may be biologically analogous to humans.

Life Span and Bone Remodeling

Bone growth and maintenance occur at different rates in humans and dogs, contributing to differing lengths of dietary representation in their respective bone collagen stable isotope values (Allen and Craig 2009; Ambrose 1986; Noe-Nygaard 1988; Schulting and Richards 2002; White *et al.* 2001). Healthy human bone remodels slowly over a long period of time and hence produces isotopic signatures representing a dietary average of up to or more than 20 years (Geyh 2001; Hedges *et al.* 2007; Wild *et al.* 2000). This relatively long span of dietary representation in human bone is advantageous as it is less likely that periods of anomalous dietary intake will be reflected in human bone collagen stable isotope values. Dogs, on the other hand, have much shorter life spans, and their bones initially grow and are remodeled much more rapidly (6 months to 3 years; Fischer *et al.* 2007a:2127; Noe-Nygaard 1988:92). This shortens the time span of dietary averaging and means that the isotopic signatures of dog bone collagen are more prone to reflecting perturbations during brief periods of dietary abnormality. In other words, dog stable isotope values could reflect a greater degree of dietary variability relative to humans in a given context. While this factor has been used by some researchers to identify variability in the availability in certain foods which may have previously gone unrecognized based on human stable isotope values (Allen and Craig 2009; Cannon *et al.* 1999), it may contribute to undermining human and dog dietary similarities. For these reasons, to strengthen CSA inferences, dog specimens should be selected for applications with care to avoid (or at least treat with caution) particularly young individuals whose bone collagen stable isotope values reflect the shortest periods of dietary averaging. Avoiding younger dog specimens is further advisable as these individuals can produce elevated $\delta^{15}\text{N}$ values reflecting recent weaning (*e.g.*, Eriksson *et al.* 2008).

Domestic, Wild, or Hybrid?

The mistaken sampling of non-domestic canids, such as wolves, coyotes, foxes, or jackals, during CSA applications would result in invalid source to subject transpositions. Dogs and their wild progenitors have always shared a large sympatric range, and hybridization events did occur in precontact and prehistoric times (*e.g.*, Crockford 2000:305). The offspring of such unions would have obtained qualities of both wild and domesticated forms, yet may still have been accepted and treated as domestic by human groups. Distinguishing whether canid remains were those of wild rather than hybrid dogs can sometimes be difficult or impossible via standard zooarchaeological analyses. To prevent the possibility of analyzing non-domestic samples, and thus rendering this factor irrelevant, it would be optimal to avoid the use of morphologically ambiguous canid remains when formulating CSA inferences.

DNA work may provide an alternative solution. A recent ancient DNA (aDNA) study has demonstrated that in some cases, it is possible to differentiate the domestic *versus* wild status of some morphologically ambiguous canid remains recovered from archaeological contexts (Horsburgh 2009). While the majority of canid DNA studies have focused on modern populations (*e.g.*, Savolainen 2006), aDNA work on archaeological dog samples continues to identify ancient dog haplotypes (*e.g.*,

Deguilloux *et al.* 2009) that will be necessary to differentiate wild forms from domestic dogs. With further work, this technique may become more widely available to CSA analysts.

Caecotrophy Among Dogs

Caecotrophy, the consumption of feces, is a behavior common among dogs (Hofmeister *et al.* 1998) and is not usually practiced by humans. It has been demonstrated that urine is depleted in ^{15}N relative to diet (Minagawa and Wada 1984), and although it has not been empirically studied, some have suggested that it is possible that a similar relationship exists between dog or human feces and diet (*e.g.*, Cannon *et al.* 1999). It could then be plausible that given the regular consumption of human feces as a dietary supplement, some dogs would consistently produce $\delta^{15}\text{N}$ values that are somewhat lower than those of their keepers. This behavioral difference has been invoked by several researchers to account for the differences (on the order of one trophic level) between the $\delta^{15}\text{N}$ values of otherwise isotopically similar humans and dogs (*e.g.*, Allitt *et al.* 2008; Cannon *et al.* 1999). However, recent research into the fractionation of stable nitrogen isotopes in the digestive systems of various herbivorous and one carnivorous mammal species suggests that feces is, to varying degrees, slightly enriched or equal in ^{15}N relative to diet regardless of reliance on hind or foregut fermentation (Ben-David *et al.* 1998; Hwang *et al.* 2007; Sponheimer *et al.* 2003b). This research (Ben-David *et al.* 1998) also shows that nitrogen isotope fractionation occurs at different levels and directions as digesta passes through the digestive tract on inter- and intraspecies scales. Unfortunately, none of the species thus far examined have been mid-sized omnivorous mammals using hindgut fermentation similar to the digestive systems of humans and dogs. Until further controlled studies are conducted on these or similar species, this difference in human and dog behavior presents an unaddressable variable in CSA applications and, for purposes of transparency, should be noted as such in interpretations.

Challenges Pertaining to Cultural Context

Human perception and treatment of dogs is a culturally mediated, and therefore highly variable, phenomenon (*cf.* Serpell 1995). The following cultural factors represent some interpretive aspects of transposing dietary information from dogs to humans as well as the relevance each might have to the strength of a given direct analogical CSA application.

Dog Worship

The spiritual significance of dogs in a given cultural context may affect their feeding habits as well as the range of food items available to them. The isotopic composition of different groups of dogs' diets and the strictness to which these were adhered could affect the degree to which human and dog diets converged. For instance, White and colleagues (White 2004; White *et al.* 2001, 2006:145) found that dogs buried in ritual cache contexts in a number of Mayan sites produced stable isotope

values disparate from both humans and other dogs. These cache dogs had apparently maintained a diet that was almost exclusively maize-based. These studies demonstrate the possibility that, for spiritual reasons, certain dogs may have been fed an intentionally restricted diet which can be unlike that of their human keepers' and cautions the unselective and/or wholesale transposition of dog dietary stable isotope information to the human subject without giving consideration to the relevance of the archaeological conditions under which dog remains in question were collected.

Dogs for Dinner

Dogs have been eaten among many ancient peoples not only as ceremonial or emergency food supplies (e.g., Kerber 1997; Serpell 1995:248–250) but also as common fare (e.g. Wing 1978). If, in a given context, diet was similar between humans and dogs, except for the former's consumption of the latter, then, due to the trophic level effect (see “[Stable Isotope Theory Background](#)”), human $\delta^{15}\text{N}$ values will be slightly higher than dogs. This possibility has been employed in some studies to help account for human $\delta^{15}\text{N}$ values which are elevated over dogs (Borić *et al.* 2004; Richards *et al.* 2009). Such dietary inconsistency may become further complicated if dog meat was considered a prestige or otherwise unusual food item and thus eaten most by a subgroup of the human population. Thus, cultural norms regarding the regular consumption of dog meat may result in some human $\delta^{15}\text{N}$ values becoming enriched relative to dogs. The potential for this factor to influence similarity between human and dog isotope values may be difficult to address for more ancient contexts in which direct historic ethnographical analogies cannot be considered or where zooarchaeological evidence of dog consumption is absent. For this reason, the relevance of dog consumption as a factor in determining the strength of a CSA argument may be challenging to assess in some cases.

Separate Treatment of Differing Dog Breeds

Some ancient groups bred dogs for special tasks or roles not fulfilled by common domestic dogs, including hunting unusual or dangerous animals such as bears (e.g., the Tahltan bear dog: Crisp 1956; Wilcox and Walkowicz 1989), as special companions, or as food items (e.g., Mexican hairless dogs: Clutton-Brock and Hammond 1994). If these alternate tasks or roles resulted in certain breeds receiving different treatment, it may be reasonable to suspect them of possibly having had a restricted or otherwise unusual diet. For instance, Schulting (1994) confirmed the speculated existence of a dog bred solely for its hair among the Coast Salish culture of coastal British Columbia, Canada. These dogs had been kept in special pens to ensure the purity of their bloodline and were systematically sheared for their wool which was used to make blankets. Schulting notes that according to ethnographical sources and $\delta^{13}\text{C}$ values measured in the fibers of a preserved dog hair blanket, these wool dogs may have been fed a special diet, based almost entirely on salmon (1994:62), a diet which could have differed from contemporaneous humans and common dog diets. If multiple breeds are recognized in applicable ethnographic and archaeological literature or are osteologically (or genetically) distinguishable, it may be necessary to conduct preliminary isotopic comparisons to confirm that breed type

did not have a bearing on diet within a given context. In short, this factor might negatively affect CSA arguments that do not assess potential for differential treatment of dog breeds in a given context. In contexts where only one breed existed, this factor may be irrelevant.

Technological Change

Dogs have been a form of technology for ancient peoples who relied upon them for services including hunting acumen, sentry, and traction capacity (*cf.* Serpell 1995). It is possible that processes or events resulting in technological change could have affected the ways in which humans interacted with dogs or relied upon their services. For example, the introduction of snowmobiles in some northern regions provided indigenous communities with a new technology whose traction capacity far exceeded their traditional sled dogs. In the Canadian Arctic, this resulted in the widespread abandonment of dog sledding among Inuit groups (Smith 1972). With little use for large dog teams that require constant feeding, most sled dogs were dispatched shortly after (Smith 1972). In other more ancient contexts where dogs may still have provided alternative services, such a technological shift may only have resulted in a change in roles. This role transfer could easily affect human views and, thus, feeding of dogs. The potential for this factor to influence similarity between human and dog stable isotope values is also difficult to address with regards to ancient contexts in which no appeal can be made to direct historic ethnographical analogies. Again, for this reason, the relevance this factor may hold in determining the strength of a CSA argument may vary.

Economic Transactions

Some ancient groups valued canid remains and have viewed them as a material which could be traded. When objects incorporating dog skeletal elements are passed between groups with distinctive dietary regimes, their stable isotope values may not reflect diet in the secondary cultural context. Eriksson and Zagorska (2003) provide an example of this problem when analyzing dog teeth from tooth-pendant necklaces among inland European hunter-gathers. Eriksson and Zagorska (2003:167) found that while some teeth produced isotope values generally consistent with contemporaneous human data, others produced a distinctive marine dietary signal. This was interpreted by the authors as possible imported materials from a coastal region. This example illustrates the potential for the trade of dog remains to result in the misidentification of correct source (dog) materials that are applicable to targeted subject (associated human keepers) in CSA applications. This factor might be addressed by employing other mobility-oriented isotope systems such as strontium isotope analyses (for a review, see Bentley 2006). Initially, however, it would be advisable to treat dog remains suspected of having been incorporated into archaeologically curated objects with special caution. In this way, the relevance of this potentially negative factor may be reduced.

Challenges Pertaining to Environmental Context

The physical environment that an ancient group occupied could have influenced the degree to which human–dog symbiosis was experienced—potentially constraining

or enabling various activities and relationships. The following factors represent challenging aspects of environmental circumstances and stimuli for CSA interpretations.

Dependence on Dog Services

Within some ancient contexts, the role of dogs in daily life may have been of pivotal significance to particular life ways, such as the use of sled dogs for transportation and traction among some northern regions. A strong interdependence can result in intensified human control over dog activities, and thus feeding might have been carefully monitored to ensure the health of working dogs. For example, among the early twentieth century Netsilik Inuit of what is now Nunavut, Canada, food availability was generally low and, at times, little excess food was available for dog feed (Balikci 1970:56). In order to maintain well-fed working dogs with the vitality needed to pull a sled in the winter and carry heavy packs in the summer, family groups usually limited themselves to keeping only one or two dogs (Balikci 1970:56). Where dogs' capacity to work, and by extension their health, were of great importance, it might be expected that dog diet was more likely to reflect direct human provisioning of food. Thus, while it may be irrelevant in many archaeological contexts where humans were not significantly reliant on dogs' services, this factor could positively reinforce CSA applications in certain environments, particularly in northern areas. There have been relatively few studies characterizing stable isotope values of associated human and dog remains from Arctic regions (Chu 1994:39; Coltrain 2009; Katzenberg *et al.* 2010:185; Losey *et al.* 2011); future cross-contextual analyses would provide an opportunity to assess this possibility.

Isolation

A human group's proximity to geographical barriers can affect how they make dog-related economic transactions. For instance, without penning technology, trade of living socialized dogs may have been avoided due to their loyal quality of returning to the original owner shortly after the transaction. This was the case among early twentieth century Plains Cree groups of what is now Manitoba, Canada, who would not trade their dogs with local neighbors but would trade with long-distance Hudson's Bay Company travelers who were sure to transport a dog far enough away that its return was unlikely (Mandelbaum 1979:66). Under these conditions (and recognizing that this loyalty is likely a quality common to most fully domesticated dogs independent of time and space), it may be reasonable to suggest that most domestic dog remains present in an archaeological context are likely to represent animals endogenous to a particular group and their diet.

On the other hand, in some environments, this might not have been the case, such as island or other contexts where isolation could keep dogs from escaping their new owners regardless of group socialization. As would be the case with human immigrants, depending on the traded dog's post-transaction life span, its bone collagen isotope values could still reflect the dietary regime of previous keepers. Thus, in cases where a dog died shortly after it was traded, its isotope values would likely reflect an exogenous dietary regime, thereby complicating CSA inferences.

Furthermore, in contrast with artifact trade-based complications, where dog remains may have been fashioned into recognizable cultural objects, the remains of traded living dogs may not be easily distinguished from those of endemic dogs. Thus, the relevance of this factor to the strength of CSA inferences may be considered mainly in contexts sufficiently isolated to preclude the escape of traded dogs. Comparing the isotope values of different dogs and considering the possibility that outliers may have been traded into the group shortly before death could potentially address this problem and strengthen CSA arguments.

While the above factors are not an exhaustive survey of possible influences on the suitability of dog remains as surrogates for their human keepers' stable isotope values, they do provide examples of the kinds of considerations necessary for substantiating CSA inferences relying on direct analogical reasoning. Several of these factors have appeared in discussions of CSA results, but rarely have researchers devoted a substantial amount of systematic consideration to the ways in which these dimensions of comparison can positively, negatively, or neutrally influence the strength of conclusions regarding the appropriateness of dog stable isotope values as surrogates for those of humans in paleodietary reconstructions. Significantly, this lack of consideration has led to some researchers' wholesale cautioning against the use of the CSA (Bocherens *et al.* 2000; Eriksson 2004; Eriksson and Zagorska 2003:160–162). While these warnings are productive contributions to debates over CSA validity, such criticism might be partially obviated and CSA interpretations clarified by a systematic and explicit recognition of both the type of analogical inference being employed and the relevance and nature of the dimensions of comparison.

Conclusion

A growing body of data from studies isotopically characterizing associated humans and dogs from various contexts appears to be increasingly confirming suggestions that dog materials may provide suitable surrogates for human remains for addressing questions related to human dietary practices. Although the analysis of dog remains cannot allow for the consideration of human diet in relation to factors such as age, sex and gender, or status, it is an attractive and important means of partially circumventing issues around the destructive analyses of culturally and scientifically important human remains (Allitt *et al.* 2008; Chilton *et al.* 2001; Grier 2006:132; Hogue 2003; Katzenberg 2006:272; White 2004) and can often also allow for some general dietary indication to be made in contexts where human remains may be absent or poorly preserved (DeBoer and Tykot 2007; Hogue 2002, 2003; Noe-Nygaard 1995:245; White 2004). Accordingly, a growing number of CSA applications have surfaced in recent literature.

Although dog bone collagen and other tissues can often be used for addressing questions related to human dietary practices, inferences drawn from CSA applications must be made with caution to ensure the clarity and transparency of conclusions. Here, it has been shown that CSA applications are essentially analogical inferences which can be divided into two groups—those which rely on indirect analogies and those which rely on direct analogies. Each route of interpretation attempts to provide a specific type of

information and may require different levels of substantiation. Recognizing this distinction is an important step toward establishing the credibility of different CSA interpretations and allows for a conceptual CSA framework for structuring the ways in which interpretations are qualified.

For cases where CSA applications rely on a direct analogy—that is, where stable isotope values of dogs are transposed directly onto associated but unavailable humans for purposes of full-scale dietary reconstruction—a framework of three categories of factors has been outlined which can help establish positive, negative, and neutral dimensions of comparison. Consideration of such factors is important for producing more convincing CSA interpretations of human diet.

In conclusion, CSA applications have substantial potential for addressing current issues facing stable isotope-based human paleodietary reconstructions and will likely continue to have an increasing presence in the literature. Considering the analogical nature of these inferences, it is imperative for researchers to remain cognizant of the tenuous and contextual qualities of analogical reasoning and take steps toward clarifying and substantiating the ways in which dogs are being used as dietary analogs. It is suggested that CSA applications may benefit from explicitly detailing the following aspects of inferences made:

1. The type and nature of the analogical reasoning employed.
2. A systematic assessment of the ways in which the stable isotopic values of compared dogs and humans are, and are expected to be, like, unlike, or of unknown likeness. The categorical system of potentially influential cultural, environmental, and biobehavioral factors suggested herein may aid in offering structure to this effort.

An important and final note is that information on dog diets is interesting and significant in and of itself. Information on dog diets can help us better understand the aspects of many relationships between humans and dogs including domestication, migrations, dog trade, spirituality, and more.

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