Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Dental microwear evidence for dietary uniformity in early Holocene Lagoa Santa, Brazil: insights from SSFA and STA

Maria Rita Guedes Carvalho
maria.guedes-carvalho@uni-tuebingen.de
University of Tübingen
Pedro Da-Gloria
Universidade Federal do Pará
Mercedes Okumura
Universidade de São Paulo
Kasper Hansen
University of Copenhagen
Christopher Schmidt
University of Indianapolis
Sireen El-Zaatari
University of Tübingen
Katerina Harvati
University of Tübingen

Research Article

Keywords:

Posted Date: November 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11281424/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

TITLE

Dental microwear evidence for dietary uniformity in early Holocene Lagoa Santa, Brazil: insights from SSFA and STA

AUTHORS

Maria Rita Guedes Carvalho [1] (ORCID: 0000-0001-7234-8493)

★ maria.guedes-carvalho@uni-tuebingen.de (corresponding author)

Dr. Pedro Da-Gloria[2] (ORCID: 0000-0002-6282-7826)

Dr. Mercedes Okumura[3] (ORCID: 0000-0002-1894-6430)

Dr. Kasper Lykke Hansen[4] (ORCID: 0000-0002-5257-0633)

Dr. Christopher Schmidt[5]

Dr. Sireen El Zaatari [1,6]

Dr. Katerina Harvati [1,6,7] (ORCID: 0000-0001-5998-4794)

AFFILIATIONS

1- Paleoanthropology, Institute for Archaeological Sciences and Senckenberg Centre for Human Evolution and Palaeoenvironment, Department of Geosciences, Eberhard Karls University of Tübingen

2-Institute of Philosophy and Human Sciences, University of Pará.

3- Dept. of Genetics and Evolutionary Biology, Institute of Biosciences, University of Sao Paulo, Brazil.

4- Globe Institute, Section for Geogenetics, University of Copenhagen, Universitetsparken 15, 2100 Copenhagen Ø, Denmark.

5- Department of Anthropology, University of Indianapolis, Indianapolis, IN 46227, USA.

6- EXC 3101 “HUMAN ORIGINS - Excellence Cluster for Integrative Human Origins Studies”, University of Tübingen, Germany.

7- DFG Center for Advanced Studies “Words, Bones, Genes, Tools: Tracking linguistic, cultural and biological trajectories of the human past”, Eberhard Karls University of Tübingen.

STATEMENTS AND DECLARATIONS

Conflict of Interest Statement: The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval Statement: The study of human remains was carried out in accordance with national legislation (National Law No. 25.743; National Law No. 25.517)

Data Availability Statement: The complete dataset of dental microwear texture parameters and raw material (scans) generated or analyzed during this study are included in the published article or supplementary files.

Funding Statement: This research was supported by the Deutsche Forschungsgemeinschaft (DFG; Harvati Leibniz award 2021; DFG FOR-2237). SEZ and KH are supported by the European Research Council (ERC-CoG-101001889 and ERC-AdG-101019659 respectively) and KH is also supported by the Carl Friedrich von Siemens Foundation. MO holds a CNPq Productivity Scholarship (302809/2026-0).

ACKNOWLEDGEMENTS

We express our sincere gratitude to the staff and researchers at the Laboratório de Estudos Evolutivos Humanos (LEEH), University of São Paulo, Brazil, for granting access to the human skeletal collections under their care and for their continuous support and assistance throughout the data collection phase. We are especially thankful to Kasper Lykke Hansen and

Kurt Kjær, University of Copenhagen, Denmark, for providing access to specimens from the legendary Lund Collection and for the generous help during the sampling process.

ABSTRACT

Early Holocene populations from the Lagoa Santa region of Brazil have long been considered culturally persistent, yet the extent of dietary variation across its numerous archaeological sites has remained untested. We address this gap by analyzing dental microwear textures from 45 individuals using both Scale Sensitive Fractal Analysis (SSFA) parameters complemented by a newly applied open-source approach based on ISO textural parameters. Our results consistently point to a striking dietary uniformity across sites, with no significant differences detected by SSFA and only minor, non-robust nuances identified by other parameters. These findings are corroborated by the absence of clear clustering in multivariate analyses and are consistent with other lines of evidence—including stable isotopes, archaeobotany, and zooarchaeology—that depict a uniform generalized foraging economy based on plants and small-to-medium game. The uniformity observed across both space and the span of the Early Holocene occupation of the area lends strong support to the notion of a cultural persistence in the region. Methodologically, our parallel application of SSFA and open-source STA demonstrates that both approaches converge on the same dietary interpretations, validating the use of more transparent and accessible analytical tools in dental microwear research.

KEYWORDS

Lagoa Santa, Dental microwear texture analysis (DMTA), Early Holocene, Paleodiet

INTRODUCTION

The Lagoa Santa region (in modern-day state of Minas Gerais, Brazil, 19° 37′ 37″ S, 43° 53′ 24″ W) is invaluable for understanding the peopling of the Americas (Neves 2016). Its numerous archaeological sites, predominantly dating to between 11,000 and 7,000 years BP and yielding around 250 skeletons (Da Glória et al. 2017), have been attracting the attention

of archaeologists since the 19th century (Prous 2013). To this day, these sites continue to provide insights into South America's earliest human occupation since the Late Pleistocene (Neves et al. 2014).

Archaeological evidence suggests that the occupation of the Lagoa Santa region began sometime between 11,200 and 12,300 BP and persisted until approximately 8000 BP, when it ended abruptly, likely due to climatic fluctuations (Da Gloria & Bueno 2018). Short-term occupations culturally similar to the previous ones are then attested for around 5000 BP (Araujo et al. 2018), the area was only permanently reoccupied around 2000 BP—but by populations culturally distinct from the earlier settlers (Araujo et al. 2005; 2025). The antiquity of the evidence for the earliest human activity in the region is supported by the dating of the Lagoa Santa human remains themselves, with the oldest of which, i.e., the famous 'Luzia', dating back to roughly 11,000 BP (Feathers et al. 2010). Yet, as Luzia does not appear to have been intentionally buried, it seems that the Lagoa Santa sites did not form centers for burial activity at the time of initial occupation, but that the funerary practices, for which these rockshelters are best known for, only emerged later in the Early Holocene (Da Gloria & Bueno 2018). This intense funerary activity in the rockshelters has become a major focus for archaeological research due to the exceptionally favorable skeletal preservation conditions. While, throughout most of Brazil, acidic soils and tropical climate lead to rapid organic decomposition, the karst geology of the Lagoa Santa area, in contrast, offers a protective environment better preserving the remains (Corrêa Novo 2020).

Yet, the Lagoa Santa rockshelters were not used exclusively as burial grounds; they also preserve evidence (e.g.,wall engravings, hearths, lithics artifacts, and faunal bones) of their utilization by humans for other activities (Da Gloria et al. 2017). Thus, aside from funerary practices, the sites also provide information on other aspects of human life and behavior (Neves et al. 2004; Sousa et al. 2017; Araujo et al. 2018). The cultural aspects of the Lagoa Santa inhabitants and their variation across sites and over the time span of the region's occupation have been investigated through multiple proxies. Overall, throughout the Early Holocene, in spite of evidence for climatic fluctuations (Araujo et al., 2013), lithic technology, subsistence practices, and other aspects of material culture in the Lagoa Santa region appear to have remained remarkably stable, despite minor diachronic variation (Araujo et al. 2018). This stability stands in stark contrast to pronounced transformations observed in funerary practices throughout the duration of the Early Holocene, at least at Lapa do Santo (Strauss

2016). These findings prompted Araujo et al. (2018) to use the term "extreme cultural persistence" to characterize the Lagoa Santa inhabitants' maintenance of the same cultural tradition with its core technological and subsistence norms over a few millennia.

Dietary reconstructions from multiple available sources can also be interpreted as consistent with a pattern of cultural uniformity within and across sites during the Early Holocene. These constantly indicate that the Lagoa Santa inhabitants followed a hunter-gatherer economy based primarily on the exploitation of plant resources, supplemented by the hunting of small and medium-sized animals. Isotopic analyses of carbon and nitrogen of human bone collagen from the sites of Lapa do Santo and Lapa das Boleiras indicate that plants constituted a significant component of the inhabitants' diet in the Early Holocene (Hermenegildo 2009). Carbon isotope data ($\delta^{13}C$) suggest that C4 plants—whether directly or indirectly consumed—comprised approximately 10–15% of the diet. Nitrogen isotope values ($\delta^{15}N$) range from 7.0 to 8.5‰, reflecting the consumption of intermediate to exclusively herbivorous animals, such as deer (*Mazama* sp.; average 5.1‰) and, to a lesser extent, omnivorous species, like Testudines; average 10.0‰). Together, these results point to a generalized subsistence strategy based on plants and small to medium-sized primary consumers.

The utilization of various plant species during the Early Holocene is documented by further evidence. Macro-archaeobotanical remains of fruit-bearing plants such as jatobá (*Hymenaea* sp.), pequi (*Caryocar brasiliense*), and araticum (*Annona classiflora*) were identified at the early Holocene site of Lapa das Boleiras (Nakamura et al. 2010). Additionally, studies of micro-remains and use-wear analyses on lithic artifacts recovered from the site of Lapa Grande do Taquaraçu have revealed starch grains on the majority of artifacts, supporting heavy plant processing (Flores et al. 2016; 2019; 2023; Ortega 2019).

In terms of fauna, the zooarchaeological material recovered from the Early Holocene layers of Lapa do Santo indicate a dietary preference for medium and small-sized prey, including species such as deer (*Mazama* sp.), armadillos (*Dasypus novemcinctus*), peccaries (*Tayassu* sp.), cavies (*Cavia aperea*), alongside birds, fish, reptiles (*Crocodylia*), amphibians (*Epicrates cenchria, Ameiva ameiva*), and mollusks (*Strophocheiloidea*) (Chahud et al. 2021; Mingatos & Okumura 2016). Notably, there seems to have been a deliberate avoidance of consumption of larger prey or non-dietary utilization of their bones even though now extinct megafauna did chronologically overlap with human occupation in the region (Piló & Neves

2013; Hubbe et al. 2013) and tapir (*Tapirus terrestris*) continued to be present in the region beyond the extinction of most other megafaunal species (Araujo et al. 2012).

Studies of dental remains of the Lagoa Santa individuals provide complementary clues on dietary patterns. A comprehensive analysis of oral health parameters in 949 teeth belonging to 113 individuals from 17 archaeological sites revealed a prevalence of caries and abscesses higher than usually expected for hunter-gatherer populations (Da-Glória & Larsen 2014). This was particularly evident among females, who also exhibited high rates of antemortem tooth loss. This pattern suggests a diet rich in fermentable carbohydrates, likely derived from the consumption of sugary fruits and potentially tubers (Da-Glória & Larsen 2014).

Dental microwear texture analysis (DMTA) has also been performed on 23 Lagoa Santa individuals, offering insights into the mechanical properties of their foods. This study found that, overall, the Lagoa Santa teeth were characterized by high complexity (*Asfc*) and relatively low anisotropy (*epLsar*), a pattern typical of hunter-gatherers who consumed hard, abrasive, and poorly processed foods (Da-Gloria & Schmidt 2020). These results positioned the Lagoa Santa inhabitants as "hard-diet foragers," with microwear consistent with the consumption of hard items such as seeds and tubers containing grit, further corroborating the archaeobotanical evidence (Schmidt et al. 2019). The study also noted a relatively high level of variation, particularly in surface complexity values, within their Lagoa Santa sample. The authors examined whether this variation could be explained by age and sex factors but found no significant correlations of microwear signatures with these divisions (Da-Gloria & Schmidt 2020). The authors did suggest that dietary seasonality might explain this variation; however, as their sample included individuals from various sites in the Lagoa Santa region, inter-site variation in diet, if present, could have potentially also driven such variation.

OBJECTIVES

In this study, we analyze dental microwear texture on an expanded sample of individuals, with the aim of assessing inter-site dietary variability, and further investigating the arguments for dietary uniformity of the Lagoa Santa inhabitants. We use two complementary approaches using scale sensitive fractal analysis and surface texture analysis to allow the most nuanced investigation of dietary variability among early Holocene human

populations from the Lagoa Santa region, offering an opportunity to assess whether subsistence practices varied across different sites.

MATERIALS

A total of 53 individuals from the Lagoa Santa sites were included in this study. Out of these, eight had to be excluded due to preservation issues (see below). From the remaining 45 individuals, 34 had precise provenience information; these were recovered from the sites of Lapa Mortuária, Lapa da Amoreira, Lapa do Santo, Lapa do Sumidouro, Lapa da Cerca Grande, and Santana do Riacho. The remaining 11 individuals are part of the Harold Walter collection, which consists of fortuitous findings from several archaeological sites in the Lagoa Santa region, including Abrigo de Limeira, Abrigo de Mãe Rosa, Abrigo de Samambaia, Abrigo do Eucalipto, Abrigo do Galinheiro, Abrigo do Sumidouro, and Lagoa Funda, but which does not associate specific individuals with specific sites (Da Glória & Larsen 2014; Prous 2013). Table 1 gives a complete summary of the study sample.

Table 1- Sample Summary

Site	N	Housing institution
Lapa do Sumidouro	19	Natural History Museum of Denmark (NHMD)
Lapa do Santo	8	Laboratorio de Estudos Evolutivos Humanos - IB, USP (LEEH -IB - USP)
Lapa Mortuária	4	Museu Nacional do Rio de Janeiro (MN-UFRJ)
Santana do Riacho	1	Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais (MHNJB-UFMG)
Lapa da Cerca Grande	1	Museu Nacional do Rio de Janeiro (MN-UFRJ)
Lapa da Amoreira	1	Museu Nacional do Rio de Janeiro (MN-UFRJ)
Harold Walter (collection)	11	Museu de História Natural e Jardim Botânico da Universidade Federal de Minas Gerais (MHNJB-UFMG)
Total	45	

The availability and quality of the contextual information for the sampled individuals is highly variable. While some sites, such as Lapa do Santo and Lapa do Sumidouro, have been subjected to comprehensive scientific investigations, others, e.g., Lapa da Amoreira and Lapa Mortuária, lack fundamental stratigraphic and contextual data due to excavations that did not adhere to modern scientific rigor (Da Glória 2012; Tavares et al. 2019). For the sites within our sample that possess reliable contextual data, a brief summary is provided below.

Lapa do Santo: Excavated between 2001 and 2009, this site has been extensively studied (Neves et al. 2014). Radiocarbon dates indicate an occupation spanning from approximately 10,500 to 7,900 BP (Araujo et al. 2012). This chronological control reveals a prolonged and intensive use of the shelter for over two and a half millennia, a finding supported by sediment analysis showing clear evidence of repeated in-situ combustion activities (Neves et al. 2014).

The material culture recovered from Lapa do Santo demonstrates remarkable technological persistence throughout the Early Holocene occupation, with a predominance of flakes (Moreno de Souza & Araujo 2018), and an abundant bone industry that includes spatulas, burins, and rare fishhooks (Mingatos & Okumura 2007; Pugliese 2007). Furthermore, microbotanical analysis of starch grains and phytoliths recovered from lithic tools has provided direct evidence of plant processing (Flores et al. 2016; Flores et al. 2023). These studies have identified a range of plants, including wild grasses (*Poaceae*), palms (*Arecaceae*), yams (*Dioscorea sp.*), sweet potato (*Ipomoea batatas*), and pepper (*Capsicum* sp.), which were processed while raw (Ortega 2019).

Faunal assemblages are diverse, including remains of deer (*Mazama* sp. and *Subulo* sp.), armadillo (*Dasypus novemcinctus*), paca (*Cuniculus paca*), peccary (*Tayassu* sp.), cavy (*Cavia* sp.), Brazilian rabbit (*Sylvilagus brasiliensis*), reptiles, and birds. Taphonomic analysis confirms that the vast majority of the accumulation of these remains are anthropic in origin (Chahud et al. 2021; Kipnis et al. 2010). Stable isotope analysis of human bones from the site ($\delta^{15}N$ values ranging from 7.0 to 8.5%) indicate a diet based on a mix of plants and primary consumers like deer and cavies. The data suggests that indirect consumption of C4 plants (like some grasses or maize) constituted about 10-15% of the human diet (Hermenegildo 2009). Further insight into the diet and health of these populations comes from the analysis of dental caries. The inhabitants of Lapa do Santo show a surprisingly high prevalence of caries (5.50% of permanent teeth; 69.23% of individuals) compared to other hunter-gatherer samples

worldwide (Da Gloria & Larsen 2014). This is likely explained by their adaptation to a tropical environment rich in starchy and sugary carbohydrates, such as tubers and fruits.

The most striking aspect of Lapa do Santo is its funerary diversity. Burial practices began around 10,000 years BP with simple primary articulated burials. Later, around 9,500 years BP, practices shifted to the manipulation and burial of disarticulated bones from multiple individuals. Subsequently, around 8,500 years BP, disarticulated skeletons were deposited in circular pits. Additional patterns include skeletons with removed limbs, bundled disarticulated skeletons, cremations, and burials covered by sandstone blocks. This diversity is unknown from the early Holocene in the Americans and challenges the traditional view that these groups were culturally static (Strauss et al. 2016). In the absence of elaborate grave goods, ritual elaboration seems to focus on the body itself (Neves et al. 2014).

Lapa do Sumidouro: This site holds a foundational place in the history of American archaeology. Initially excavated in the 1840s by the Danish naturalist Peter Lund, it was the first site to suggest a deep human antiquity in the New World. Lund recovered abundant human skeletal remains in association with extinct megafaunal fossils, leading him to propose that humans and megafauna were coeval in the region—a radical idea at the time that challenged the prevailing catastrophist paradigm (Neves et al. 2007). Despite this, Lund's interpretations were heavily criticized, with skeptics arguing that water action within the cave's active swallet system could have potentially mixed materials from different periods (Hrdlička 1912).

While the original excavations lacked detailed stratigraphic control, modern research has largely vindicated Lund. Optically Stimulated Luminescence (OSL) dating of the sedimentary layers containing the Paleoindian levels has provided minimum ages of 9.9 ± 0.7 ky at 1.37 m depth, 10.1 ± 0.7 ky at 1.60 m, and 12.5 ± 0.9 ky at 1.96 m (Araujo et al. 2012; Araujo & Feathers 2008). These dates confirm a minimum age of approximately 8,000 BP for the human and animal bones, and strongly support an early Holocene or even terminal Pleistocene occupation (Piló et al. 2005; Neves 1989). The presence of megafaunal bones at the site thus confirms the coexistence of humans and extinct fauna in the region, though direct evidence for their consumption—such as cut marks or processing tools—has yet to be found (Piló & Neves 2003).

Lapa da Cerca Grande: As the largest limestone outcrop within the Lagoa Santa karst of Minas Gerais, Brazil, Cerca Grande contains numerous rockshelters that have played a

significant role in shaping the archaeological history of the region. First investigated by Peter Lund in 1836, the site generated an important paleontological collection and yielded the first descriptions of the impressive prehistoric rock art panels adorning its walls (Neves et al. 2004). Lund's early work suggested a deep human presence in the area, a hypothesis later confirmed by controlled excavations conducted in 1956 by Hurt and Blasi across seven different rockshelters at Cerca Grande. Their work produced the first radiocarbon dates for the Lagoa Santa region, supporting Lund's assertion that humans were present at least since the Late Pleistocene or Early Holocene (Hurt 1960; 1964; Hurt and Blasi 1969).

Excavations at Cerca Grande revealed numerous human burials across multiple rockshelters. Rockshelter 2 yielded four highly fragmented skeletons, while rockshelter 5 produced five. Rockshelter 6 contained at least eleven burials, though much of the original burial area had been destroyed by mining activities, and rockshelter 7 contained a single interment (Hurt and Blasi 1969). All burials followed a consistent pattern: shallow graves, hyper-flexed body positioning, few funerary goods, and the use of small stone slabs surrounding and covering the graves. Radiocarbon dating places these burials firmly in the Early Holocene, with charcoal dates ranging from approximately 9,700 to 10,500 BP and direct bone collagen dates on human skeletons yielding ages between approximately 9,030 and 9,400 BP (Araujo et al. 2012; Neves et al. 2004). Interestingly, marine shells found in an older stratum at Cerca Grande suggest possible exchange networks with coastal populations during this period (Da Gloria 2021; Hurt and Blasi 1969).

Santana do Riacho: Located approximately 60 km from the main Lagoa Santa karst, within the Serra do Cipó region of Minas Gerais, this site is still considered part of the broader Lagoa Santa archaeological zone. First investigated in the 1970s by André Prous, who sought an intact shelter rich in archaeological remains, the site has yielded a wealth of material culture and burials (Prous 2013). The occupational sequence extends back to nearly 12,000 BP, with evidence of human presence in the terminal Pleistocene, though the burials themselves are firmly dated to between 9,500 and 8,200 BP (Neves et al. 2003; Prous 2013). Over 40 individuals have been recovered, mostly concentrated around a large quartzite block within the shelter, with bodies typically interred in fetal position, sometimes wrapped in hammocks manufactured using the twined technique (Prous 2013; Neves et al. 2003). Burial pits were shallow, often filled with ashes and charcoal, and contained associated items such

as wood-bead necklaces, lithic tools, and occasionally red pigment covering infants (Neves et al. 2003).

In a survey on osteopathologies, the skeletons recovered from this site did not show any signs of metabolic or biomechanical stress that compromised their general health, growth, or mobility, indicating a successful biocultural adaptive model (Cornero & Neves 2011). Diseases associated with nutritional deficiencies were moderate, with 11% of individuals showing signs of porotic hyperostosis and cribra orbitalia, while low rates of prenatal and early childhood death suggest adequate hygiene and sanitary conditions (Guimaraes & Miskievcks 2024). Traumatic lesions occurred in 33% of individuals, with evidence of fracture remodeling and survivorship (Guimaraes & Miskievcks 2024). Analyses of faunal assemblages from the terminal Pleistocene, Early Holocene, and Middle Holocene levels indicate no statistical differences in taxonomic abundance, suggesting continuity in hunting practices focused on small to medium-sized animals (Kipnis 2002, Neves et al. 2003). However, the high levels of caries in the teeth of the human skeletons—approximately 10% of teeth are affected—indicate that vegetal resources were probably of greater importance than animal meat in the Early Holocene (Cornero et al. 1999; Neves et al. 2003). This is consistent with recovered botanical remains, including *Caryocar brasiliense, Syagrus romanzoffiana* and *Hymenaea* sp., from one exceptional burial that dates to nearly 10,000 years ago (Prous 2013).

METHODS

After receiving curatorial approval, silicone molds of the dental crowns of permanent molars from 53 individuals were created at the institutions where the remains are housed using Coltene® President Regular Body material. High-resolution epoxy replicas (Epo-Tek 301, Epoxy Technologies) were produced from those silicon molds at the University of Tuebingen's Paleoanthropology laboratory.

To obtain microwear texture data, the molar replicas were scanned using a white-light confocal profiler (PLu Neox white-light confocal imaging profiler — Sensofar, Barcelona, Spain). An initial low-magnification (10x) screening excluded 8 individuals with poorly preserved occlusal surfaces. From the remaining 45 individuals, scans of crushing/grinding occlusal areas (facets 9-13 — Meier & Schneck 1982) were taken at 100x magnification

covering an area of 242 x 181 µm, with a lateral sampling interval of 0.17µm and a vertical resolution specification of 0.2µm. A single optimal scan was then selected to represent each individual, prioritizing those obtained from second molars (1st molar = 14, 2nd molar = 29, 3rd molar = 2). The scans were then processed using two complementary approaches to obtain a variety of texture parameters.

- Scale Sensitive Fractal Analysis (SSFA)

The first approach focused on scale sensitive fractal analysis to extract standard dental microwear texture parameters (Ungar et al. 2003). For this, the scans were processed in MountainsMap® software (Digital Surf 2023- see supplementary material for full processing steps). Three standard SSFA parameters were then calculated for each scan: complexity (*Asfc*), anisotropy (*epLsar*), and heterogeneity of complexity (*HAsfc81*).

Complexity (*Asfc*) provides a quantitative measure of dental roughness and is used as an indicator of dietary abrasiveness (Ungar et al. 2003). Elevated values result from greater exposure to abrasive particles during chewing—whether these particles come from the food itself, such as phytoliths, or from external sources like airborne grit (Teaford et al. 2006). This parameter proves particularly useful in distinguishing between dietary regimes: diets dominated by hard, brittle items yield high complexity scores, whereas those composed mostly of soft foods or foods that have been tenderized through processing (e.g., milling or cooking) produce low scores. A broad example is the comparison between hunter-gatherers and agriculturalists: the former typically present higher complexity due to less food processing, though deviations can occur depending on the specific foods consumed or the presence of environmental contaminants (El Zaatari 2010; Schmidt et al. 2019).

Anisotropy (*epLsar*) quantifies the directional component of surface texture, which is generated by the cyclic chewing of fibrous or resilient foods. Although this parameter typically correlates negatively with complexity, it is not always necessarily the case (Scott et al. 2005). Mixed diets containing both abrasive and tough constituents often yield moderate values for both parameters, whereas diets dominated by soft foods tend to produce consistently low scores across both measures (El Zaatari et al. 2010).

Heterogeneity of Complexity (*HAsfc*81) provides a measure of dietary breadth by assessing the spatial variability of complexity across different loci of a dental surface scan (Scott et al. 2006). Diets comprising a diverse array of foods with disparate mechanical

attributes tend to produce pronounced textural heterogeneity on the occlusal surface, thereby yielding elevated *HAsfc81* values. By contrast, reduced scores are indicative of a comparatively homogeneous dietary intake, marked by limited textural diversity (El Zaatari et al. 2016).

Individual values for these parameters are presented in Supplementary Table 1. Statistical multivariate analysis of variance (MANOVA) on rank transformed data for these three parameters were conducted to test for differences across archaeological sites. Sites with less than 3 individuals (i.e., Cerca Grande, Lapa da Amoreira, Santana do Riacho) were excluded from the statistical analyses. Also excluded were individuals from the Harold Walter Collection due to lack of association of specific individuals within this sample with their respective site provenance. No follow up statistical tests were conducted as no significance in the MANOVA model was detected.

- Surface Texture Analysis (STA)

The second approach applied surface texture analysis using open-source software to extract standardized parameters for surface roughness as defined by ISO 25178 in addition to an equivalent to the SSFA complexity (Asfc2 — Thiery et al. 2024). Following the workflow developed by Francisco et al. (2018a; 2018b), the scans were first imported into Gwyddion (Nečas & Klapetek 2012) for initial processing (see supplementary material for all filtering details) and then transferred to trident (Thiery et al. 2024) where a second-degree polynomial correction was applied to increase comparability of the texture parameters obtained here with those obtained through MountainsMap®. Subsequently, 24 textural parameters and their associated heterogeneity estimates were computed, resulting in a total of 360 variables (Table 2, Supplementary Table 2). Within trident, the resulting values for all variables were Box-Cox transformed and then, using ANOVA followed by Tukey HSD post hoc tests (Supplementary Table 3), were ranked according to their ability to discriminate between archaeological sites. Sites with fewer than three individuals were excluded from the statistical analysis. For the same reasons cited above, individuals from the Harold Walter Collection were also excluded from this analysis. Thus, only the sites of Lapa Mortuária, Lapa do Santo, and Lapa do Sumidouro were included in this statistical analysis. Using the “TOP 3” option in trident, the three variables that best separate each pair of classificatory categories (in this case sites) according to the Tukey HSD test were identified from the pool of variables that

showed significant discriminatory ability. The resulting nine variables were also used to generate a PCA biplot.

Table 2- Textural parameters measured in trident

Parameter	Family	Significance
Asfc2	Complexity	Area scale fractal complexity
Sdar	Complexity	Relative area (developed area/projected area -1)
Sa	Height	Mean of absolute heights
Sp	Height	Highest Peak
Sq	Height	Height standard deviation
Sv	Height	Smallest height
Ssk	Height	Height skewness
Sku	Height	Height kurtosis
Sm	Height	Mean height (0 for the whole surface, but non-zero for its samples)
Smd	Height	Median height
Rmax	Spatial	Semi-major axis of the fACF ellipsis
Sal	Spatial	Semi-minor axis of the fACF ellipsis
Stri	Spatial	Rmax/Sal ratio
b.sl	Spatial	Highest slope of fACF at the distance rs from the origin
r.sl	Spatial	b.sl/s.sl ratio
s.sl	Spatial	Smallest slope of fACF at the distance rs from the origin
Std ^{EX}	Spatial	Texture direction
Sk1, Sk2	Topology	Relative area of the surface above h1 and h2 respectively
Smc1, Smc2	Topology	Median relative area of the cells with heights exceeding h1 and h2 respectively
Snb1, Snb2	Topology	Number of cells with heights exceeding h1 and h2 respectively
Sh	Topology	Percentage of quasi-horizontal faces (normal within a 4° cone)

Heterogeneity: min (minimal value), max (maximal value), sd (standard deviation), mean (arithmetic mean), med (median), fst.05 (5^{th} percentile), lst.05 (95^{th} percentile), min.05 (mean under the 5^{th} percentile), max.05 (mean above 95^{th} percentile), fst.25 (1^{st} quartile), lst.25 (3^{rd} quartile), min.25 (mean under 1^{st} quartile), max.25 (mean above 3^{rd} quartile), skw (skewness of histogram distribution), kurt (kurtosis of histogram distribution).

RESULTS

- SSFA

The MANOVA model conducted on the three SSFA parameters detected no significant differences among the sites: Pillai's trace = 0.45717, F(12, 108) = 1.6181, p = 0.097. Figure 1 presents boxplots illustrating the distributions of the parameters by site.

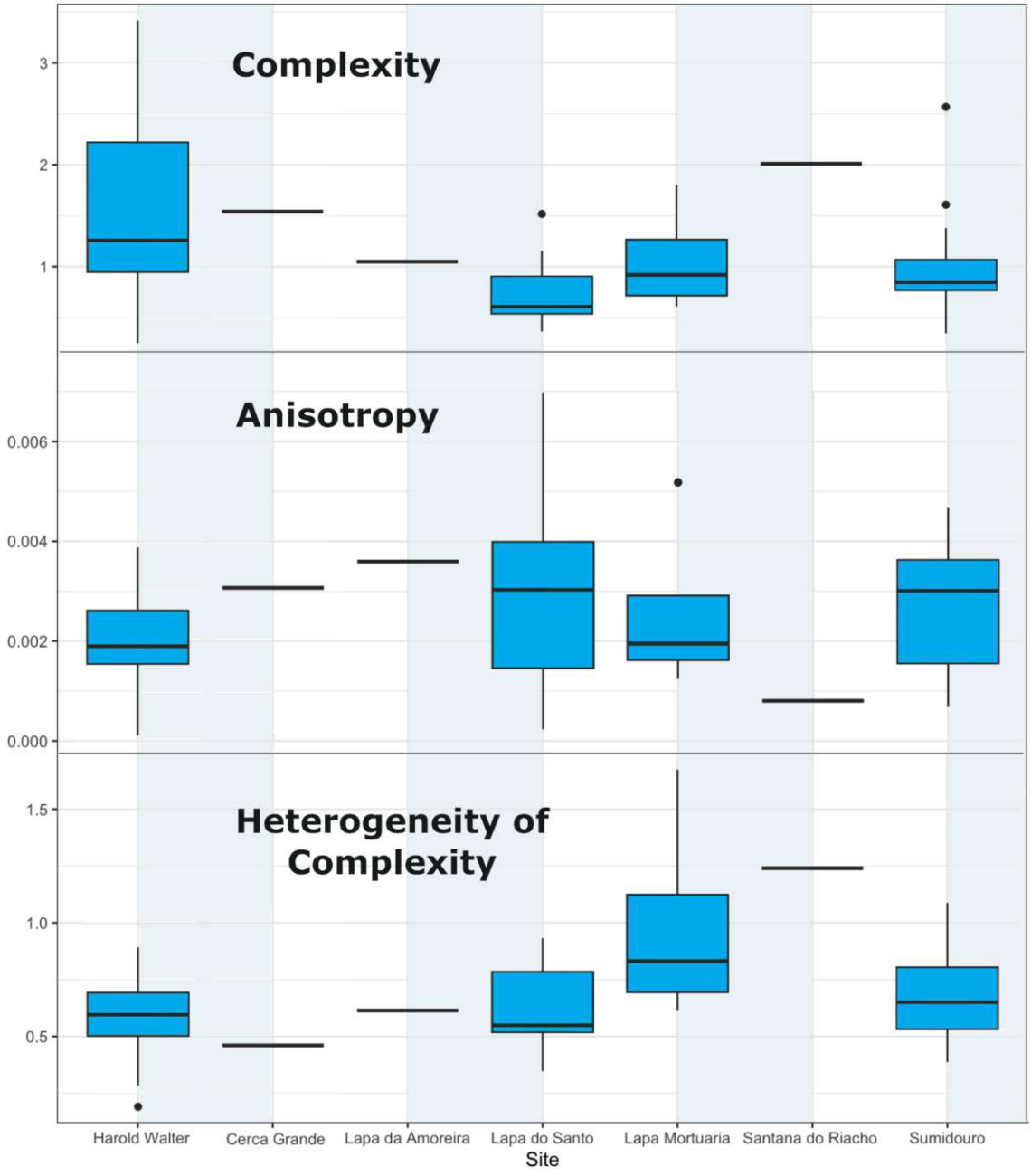


Fig. 1 Boxplots of the three SSFA dental microwear texture parameters (Asfc, epLsar, and HAsfc81) by archaeological site. Boxes represent the interquartile range (IQR) with the median indicated by the horizontal line. Whiskers extend to the minimum and maximum values within 1.5 × IQR; outliers are shown as individual points.

- STA

The statistical ANOVA analyses conducted within trident showed 54 discriminant variables for the category of archaeological site (Supplementary Materials – Table 3). None of these, however, correspond to the central ISO parameters listed in Table 2; but rather to heterogeneity estimations of some of these spatial, height and topological parameters. The subsequent pairwise post-hoc comparisons (Tukey HSD) automatically selected the nine variables that best differentiate each archaeological site by the "Top 3" function. Through this, Lapa do Sumidouro is differentiated from the other two sites by the height heterogeneity estimations (Sq.min, Sa.min, and Sa.fst.05), Lapa do Santo is differentiated by height and topology heterogeneity estimations (Sm.max.05, Snb1.max.05, and Sku.median), and finally, Lapa Mortuária is differentiated by height and topology heterogeneity estimations (Sv.skw, Snb1.kurt, and Snb1.skw).

However, using these same nine "Top 3" variables that best differentiated the sites in a PCA biplot incorporating the entire sample, i.e., including the collections omitted due to small sizes or lack of provenance information, considerable overlap in values and no clear clustering are observable, with two apparent outliers from the site of Lapa do Sumidouro (28 and 38 - Figure 2).

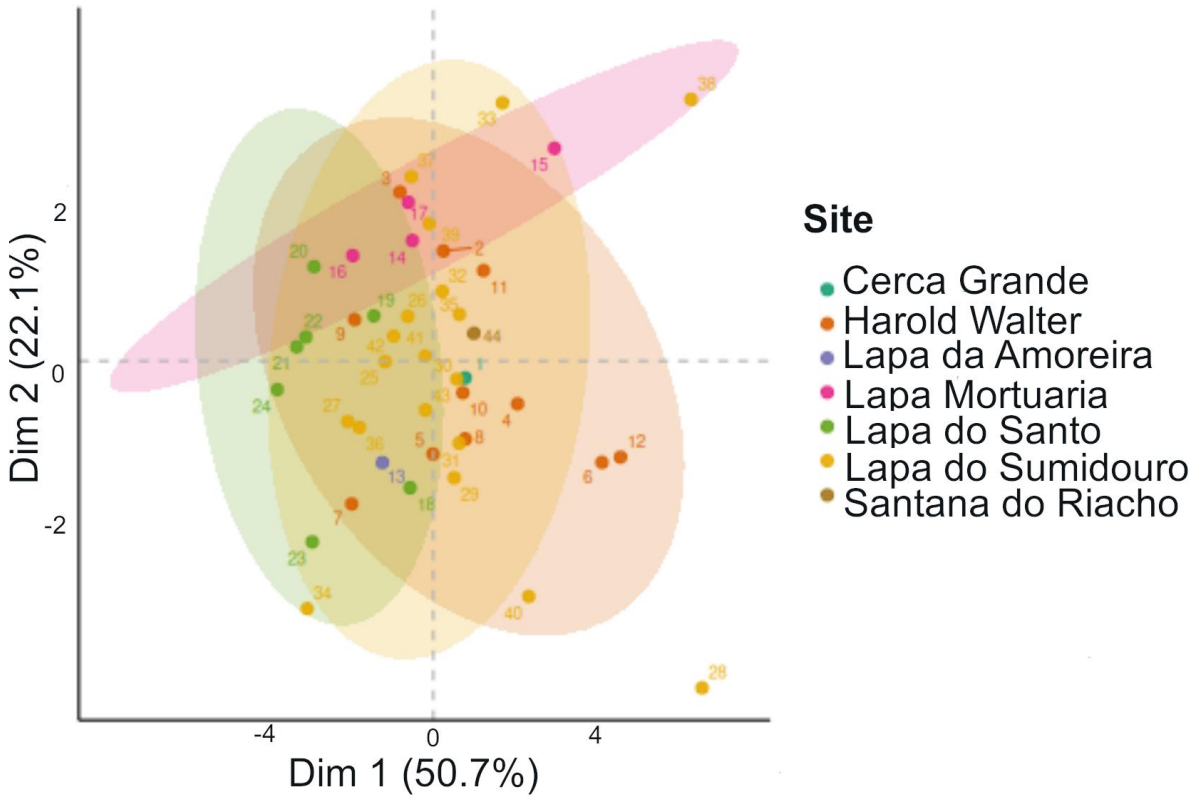


Fig. 2 Principal component analysis (PCA) biplot of the nine variables that best discriminate the archaeological sites according to the Tukey HSD post-hoc test. The biplot includes the entire sample (n = 45). Ellipses represent 95% confidence intervals around group means. Considerable overlap in values and no clear clustering are observable across sites.

DISCUSSION

Due to their abundance, exceptional preservation, and antiquity, the human skeletal remains from Lagoa Santa constitute a fundamental resource for investigating the peopling of the Americas. Within this framework, our study contributes to a deeper understanding of the dietary practices of these early settlers by examining dental microwear textures of individuals across multiple archaeological sites. While doing so, we also address a longstanding methodological concern in the field of dental microwear analysis. Since its inception in the 1920s, dental microwear analysis has undergone substantial refinement, culminating with the adoption of Scale-Sensitive Fractal Analysis (SSFA), which enhanced both

the objectivity of surface feature evaluation and the comparability of data across studies (Ungar et al. 2003; Caporale & Ungar 2016). Nevertheless, the continued reliance of DMTA on proprietary software for surface processing and parameter estimation poses persistent challenges, including high costs and limited methodological transparency (Winkler & Kubo 2025). Here, we explored the use of an open-source alternative, alongside the established SSFA protocol, as an initial step toward more accessible and transparent DMTA workflows.

Our results demonstrate that both analytical approaches converge on the same overarching conclusion: dental microwear textures of the Lagoa Santa individuals do not differ significantly across archaeological sites. This conclusion is supported by the absence of statistically significant differences in any of the SSFA and the central ISO-based parameters across sites. This similarity in dental microwear signatures of individuals across sites supports an overarching uniformity in dietary patterns which aligns with other independent lines of dietary evidence from the Lagoa Santa region. This dietary uniformity is also broadly compatible with the picture of cultural stability proposed by Araujo et al. (2018) based on the analysis of lithic technology, bone artifacts, and faunal exploitation strategies at Lapa do Santo. While the concept of "extreme cultural persistence" may be debated, our DMTA results are certainly consistent with a pattern of long-term dietary and cultural continuity in the region.

In a previous dental microwear study on a smaller sample of the Lagoa Santa individuals, Da Glória and Schmidt (2020) performed comparison of microwear signatures within the sample split by age, sex, and dental macrowear level and found no differences in microwear signatures across the different categories. This finding is further supported by our argument for a remarkably uniform diet across the Lagoa Santa population as a whole. In a broader comparative framework, Schmidt et al. (2019) compared this sample with other human populations from around the globe and, based on their high complexity (*Asfc*) values, classified the Lagoa Santa population as foragers who consumed hard foods. This trend is not confirmed in our sample, where average *Asfc* values are lower and hover around one, with the exception of a few individuals who exhibited values around three. It should be borne in mind, however, that our *Asfc* values are not directly compared to those of Schmidt et al. (2019) owing to the use of different microscopes. Nevertheless, when our data are compared to those of other hunter-gatherers whose microwear was analysed using the same

microscope as in the present study, Lagoa Santa does not stand out as having high Asfc values (Carvalho et al. 2026).

As expected, the inclusion of heterogeneity estimates of the ISO parameters allowed for the detection of subtler inter-site nuances (Francisco et al. 2018b). Specifically, 54 discriminant variables were identified in the ANOVA, all corresponding to heterogeneity estimates of height and topology parameters. The subsequent Tukey HSD test revealed that Lapa do Sumidouro, Lapa do Santo, and Lapa Mortuária could be differentiated from one another by specific combinations of these variables. These subtle differences, however, must be interpreted with caution. They emerged from a statistical comparison that is limited after excluding sites with fewer than three individuals, as well as the Harold Walter Collection— whose individuals span multiple sites but lack exact associated provenience information. When the complete sample is considered in a PCA biplot (Figure 2) based on these discriminating variables, the values overlap extensively, confirming the absence of clear clustering of individuals by sites. It should be noted that the temporal span was not considered in this study due to a lack of fine chronological control for the sampled individuals and sites, even though they are known to date between 9,500 and 7,500 BP. Better-resolved chronologies could potentially detect nuanced temporal patterns or subtle shifts that could be linked to known early Holocene climatic oscillations in the future. Still, the fact that no visible clustering emerges despite our sample encompassing approximately 2,500 years of occupation further strengthens the argument for dietary uniformity across the Lagoa Santa region.

CONCLUSION

In this study, we investigated whether dental microwear textures differ significantly among Early Holocene human samples from different archaeological sites in the Lagoa Santa region of central Brazil. To address this question, we employed two complementary analytical approaches— scale-sensitive fractal analysis (SSFA) and an open-source alternative based on ISO-parameters (STA), allowing us to also evaluate the consistency and comparability of these two methodological frameworks.

The results demonstrate that dietary interpretations based on ISO-parameters (STA) are consistent with those obtained from traditional SSFA analyses. Both approaches converge

on the same finding: no consistent or robust difference in microwear signature clearly separates the archaeological sites of Lagoa Santa, even if STA detects subtle site-level nuances.

The dietary homogeneity we observe reinforces other lines of evidence for long-term subsistence stability in the region, characterized by reliance on plant resources and small to medium-sized game. While refined chronological control might reveal additional temporal nuances, our results support a picture of resilient foraging adaptation among early Holocene populations of central Brazil. Importantly, this study provides a proof of concept for the use of open-source DMTA tools, paving the way for more transparent and collaborative research in dental microwear analysis.

REFERENCES

Araujo AG, Feathers JK (2008) First notice of open-air paleoamerican sites at Lagoa Santa: some geomorphological and paleoenvironmental aspects, and implications for future research. Curr Res Pleistocene 25:27–29

Araujo AG, Neves WA, Kipnis R (2012) Lagoa Santa revisited: an overview of the chronology, subsistence, and material culture of Paleoindian sites in Eastern Central Brazil. Latin Am Antiq 23:533–550. https://doi.org/10.7183/1045-6635.23.4.533

Araujo AG, Neves WA, Piló LB, Atui JPV (2005) Holocene dryness and human occupation in Brazil during the "Archaic Gap". Quat Res 64:298–307. https://doi.org/10.1016/j.yqres.2005.08.002

Araujo AG, Pugliese Jr FA, Santos RO, Okumura M (2018) Extreme cultural persistence in eastern-central Brazil: the case of Lagoa Santa Paleoindians. An Acad Bras Cienc 90:2501–2521.

Araujo, A. G., Correa, L. C., Perez, G. C., Di Gregorio, E. D., & Okumura, M. (2025). Human-environment interaction during the Holocene in Eastern South America: Rapid climate changes and population dynamics. *PloS one*, *20*(2), e0315747.

Caporale SS, Ungar PS (2016) Rodent incisor microwear as a proxy for ecological reconstruction. Palaeogeogr Palaeoclimatol Palaeoecol 446:225–233.

Carvalho, M. R. G., Messineo, P. G., van Raap, M. A. R., Flensborg, G., Martínez, G., Scheifler, N. A., & Harvati, K. (2026). Dental Microwear Evidence of Holocene Dietary Variability in the Argentinian Pampas and Paraná Delta. *American Journal of Biological Anthropology*, *191*(1), e70330.

Chahud A, Figueiredo GF, Mingatos GS, Okumura M (2021) Taxonomic analysis of the Quaternary archaeofauna found at the Lapa do Santo site, Lagoa Santa region, Brazil. J Quat Sci 36:1268–1278.

Cornero S, Neves W (2011) Primeros sudamericanos en Brasil Central: Abordaje biológico de poblaciones tempranas. Santana do Riacho, Brasil Central. 1º Congresso Internacional de Arqueologia de la Cuenca del Plata, Buenos Aires, Argentina

Cornero S, Neves W, Prous A (1999) Prevalencia de caries en una muestra de la población de Santana do Riacho I, o el mito del paleoindio cazador. Rev Argent Antropol Biol 2

Corrêa Novo SP (2020) Brazilian mummies. In: The handbook of mummy studies: new frontiers in scientific and cultural perspectives. Springer, Singapore, 1–12. https://doi.org/10.1007/978-981-15-1614-6_15-1

Da-Glória P (2012) Health and lifestyle in the Paleoamericans: Early Holocene biocultural adaptation at Lagoa Santa, central Brazil. Dissertation, The Ohio State University

Da-Glória P, Larsen CS (2014) Oral health of the Paleoamericans of Lagoa Santa, central Brazil. Am J Phys Anthropol 154:11–26. https://doi.org/10.1002/ajpa.22467

Da-Glória P, Neves WA, Hubbe M (2016) História das pesquisas em Lagoa Santa, Minas Gerais: ossos humanos e patrimônio arqueológico. In: IV Seminário de Preservação do Patrimônio Arqueológico, Rio de Janeiro, Museu de Astronomia e Ciências Afins, 433–443

Da-Gloria, P., Neves, W. A., & Hubbe, M. (2017). Archaeological and paleontological research in Lagoa Santa. *The quest for the first Americans. Cham: Springer*, 45-51.

Da-Glória P, Schmidt CW (2020) Dental microwear texture analyses of the Paleoamericans of Lagoa Santa, Central-Eastern Brazil. In: Dental wear in evolutionary and biocultural contexts. Academic Press, 243–262. https://doi.org/10.1016/B978-0-12-815599-8.00011-3

Da-Glória P, Oliveira RE, Neves WA (2017) Dental caries at Lapa do Santo, central-eastern Brazil: an Early Holocene archaeological site. An Acad Bras Cienc 89:307–316.

Da-Gloria, P., & Bueno, L. (2018). 7 Biocultural Adaptation and Resilience in the Hunter-Gatherers of Lagoa Santa. *Hunter-gatherer adaptation and resilience: a bioarchaeological perspective*, *81*, 141.

Da-Gloria P (2021) Bioarqueologia dos primeiros habitantes do Brasil Central: Saúde e estilo de vida na região de Lagoa Santa, Minas Gerais. Cad LEPAARQ 18:7–40

El Zaatari S (2010) Occlusal microwear texture analysis and the diets of historical/prehistoric hunter-gatherers. Int J Osteoarchaeol 20:67–87.

El Zaatari S, Grine FE, Ungar PS, Hublin JJ (2016) Neandertal versus modern human dietary responses to climatic fluctuations. PLoS ONE 11:e0153277. https://doi.org/10.1371/journal.pone.0153277

Feathers, J., Kipnis, R., Piló, L., Arroyo-Kalin, M., & Coblentz, D. (2010). How old is Luzia? Luminescence dating and stratigraphic integrity at Lapa Vermelha, Lagoa Santa, Brazil. *Geoarchaeology*, *25*(4), 395-436.

Flores R, Sousa JCMD, Araújo AGDM, Ceccantini G (2016) Before Lagoa Santa: micro-remain and technological analysis in a lithic artifact from the Itaparica industry. J Lithic Stud 3:24.

Flores RA, de Mello Araújo AG, Ceccantini G (2019) Uso de combustíveis e processamento de vegetais amiláceos em Lapa Grande de Taquaraçu. In: Arqueologia hoje: tendências e debates.

Flores R, Venezia ME, Araújo AGDM, Ceccantini G (2023) Confirmation of starchy plant processing in Lagoa Santa by Paleoindian people: results of microremain and use-wear analysis at Lapa Grande de Taquaraçu. PaleoAmerica 9:7–24.

Francisco A, Blondel C, Brunetière N, Ramdarshan A, Merceron G (2018a) Enamel surface topography analysis for diet discrimination. A methodology to enhance and select discriminative parameters. Surf Topogr Metrol Prop 6:015002.

Francisco A, Brunetière N, Merceron G (2018b) Gathering and analyzing surface parameters for diet identification purposes. Technologies 6:75. https://doi.org/10.3390/technologies6030075

Guimaraes NRD, Miszkiewicz J (2024) Mobility patterns in Grande Abrigo de Santana do Riacho, Minas Gerais, Brazil: insights from histomorphometric analysis of skeletal remains. Rev Arqueol 37:236–260.

Hermenegildo T (2009) Reconstituição da dieta e dos padrões de subsistência das populações pré-históricas de caçadores-coletores do Brasil Central através da ecologia isotópica. Dissertation, Universidade de São Paulo

Hrdlička A (1912) Early man in South America (No. 52). US Government Printing Office, Washington

Hubbe A, Hubbe M, Neves WA (2013) The Brazilian megamastofauna of the Pleistocene/Holocene transition and its relationship with the early human settlement of the continent. Earth-Sci Rev 118:1–10.

Hurt WR (1960) The cultural complexes from the Lagoa Santa region, Brazil. Am Anthropol 62:569–585. https://doi.org/10.1525/aa.1960.62.4.02a00020

Hurt WR (1964) Recent radiocarbon dates for Central and Southern Brazil. Am Antiq 30:25–33.

Hurt WR, Blasi O (1969) O projeto arqueológico Lagoa Santa, Minas Gerais, Brasil. Arq Mus Paranaense NS Arqueol 4:1–63

Kaiser TM, Brinkmann G (2006) Measuring dental wear equilibriums—the use of industrial surface texture parameters to infer the diets of fossil mammals. Palaeogeogr Palaeoclimatol Palaeoecol 239:221–240. https://doi.org/10.1016/j.palaeo.2006.01.013

Kipnis, R. (2002). Foraging societies of Eastern Central Brazil: an evolutionary ecological study of subsistence strategies during the terminal Pleistocene and early/middle Holocene. *Ann Arbor*.

Kipnis R, Bissaro MC, Prado HM (2010) Os restos faunísticos. In: Araújo AGM, Neves WA (eds) Lapa das Boleiras: um sítio paleoíndio do carste de Lagoa Santa, MG, Brasil. Annablume, São Paulo, 121–147

Louail M, Ferchaud S, Souron A, Walker AE, Merceron G (2021) Dental microwear textures differ in pigs with overall similar diets but fed with different seeds. Palaeogeogr Palaeoclimatol Palaeoecol 572:110415. https://doi.org/10.1016/j.palaeo.2021.110415

Maier W, Schneck G (1982) Functional morphology of hominoid dentitions. J Hum Evol 11:693–696.

Mingatos GS, Okumura M (2016) Modelo de amplitude de dieta aplicada a restos faunísticos do sítio Lapa do Santo (MG) e suas implicações para o entendimento da dieta em grupos paleoíndios do Brasil central. Palaeoindian Archaeol 1:15–31.

Mingatos, G. S., & Okumura, M. (2020). Cervídeos como fonte de matéria-prima para produção de artefatos: Estudos de caso em três sítios arqueológicos associados a grupos caçadores-coletores do sudeste e sul do Brasil. *Latin American Antiquity*, *31*(2), 292-307.

Moreno de Sousa, J. C., & Araujo, A. G. D. M. (2018). Microliths and polished stone tools during the Pleistocene-Holocene transition and early Holocene in South America: the Lagoa Santa lithic industry. *PaleoAmerica*, *4*(3), 219-238.

Nakamura C, Melo Jr JCF, Ceccantini G (2010) Macro-restos vegetais: uma abordagem paleoetnobotânica e paleoambiental. In: Araújo AGM, Neves WA (eds) Lapa das Boleiras: um sítio paleoíndio do carste de Lagoa Santa, MG, Brasil. Annablume, São Paulo, pp 163–190

Nečas D, Klapetek P (2012) Gwyddion: an open-source software for SPM data analysis. Cent Eur J Phys 10:181–188. https://doi.org/10.2478/s11534-011-0096-2

Neves WA (1989) Dados cranianos de remanescentes ósseos humanos da gruta do Sumidouro, MG, Brasil depositados em instituições da Europa. Arq Mus Hist Nat UFMG 11:301–313

Neves WA, Araujo AG, Bernardo DV, Kipnis R, Feathers JK (2012) Rock art at the Pleistocene/Holocene boundary in eastern South America. PLoS ONE 7:e32228. https://doi.org/10.1371/journal.pone.0032228

Neves WA, Atui JPV (2004) O mito da homogeneidade biológica na população paleoíndia de Lagoa Santa: implicações antropológicas. Rev Antropol 47:159–205.

Neves WA, Da-Glória P, Hubbe M (2016) Lagoa Santa: em busca dos primeiros americanos. Cienc Cult 68:52–55.

Neves WA, González-José R, Hubbe M, Kipnis R, Araújo A, Blasi O (2004) Early Holocene human skeletal remains from Cerca Grande, Lagoa Santa, Central Brazil, and the origins of the first Americans. World Archaeol 36:479–501.

Neves WA, Hubbe M, Piló LB (2007) Early Holocene human skeletal remains from Sumidouro Cave, Lagoa Santa, Brazil: history of discoveries, geological and chronological context, and comparative cranial morphology. J Hum Evol 52:16–30. https://doi.org/10.1016/j.jhevol.2006.07.012

Neves WA, Hubbe M, Strauss AM, Bernardo DV (2014) Morfologia craniana dos remanescentes ósseos humanos da Lapa do Santo, Lagoa Santa, Minas Gerais, Brasil: implicações para o povoamento das Américas. Bol Mus Para Emilio Goeldi Cienc Hum 9:715–740.

Neves WA, Prous A, González-José R, Kipnis R, Powell J (2003) Early Holocene human skeletal remains from Santana do Riacho, Brazil: implications for the settlement of the New World. J Hum Evol 45:19–42. https://doi.org/10.1016/S0047-2484(03)00081-2

Ortega DD (2019) Microvestígios em artefatos líticos do sítio Lapa do Santo (Lagoa Santa, Minas Gerais). Master's thesis, Universidade de São Paulo

Piló, L. B., Auler, A. S., Neves, W. A., Wang, X., Cheng, H., & Edwards, R. L. (2005). Geochronology, sediment provenance, and fossil emplacement at Sumidouro Cave, a classic late Pleistocene/early Holocene paleoanthropological site in eastern Brazil. *Geoarchaeology: An International Journal*, *20*(8), 751-764.

Piló LB, Neves WA (2003) Novas datações 14C (AMS) confirmam a tese da coexistência do homem com a megamastofauna pleistocênica na região cárstica de Lagoa Santa, MG. In: Congresso Brasileiro de Espeleologia, 27, pp 100–104

Prous, A. (2013). As muitas arqueologias das Minas Gerais. *Revista Espinhaço* 2:36–54.

Pugliese Junior, F. A. (2007). *Os líticos de Lagoa Santa: um estudo sobre organização tecnológica de caçadores-coletores do Brasil Central* (Doctoral dissertation, Universidade de São Paulo).

Schmidt, C. W., Remy, A., Van Sessen, R., Willman, J., Krueger, K., Scott, R., & Herrmann, N. (2019). Dental microwear texture analysis of Homo sapiens sapiens: Foragers, farmers, and pastoralists. *American Journal of Physical Anthropology*, *169*(2), 207-226.

Schmidt, C. W., El Zaatari, S., & Van Sessen, R. (2020). Dental microwear texture analysis in bioarchaeology. In *Dental wear in evolutionary and biocultural contexts* (pp. 143-168). Academic Press.

Scott, R. S., Ungar, P. S., Bergstrom, T. S., Brown, C. A., Childs, B. E., Teaford, M. F., & Walker, A. (2006). Dental microwear texture analysis: technical considerations. *Journal of human evolution*, *51*(4), 339-349.

Scott, R. S., Teaford, M. F., & Ungar, P. S. (2012). Dental microwear texture and anthropoid diets. *American Journal of Physical Anthropology*, *147*(4), 551-579.

Sousa, D. V., Ker, J. C., Prous, A., Schaefer, C. E., Rodet, M. J., Oliveira, F. S., & Silva, R. C. (2017). Archaeoanthrosol formation and evolution of the “Santana do Riacho” archaeological shelter: An old burial site in South America. *Geoarchaeology*, *32*(6), 678-693.

Strauss, A., Oliveira, R. E., Villagran, X. S., Bernardo, D. V., Salazar-García, D. C., Bissaro Jr, M. C., & Neves, W. (2016). Early Holocene ritual complexity in South America: the archaeological record of Lapa do Santo (east-central Brazil). *Antiquity*, *90*(354), 1454-1473.

Tavares, V., Reis, S., Monteiro, M., & Rodrigues-Carvalho, C. (2019). Resgatando a memória do acervo documental de Padberg-Drenkpol sobre o sítio arqueológico Lapa Mortuária de Confins (região de Lagoa Santa-MG). *Revista de Arqueologia*, *32*(2), 135-148.

Teaford, M. F., Lucas, P. W., Ungar, P. S., & Glander, K. E. (2006). Mechanical defenses in leaves eaten by Costa Rican howling monkeys (Alouatta palliata). *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *129*(1), 99-104.

Thiery, G., Francisco, A., Louail, M., Berlioz, E., Blondel, C., Brunetière, N., & Merceron, G. (2024). Introducing 'trident': A graphical interface for discriminating groups using dental microwear texture analysis. *Peer Community Journal*, *4*.

Ungar, P. S., Brown, C. A., Bergstrom, T. S., & Walker, A. (2003). Quantification of dental microwear by tandem scanning confocal microscopy and scale-sensitive fractal analyses. *Scanning: The Journal of Scanning Microscopies*, *25*(4), 185-193.

Winkler, D. E., & Kubo, M. O. (2025). Inter-microscope comparability of dental microwear texture data obtained from different optical profilometers: Part I Reproducibility of diet inference using different instruments. *The anatomical record*, *309*(9), 2442-2454.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table2.csv
- Table1.docx
- SurfaceprocessingstepsMountainsMapandGwyddion.docx
- Table3.csv
- Scans.zip