Title

A Canine Surrogacy Approach to Human Paleodietary Bone Chemistry: Past Development and Future Directions

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Abstract

When archaeological human remains are absent or otherwise unavailable for bone chemistry-based paleodietary reconstructions, dog remains may provide an appropriate surrogate material for approximating ancient human diet. This "canine surrogacy approach" (CSA) has developed over the past thirty years and is becoming more common in archaeological science literature. A dearth of continued innovation in CSA applications as well as recent criticisms of its feasibility may reflect the absence of a cohesive overview of the approach's development, its underlying analogical nature, as well as variation and inconsistency in the ways it has been applied. Considering the CSA's invaluable potential to partially circumvent the destructive analysis of human remains, thereby addressing the increasingly recognized concerns of indigenous groups, such considerations would be timely and germane. Recent research has characterized the role of analogy in CSA applications and devised a framework for making CSA interpretations. Complementing that work, this paper provides an outline of the CSA's inception and evolution with particular emphasis on identifying the impetuses for, and trends in, its development. In addition to clarifying the CSA's origin as well as where and why it is applied today, this review provides an opportunity to identify future directions for productive methodological innovation.

Keywords

Dogs; paleodiet; bone chemistry; stable isotope; human proxy.

Introduction

Reconstructing dietary regimes is one way through which archaeologists understand ancient human lifeways. Stable isotope analyses have been established as an effective method for reconstructing ancient diet (Katzenberg 2008). Stable isotope based paleodietary reconstructions are founded on the premise that 'you are what you eat,' and that different kinds of foods have distinguishable isotopic compositions. With this foundational knowledge, archaeological bone chemists study stable carbon and nitrogen isotope compositions preserved in ancient human tissues to understand past dietary trends. This form of paleodietary reconstruction is important as it is one of few ways in which archaeologists can obtain direct information on past human dietary and nutritional practices. Though highly valuable, stable isotope work is destructive. For this reason, in some parts of the world, isotopic analysis 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 light of legislation such as the Native American Graves Protection and Repatriation Act (NAGPRA), archaeological bone chemists dealing with issues of the inaccessibility of human remains for stable isotope based research have sought materials that may provide an analog for human remains. The 'canine surrogacy approach' (CSA; Guiry 2012a) has been one result of these efforts. The CSA analyzes ancient dog (*Canis familiaris*) remains as proxy for human materials in order to understand human dietary practices (e.g. Cannon et al. 1999). The approach is based on the fact that dogs have often subsisted on the scraps of human meals and thus may have isotopic dietary signatures similar to contemporaneous humans.

Over the past 30 years, the CSA has developed and evolved at varying rates, at different times and places, and for a variety of reasons. Despite a recent flurry of more sophisticated development, researchers are still stressing an unrealized potential for dogs to act as proxies for humans (e.g. Spence and White 2009:240). At the same time, there remains some uncertainty in the literature in regard to what the CSA is, as well as criticism of its validity as an effective tool for studying human diets (e.g. Bocherens et al. 2000; Eriksson and Zagorska 2003:160-162; Eriksson 2004). The lack of continued innovation in CSA applications and recent criticisms of its feasibility may reflect the absence of a cohesive overview of the approach's development and its underlying analogical nature, as well as variation and inconsistency in the ways it has been applied. Considering the CSA's invaluable potential to partially circumvent the destructive analysis of human remains, thereby addressing the increasingly recognized concerns of indigenous groups, such an analysis is timely and germane. A recent article (Guiry 2012a) has characterized the role of analogy in CSA applications and devised a framework for making CSA interpretations. Advancing this work, the purpose of this paper is to provide an outline of the CSA's inception and evolution with particular emphasis on identifying the impetuses for, and trends in, its development. In addition to clarifying the CSA's origin as well as where and why it is applied today, this review of the CSA's development provides an opportunity to identify future directions for productive methodological innovation.

Stable Isotope Theory

A brief outline of bone and dentine collagen stable isotope theory is necessary to provide background information for the following discussion. Stable isotope information from bone and dentine collagen is thought to primarily reflect the protein component of dietary intake (Ambrose and Norr 1993; Tieszen and Fagre 1993). Stable carbon isotope ratios (^{13}C to ^{12}C relative to a standard, reported as $\delta^{13}C$) can indicate the relative amount of plants with different photosynthetic (C_3 or C_4) pathways contributing to a diet either directly through consumption of plant foods or indirectly through consumption of animal flesh (Schwarcz and Schoeninger 1991). Differences in the carbon sources of plants inhabiting aquatic *versus* terrestrial ecosystems also allows $\delta^{13}C$ values to be used as an indicator of diets incorporating marine or freshwater ecosystems (Schwarcz and Schoeninger 1991). Specifically, animals and plants feeding in marine environments have $\delta^{13}C$ values that are about 7‰ higher than species inhabiting terrestrial ecosystems (Chisholm et al. 1982). Ratios of ^{15}N to ^{14}N relative to a standard (reported as $\delta^{15}N$) increase by roughly 3-5‰ with each trophic level step up a given food chain and, for this reason, they can be used to differentiate herbivorous, omnivorous and carnivorous diets (Ambrose and DeNiro 1986; DeNiro and Epstein 1981; Schoeninger and DeNiro 1984; for review see Hedges and Reynard 2007). Aquatic ecosystems often have extended food chains with several additional levels and, for this reason, aquatic derived diets focusing on high trophic level species can also be differentiated from terrestrial focused diets based on $\delta^{15}N$ values (Schoeninger et al. 1983).

By using dog materials as a proxy for those of humans, part of the value of data deriving from stable isotope analyses, namely the direct relationship between diet and isotopic ratios preserved in *human* tissues, is overlooked and in this way the CSA might be considered an indirect approach to paelodietary inquiries. However, it should be pointed out that, if dogs are taken to be a proxy for direct forms of analyses of human remains, they still provide a different kind of information than other lines of paleodietary inquiry (such as paleoethnobotany and zooarchaeology), for instance, in that the stable isotope values of dogs reflect long term averaging of dietary intake and that foods which may otherwise be invisible in the archaeological record (e.g. certain plant materials) are detectable. For a discussion of issues surrounding the analogical relationship between dogs and humans in CSA applications see Guiry (2012a).

Early Indications of Human-Dog Food Sharing Relationships

Research contributing to the CSA began in 1978 (Burleigh and Brothwell 1978), almost immediately after stable isotope analysis was first applied to human remains for paleodietary reconstruction (Van der Merwe and Vogel 1978). Early development occurred at different rates for stable carbon and nitrogen isotope analyses and was often a byproduct of research aimed at interpreting other aspects of human and animal diets. For the most part, this form of passive development continued throughout the 1980s and 1990s. The following discussion provides a comprehensive overview of this early research.

The Stable Carbon Isotope Evidence

During a routine radiocarbon dating exercise on ancient Peruvian dog hair, Burleigh and Brothwell (1978) found elevated $\delta^{13}C$ values and interpreted them as evidence that maize had been a significant component of dog diet. Burliegh and Brothwell (1978) extended these analyses to dog bone collagen from post agricultural precontact Ecuador and Mexico and estimated that these dogs consumed a diet composed of over 60% maize. Later demonstration that similar human $\delta^{13}C$ values can result from consumption of marine derived foods (Tauber 1981), as well as the possibility that such values could also reflect dogs' consumption of human feces, resulted in some criticism of this interpretation (Klepinger 1984:86; Noe Nygarrd 1988). However, the implication that stable carbon isotopes could be used to indicate that humans had been provisioning their dogs remained unquestioned.

Later radiocarbon dating projects involving precontact dog remains from eastern North America during the 1980s yielded $\delta^{13}C$ values (e.g. Nelson 1989) that Little and Schoeninger (1995:362-363) interpreted as reflecting human provisioning of marine derived foods. A series of radiocarbon dates taken from unidentified animal bones from post agricultural precontact Mayan contexts in Central America yielded elevated $\delta^{13}C$ values (Hedges et al. 1991:132) that prompted Tykot and colleagues (1996:356) to suggest that these remains belonged to maize-fed dogs. During the early 1990s $\delta^{13}C$ work on dog hair keratin and bone collagen from coastal precontact British Columbia, Canada, and Arizona, USA, provided evidence that dog diets had been strongly influenced by human exploitation of marine foods and maize, respectively (Berry 1992:141; Ezzo and Stiner 2000; Schulting 1994).

In1988 Noe-Nygaard published pioneering work that would lay the foundation for using stable isotope information derived from dogs as a proxy for their human keepers. In light of the paucity of human remains recovered from Mesolithic and Early Neolithic Danish sites, Noe-Nygaard sought to: A) establish a similarity between the bone collagen $\delta^{13}C$ values of dog (n=15) and human (n=4) remains at 16 coastal and inland sites; and, B) assess whether or not they would show the same dietary shifts between Mesolithic and Neolithic observed in another northern group (Tauber 1981). Like the humans, all dogs, save three, produced stable isotope ratios showing the expected trend of decreasing $\delta^{13}C$ values (a greater reliance on terrestrial resources) as they moved temporally from the Mesolithic into the Neolithic. Noe-Nygaard concluded that "Dog bone collagen from prehistoric sites may be used as a supplement to prehistoric human bone collagen $^{13}C/^{12}C$ estimates of diet in prehistoric man" (1988:94). Noe-Nygaard (1995: 248, 261-262) later applied this technique to additional Scandinavian dog remains in lieu of appropriate human materials and found similar $\delta^{13}C$ results.

Noe-Nygaard further extended this new technique to uncover information on seasonal mobility. In 1990, Clutton-Brock and Noe-Nygaard published work in which the diets of three dogs from various inland and coastal sites in England (Star Carr and Seamer Carr) and Denmark (Kongemose) were characterized via $\delta^{13}C$ analysis. Stable carbon isotope signatures from two dogs collected from inland sites produced elevated $\delta^{13}C$ values consistent with a marine diet. The authors interpreted this data as suggesting that these dogs, and their human keepers, seasonally migrated to coastal areas to exploit marine resources. Although the northern environmental settings in which these sites are located likely precludes potential dietary inputs from C_4 plants, the interpretation of these dogs' $\delta^{13}C$ values was questioned based on a localized anomalous 'hard water' effect discovered at the Seamer Carr site (Day 1995). Later application of $\delta^{15}N$ analyses to dog remains from this site settled the dispute (Dark 2003; Schulting and Richards 2002; 2009). This and the aforementioned questioning of interpretations of dog diets based only on $\delta^{13}C$ values highlights the importance of applying multiple lines of analyses, such as $\delta^{15}N$ or stable sulfur isotope ($\delta^{34}S$; see below) measurements, when establishing the suitability of dogs as dietary proxies for their humans keepers.

The Stable Nitrogen Isotope Evidence

In 1986 (Katzenberg 1988:311) and 1988 (Katzenberg and Kelly 1991:212), analyses of human and dog remains from Ontario, Canada, and New Mexico, USA, respectively, provided early indications that, in addition to $\delta^{13}C$ values, dog $\delta^{15}N$ values may also reflect human food provisioning. These findings were echoed in research by Murray and Schoeninger (1988:163-164) on Iron Age remains from Slovenia, by Katzenberg (1989) on Huron remains from historic Ontario, Canada, and by White and Schwarcz (1989) on precontact Mayan remains from Belize.

Studies published during the early and mid 1990s continued to apply $\delta^{15}N$ in tandem with $\delta^{13}C$ analyses to dog and human remains, albeit mainly in post maize agricultural contexts in South America and southern North America (Gerry 1993:157-159, 162, 164, 1997; Gerry and Kruger 1997:201; Tuross et al. 1994; Tykot et al. 1996:358; White et al. 1993). Most authors comment on the $\delta^{13}C$ evidence suggesting that dogs consumed substantial quantities of human provisioned maize; however, no in-depth discussion of dog $\delta^{15}N$ values in relation to those of humans is provided. One study conducted on precontact marine-hunting Asiatic groups produced data demonstrating similarities between dog and human diet in both $\delta^{13}C$ and $\delta^{15}N$ values but focused instead on a discussion of the greater degree of variation observed in dog $\delta^{15}N$ values when compared to those of humans (Chu 1998:38-39, 52).

Following in the path of Noe-Nygaard (1988), Cannon and colleagues (1999) published the first attempt to use $\delta^{13}C$ and $\delta^{15}N$ values of dog bone collagen as a proxy for that of unavailable humans at a precontact marine oriented hunter-gatherer site in British Columbia, Canada. The authors note that, whereas human remains recovered from the site are dated to a relatively restricted time period, dog remains are available from all time periods. To enhance the temporal resolution of the paleodietary record for humans at the site, they analyzed dog remains that stratigraphically and temporally flanked and overlapped those of humans to: A) establish a similarity between human and dog $\delta^{13}C$ and $\delta^{15}N$ values; and, B) if sufficiently congruent, rely upon dog stable isotope signatures to approximate human dietary trends before and after the time periods for which human data could be obtained. The authors conclude that "dogs appear to be valid surrogates for human consumers in isotopic studies of north-west coast diet" (Cannon et al. 1999:405). In addition to Burleigh and Brothwell (1978) and Noe-Nygaard (1988), Cannon and colleagues' (1999) study has become a foundational citation in nearly all publications utilizing dog remains as a proxy for those of their human keepers (see below).

Later Work: The 1990s to Present

Building upon the CSA framework established in the 1980s and 1990s (Cannon et al. 1999; Noe-Nygaard 1988), archaeological scientists have explored many possibilities relating to the potential uses of dog remains as proxies for their human keepers. While these developments started off slowly, recent years have seen a marked increase in the frequency of CSA related publications and it is now routine for some researchers to include dog remains whenever possible in stable isotope based paleodietary reconstructions (e.g. Choy et al. 2010b; Choy and Richards 2010; Fischer et al. 2007a, b). Furthermore, impetuses for CSA use have diversified and researchers have begun to explore the applicability of a variety of techniques in addition to $\delta^{13}C$ and $\delta^{15}N$ analyses of dog bone collagen in an effort to identify new ways in which dogs may be used as surrogates for associated humans. The following discussion outlines these explorations and developments.

Increase in the Analyses of Dog Remains

CSA applications are now relatively common in the literature. (e.g. 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. 2010b; Grier 2002:132-133; Guiry 2012b; Hogue 2003, 2006; Noe-Nygaard 1995:245; Rick et al. 2011; Schulting and Richards 2002, 2009; Tankersley and Koster 2009; White et al. 2001). A substantial number of studies including human and dog bone collagen stable isotope data indicate general similarities (Guiry 2012a) in various cultural and temporal contexts in many areas of the world (Table 1).

CSA research has not been evenly spaced in terms of time of publication/dissemination or geographical region of focus. Studies prior to 2000 including stable isotope information on dog remains are relatively few in comparison to those occurring since. Figure 1 plots the number of theses, dissertations, and publications from all journals and conference proceedings known to the author (see Table 1) that apply the CSA or include similar stable isotope data from dog and human remains from comparable contexts by year. This graph clearly demonstrates significant and sustained growth in the analyses of dog remains after 2005, and suggests that the archaeological bone chemistry community has begun to explore CSA applications more seriously.

The majority of growth in publications including data on humans and dogs has occurred within a limited geographical region that notably excludes Africa and Australia. Figure 2 presents a bar graph contrasting the relative quantities of publications which are cited in Table 1 by broad geographical region. The majority of growth in publication of dog data alongside human data has occurred in Europe and the Americas with a substantial number of publications also coming from Asia. These regions coincide with the areas in which bioarchaeological research communities have been most active according to a recent analysis of articles published in the *Journal of Archaeological Science* (Butzer 2008) and are the locations in which stable isotope based paleodietary reconstructions appear to be more common. This suggests that one reason that CSA applications have not been conducted in Africa and Australia is because there is relatively less stable isotope work occurring in these regions.

Experimenting with Other Tissues and Techniques

Other dog tissues, in addition to bone dentine collagen and hair keratin, have been analyzed alongside those of humans. These analyses often utilize techniques focusing on additional isotope systems and have addressed other questions beyond diet. Explanation of appropriate background information on each of these techniques is beyond the scope of this paper (see Katezenberg 2008); however, a brief discussion will illustrate the variety of ways in which researchers have begun to consider the suitability of dogs as proxies for humans.

Several studies have analyzed stable carbon and oxygen isotopes (paleodietary and paleomobility reconstruction techniques, respectively) in dog bone and tooth apatite either incidentally during routine faunal analyses (e.g. Bösl et al. 2006; Gerry 1997; Gerry and Krugger 1997; Pechenkina et al. 2005; Prowse et al. 2004) or to intentionally assess the use of these materials as a dietary proxy for humans (e.g. Allitt et al. 2008; Chilton et al. 2001). While often similar, these studies have found some variability in the degree of congruency between human and dog stable isotope signatures. Larger scale studies would help further assess similarities between humans and dogs during stable carbon and oxygen isotope analyses of apatite.

Dog bone collagen and apatite have been characterized using several other stable isotope based paleodietary reconstruction techniques. Studies have analyzed stable sulfur isotope ratios ($\delta^{34}S$) in dog bone collagen (e.g. Nelich and

Richards 2009) and found that, of all fauna, dogs produce isotopic signatures most similar to humans (Privat et al. 2007). A very limited amount of stable hydrogen and calcium isotope measurements have also been published for dog and human bone but relations between the two were not discussed by the authors (Reynard and Hedges 2008; Reynard et al. 2010).

Compound specific $\delta^{13}C$ analyses of dog and human bone collagen amino acids have indicated similarities supporting the use of dog materials as a surrogate for their human keepers (Choy and Richards 2010; Choy et al. 2010b; Corr et al. 2009). Such compound-specific analyses can provide greatly improved resolution of nutritional components contributing to diet and for this reason may offer refined comparisons of human and dog dietary similarities. Future work comparing humans and dogs from several cultural, geographical, and temporal contexts might allow for enhanced characterizations of the suitability of dog remains as proxies for humans in CSA applications.

Strontium isotope ratio analyses of dog enamel apatite, which can help identify migration and possibly marine dietary affinities (Bentley 2006), have been recommended by some researchers to complement bone collagen $\delta^{13}C$ and $\delta^{15}N$ work (Chilton et al. 2001). Several studies have characterized strontium isotope ratios from dog tooth apatite while reconstructing patterns of human mobility but have not commented in-depth on data deriving from dogs (e.g. Giblin 2009; Thornton 2011). Smits and colleagues (2010), however, briefly note similarities between humans and dogs. Shaw and colleagues (2009) have used strontium isotope information from pigs to track human movements and colonization events through Oceania and it may be possible that dogs, as an alternative commensal animal, could serve as a proxy for their human keepers in a similar way.

Dog remains have also served as surrogates for human remains in a physical capacity (i.e. non chemical) for studying diet and health related patterns. Bathurst (2000) found similarities in skeletal stress indicators between humans and dogs and suggests that dogs be considered an independent indicator of health status for associated human populations. Bathurst and Barta (2004) further show that it may be possible to extend this surrogacy to the biomolecular level for the identification of certain diseases among human populations. Other recent research has demonstrated that in some contexts dental microware analyses of dog teeth can show results similar to those of associated humans (Hogue 2006:126; Hogue and Melsheimer 2008) and, for this reason, studies of dog tooth dental microware could aid in human paleodietary reconstructions.

In sum, a great deal of preliminary experimentation has been conducted on dog remains. The majority of isotopic work assessing human and dog dietary similarities has focused on $\delta^{13}C$ and $\delta^{15}N$ signatures in bone collagen and some researchers have stressed a need to expand this relatively narrow focus (e.g. White 2004). Taken as a whole, the body of research reviewed above suggests that further development and application of multiple lines of bone chemistry and other analyses to human and dog remains could enhance our understanding of the feasibility of CSA applications.

Justification for Studying Dogs Rather than Humans

Researchers have found it preferable or necessary to analyze dog remains rather than their human counterparts for several reasons. Early studies often cited a variety of issues relating to poor preservation and a paucity of human remains recovered from certain archeological contexts as the impetus for relying on dog remains (Black 2003; Cannon et al. 1999; Clutton Brock and Noe Nygaard 1990; Craige 2006; Hogue 2006:123; Katzenberg 2006:272; Noe-Nygaard 1988, 1995:245; White et al. 2001).

More recently, researchers have experienced issues with availability of human remains due to legal, political, and ethical factors and have cited cultural sensitivities of the descendants of archeological populations as the primary reason for relying on dog remains (Allitt 2011:73; Allitt et al. 2008; Chilton et al. 2001; Hogue 2003; Rick et al. 2011). In the United States this claim is often associated with the passing of NAGPRA and related legislation (c.f. Jenkins 2011) which curtailed the availability of many previously excavated human remains (Katzenberg 2001; Walker 2008:24). Cultural sensitivity in regard to the destructive analysis of human remains is also cited in contexts outside of the USA, such as Canada (Grier et al. 2006:132), where repatriation laws are more incipient or still in the process of development (Katzenberg 2001). To the author's knowledge, however, no studies of dog remains outside of the Americas have cited cultural sensitivity as a reason for avoiding the analysis of their human counterparts. As Europe and increasingly the Middle East and Asia are the focus of much stable isotope work (e.g. Butzer 2009), this difference in reasoning for CSA application suggests impetuses for CSA use are influenced by cultural, political and geographical factors. In other words, unlike Europe, one reason that CSA applications often appear to be related to cultural sensitivities in the Americas is the robustness of cultural, political, and ethical factors impeding access to human remains there.

As CSA applications become more common, some researchers have begun including dogs in studies alongside humans (either explicitly or implicitly) to increase the quantity of data provided on human dietary practices (Allen and Craig 2009; Choy and Richards 2009, 2010; Choy et al. 2010b; Corr et al. 2009; Craig et al. 2006; 2009; Craig 2009:19-20; Fisher et al. 2007a,b; Herrscher and Le Bras-Goude 2010; Schulting and Richards 2000:56-57). Although such studies usually include only a few dogs, they have potential to provide comparative contextual evidence for dog and human dietary similarities (Guiry 2012a).

Another potential impetus for relying on dog remains to avoid destructive analyses of human bone might be to preserve limited human materials for posterity. Although not yet cited in any CSA publication, this reason may apply in contexts where human remains exist but are exceedingly rare or unique and might be more efficiently analyzed with as yet unavailable technologies (Hublin et al. 2008).

A final commonly cited reason for conducting stable isotope research on dog remains, for CSA applications or otherwise, is that information on dog diet is interesting and valuable in and of itself (e.g. Eriksson 2003:22; Guiry 2012a). For instance, CSA and other stable isotope work as well as biomolecular studies on dog remains have illuminated aspects of dog husbandry and breeding (Schulting 1994), seasonal migration (Clutton-Brock and Noe-Nygaard 1990), dog worship and spirituality (White et al. 2001) , dog domestication (Germonpré et al. 2009), and dog trade (Eriksson and Zagorska 2003:167).

Summary and Future Directions

While early work on isotopically characterizing humans and dogs often demonstrated dietary similarities, research was not directly focused on assessing the possibility of using dog dietary information as a proxy for that of their human keepers. It was not until the later pioneering studies of Noe-Nygaard (1988) and Cannon and colleagues (1999) that researchers more fully realized the potential value of dog dietary information for accessing various aspects of ancient human subsistence practices. In doing so they initiated an approach known today as the CSA (Guiry 2012a). From relevant literature it becomes clear that CSA applications are expanding in both quantity and geographic scope. To some extent, however, a researcher's decision to apply the CSA seems to be dependent on geopolitical factors. One motive in decisions to use or not use the CSA in a given region may be correlated with the level of local indigenous concern with the use of destructive analyses on ancestral human remains.

In sum, the CSA's promulgation and evolution shows a slow initial development. A sharp and sustained increase in attention to the CSA in recent years indicates that the archaeological bone chemistry community has developed a stronger willingness to explore the utility of CSA applications despite earlier wholesale criticisms (Bocherens et al. 2000; Eriksson and Zagorska 2003:160-162; Eriksson 2004). This marks a change in how the CSA has been viewed by mainstream archaeology (Guiry 2012a) and makes the present an ideal time to take stock of how to develop this approach for the future.

From the above outline of development, current uses, and areas of growth in CSA applications, we can identify several new avenues that may be opened up as the CSA continues to evolve. As stable isotope based paleodietary reconstructions become increasingly common, and the concerns of indigenous communities around the globe continue to grain greater recognition, the CSA may also become routine in new regions of the world such as Australia, Africa, and Asia. Another relatively newly recognized factor driving an increase in CSA work, independent of geography, will be the increasing public and academic interest in understanding dog and human relationships for their own value (e.g. Barret 2011; Viegas 2008).

The disproportionate focus of most CSA applications on stable carbon and nitrogen isotope analyses is also likely to change to reflect the possibility of deriving additional, higher resolution information on past human lifeways. For instance, further research may demonstrate the feasibility of using strontium and stable oxygen isotope information from dogs as a proxy for human mobility, thereby providing additional opportunities to reduce the destructive analyses of human remains. Another promising area of research will involve assessing human and dog dietary similarities using stable sulfur ($\delta^{34}S$) and compound specific stable carbon isotope work. These developments, in conjunction with more routine analyses of greater quantities of well contextualized dogs, will provide CSA analysts with an invaluable opportunity to refine understandings of the degree to which dog diets reflect those of their human keepers.

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Figure Captions

Fig 1

CSA related research as well as studies (see Table 1) including bone collagen $\delta^{13}C$ and/or $\delta^{15}N$ data from associated dogs and humans versus time of publication/dissemination.

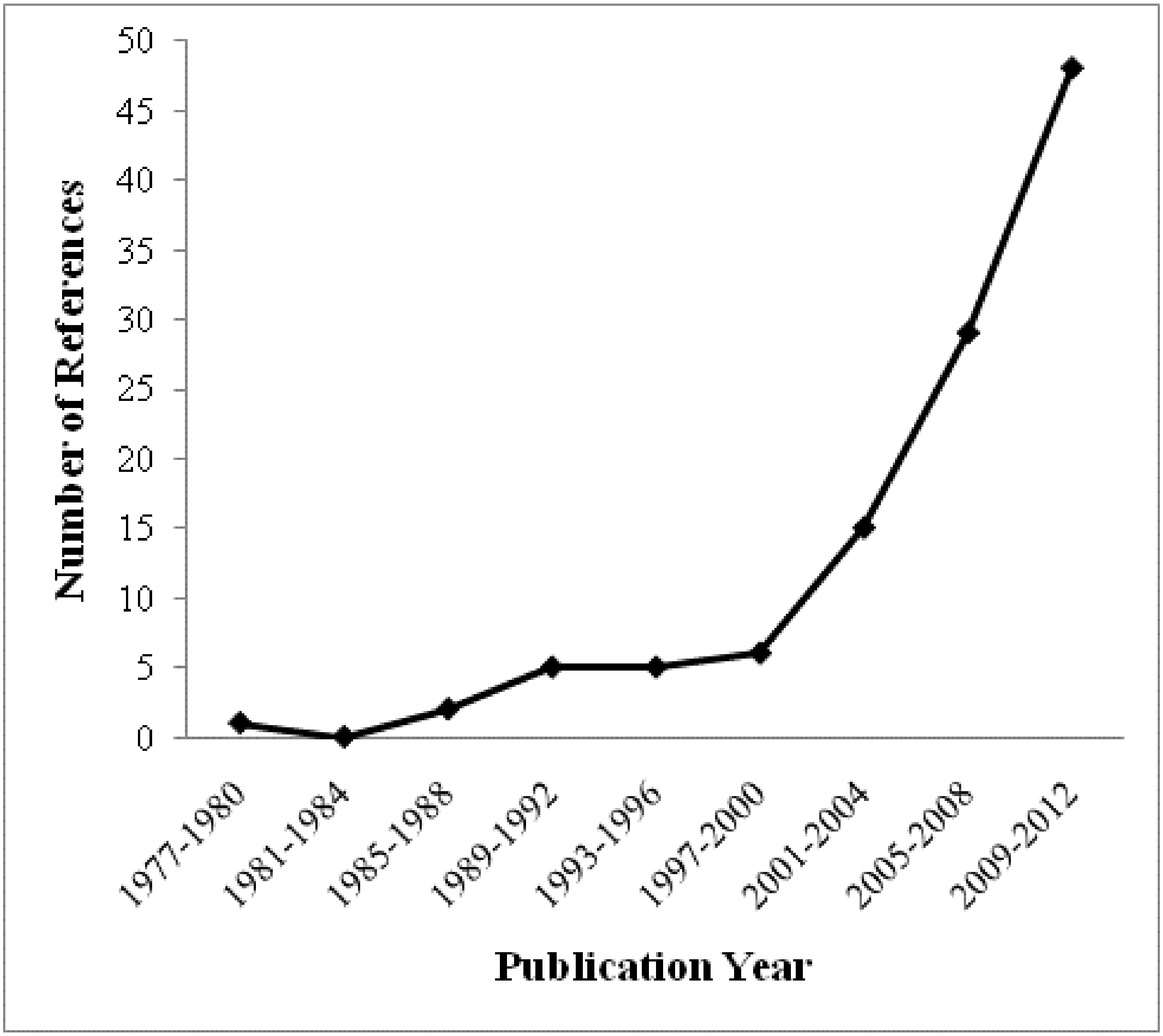

Fig 2

All CSA related research as well as studies (see Table 1) including dog and human stable isotope shown by broad geographical region. Studies containing dissimilar dog and human isotope data are also show for comparison.

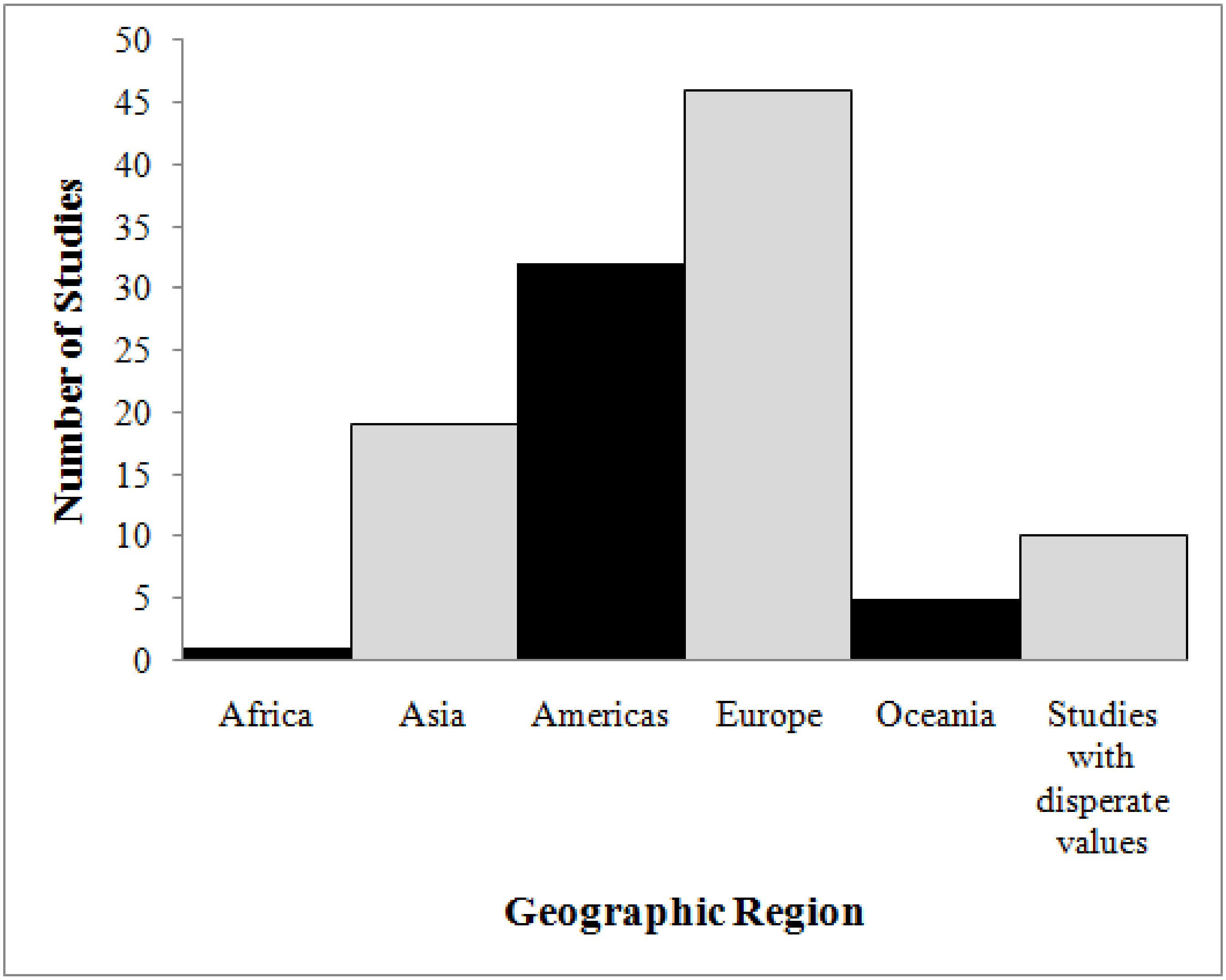

Table 1

List of CSA studies and related research that include generally similar human and dog $\delta^{13}C$ and/or $\delta^{15}N$ values organized by broad geographic region (modified from Guiry [2012]). Studies from all regions with significantly differing human and dog isotope values are also included.

Africa	Mosothwane 2010:132
Americas	Allitt et al. 2008; Berón et al. 2009; Cannon et al. 1999; Coltrain 2009; Corr et al. 2009; DeBoer and Tykot 2007; Gerry 1993:200, 216, 1997; Gerry and Krugger 1997:201, 202; Hogue 2003, 2006; Guiry 2009, 2012b; Guiry and Grimes 2010; Katzenberg 1988, 1989, 2006:266; Katzenberg and Kelly 1991:212; Rick et al. 2011; Tankersley and Koster 2009; Van der Merwe et al. 2000; White and Schwarcz 1989; White et al. 1993, 2001, 2006:145
Asia	Atahan et al. 2011; Barton et al. 2009; Bocherens et al. 2000, 2006; Choy and Richards 2009, 2010; Choy et al. 2010a,b; Chu 1994:39; Hollund et al. 2010; Katzenberg et al. 2010:185; Kusaka et al. 2008; Lanehart et al. 2011; Liu et al. 2012; Losey et al. 2011; Pechenkina et al. 2005; Webber et al. 2002, 2012
Europe	Antanaitis et al. 2008; Ascough et al. 2012; Bocherens et al. 2007; Borić and Miracle 2004; Bösl et al. 2006; Bour et al. 2011; Le Bras-Goude and Clauster 2009; Chenery et al. 2011; Craig et al. 2009; Eriksson 2004; Eriksson et al. 2008; Fischer et al. 2007a, b; Forander et al. 2008; Fuller et al. 2010, 2012; Hakenbeck et al. 2010; Hedges et al. 2008; Herrsher and Le Bras-Goude 2010 ; Honch et al., 2006, 2012; Jay and Richards, 2006, 2007:174; Jørkov et al. 2010; Keenlyside et al. 2009; Kosiba et al. 2007; Le Bras-Goude et al. 2012; Lightfoot et al. 2009, 2012; Lösch et al. 2006; Müldner and Richards 2005, 2007; Murray and Schoeninger 1988:164; Noe-Nygaard 1988, 1995:245; Petrousta and Manolis 2010; Prowse et al. 2004; Redfern et al. 2010; Richards et al. 2003; Schulting and Richards 2000:57; Shin 2011; Stevens et al. 2010; Van Strydonck et al. 2005
Oceania	Allen and Craig 2009; Craig 2007, 2009:225; Jones and Quinn 2009; Valentine et al. 2006
Studies with disparate values	Borić et al. 2004; Byers et al. 2011; Dürrwachter 2006; Jones and Quinn 2009; Thompson et al. 2005, 2008; Richards et al. 2009 Eriksson 2003; Eriksson and Zagorska 2003; Tuross et al. 1994
CSA related studies including only dog values	Berry 1992; Black 2003; Burleigh and Brothwell 1978; Chilton et al, 2001; Clutton Brock and NoeNygaard 1990; Bettinger et al. 2010 Schulting and Richards 2002, 2009; White 2004; White et al. 2004:156

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