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ORIGINAL PAPER



# Sex- and status-based differences in medieval food preparation and consumption: dental microwear analysis at Trino Vercellese, Italy

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## Abstract

Food preparation is of key importance in the medieval period where the manner of preparing ingredients had major sociocultural significance. We examine sex- and status-based differences in dental occlusal microwear from a human skeletal population from medieval Trino Vercellese, Italy, to assess intrapopulation differences in food preparation. We compare microwear results with previously reported stable carbon and nitrogen isotope data to determine the extent to which these two methods for dietary reconstruction correspond. Epoxy casts of second molars from 27 males and females of high- and low-status from medieval Trino Vercellese, Italy, were studied using field emission scanning electron microscopy. Feature tally, pit percentage, pit width, and striation width are compared between subgroups. Whereas previous isotopic data identified low-status males as outliers, dental microwear analysis indicates no differences in diet between the four sex- and status-based subgroups. However, the percentage of pitting is statistically different between males and females when status groups are pooled, with males exhibiting significantly higher values ($p = 0.017$). When sexes are pooled, low-status individuals are found to have significantly more features compared with high-status individuals ($p = 0.030$). This study demonstrates the applicability of dental microwear analysis for uncovering intra-group dietary patterns in socially stratified societies.

**Keywords** Paleodiet · Biocultural · Scanning electron microscopy · Europe · Nutritional anthropology

## Introduction

Dental microwear analysis (DMA) is a widely used analytical technique in anthropology to reconstruct diet (Carnieri 2005; Carnieri et al. 2005; El-Zaatari 2008; El-Zaatari 2010; Molleson 1993; Ungar 1994). Microwear features appear on the surface of tooth enamel as depressions or striations caused by mastication or paramasticatory behavior. Though traditionally applied to reconstructing the diets of extant and extinct primates, bioarchaeologists have adopted DMA and dental microwear texture analysis as a non-destructive, non-invasive technique for reconstructing the diets of past humans (El-Zaatari 2008; El-Zaatari 2010; Ma and Teaford 2010; Schmidt 2001; Smith 1972). DMA complements other dietary reconstruction techniques, including stable carbon and nitrogen isotope analysis and trace element analysis, providing information about what foods were eaten and how they were prepared (Bodoriková 2013; Molleson 1993; Teaford 1996; Teaford and Lytle 1996).

Two main types of microwear features are striations and pits. Ingestion of soft food, such as gruels or meat, leads to the formation of few features, but can create scratches and occasionally some pits, which leads to a higher proportion of scratches on the teeth (Molleson 1993; Teaford 1988; Teaford and Walker 1984; Ungar and Spencer 1999; Walker and Teaford 1989). High striation frequencies are associated with the ingestion of opal phytoliths or grit. An experimental study by Gügel et al. (2001) demonstrates that simulated cases of dental microwear using opal phytoliths from a variety of cereal grains can produce cereal-specific microwear signatures; however, the cereal microwear signatures show significant overlap and are not

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applicable in societies with mixed diets. High incidence of pitting on the surface of a tooth is usually a result of ingestion of hard foods, such as nuts or seeds (Grine 1986; Teaford and Walker 1984). Pit size and shape are related to the size and shape of ingested particles and the force applied during mastication (Gordon 1982; Gordon 1984; Ryan 1979). Consumption of hard and brittle items tends to leave more and larger pits on the grinding surface of teeth, whereas tougher foods tend to leave more scratches (Molleson 1993; Teaford 1988; Teaford and Walker 1984; Ungar and Spencer 1999; Walker and Teaford 1989).

In humans, DMA has been applied to the reconstruction of diet, food preparation, and mastication (El-Zaatari 2008; Lalueza et al. 1996; Ma and Teaford 2010; Molleson 1993; Organ et al. 2005; Pérez-Pérez et al. 2003; Schmidt 2001; Soltysiak 2011; Teaford 1996; Teaford et al. 2001; Ungar and Spencer 1999). Some studies of modern human populations apply DMA to understand inter-population differences among hunter-gatherers and agriculturalists (Mahoney 2007; Özdemir et al. 2013; Schmidt 2010; Ungar and Spencer 1999). Although much research using DMA focuses on dietary transitions (e.g., Schmidt 2001) and dietary differences between groups (e.g., Teaford et al. 2001), understanding within-group dietary variation, particularly among societies marked by marked social stratification with differential access to food, remains understudied (cf. Merceron et al. 2010; Pérez-Pérez et al. 1994). DMA has the potential to distinguish marked social class divisions and differential access to food, since ingredient selection, cookware, and cooking methods affect nutritional quality and the perceived cultural value of food.

Trino Vercellese is a village located in the Piedmont region of northern Italy (Fig. 1). The cemetery of the church of San Michele encompasses hundreds of individuals from the eighth to fourteenth centuries. The skeletal assemblage has been well-documented and extensively studied since the 1980s (Accorsi et al. 1999; Aimar et al. 1999; Caramiello et al. 1999; Celoria 1999; Ferro 1999; Girotti and Garetto 1999; Negro Ponzi Mancini 1999; Porro et al. 1999; Reitsema and Vercellotti 2012; Vercellotti et al. 2011).

During the medieval period in Europe, social class and sex affected which foods individuals consumed (e.g., Adamson 2004; Dembinska 1999; Montanari 1988). Wealth and high status afforded people access to more imported foods and more animal protein. Status differences in diet were likely more pronounced for males. High- and low-status women may have experienced similar dietary environments due to economic conditions and cultural norms. Both married and unmarried women in towns and villages sought work during this time to supplement their household income, usually by working as domestic servants for elite households (Power 1975). Domestic servants in elite households often took meals in their workplace (Power 1975). Due to an aversion to gluttony during the medieval period, women in particular were also expected to display disinterest in food at the dinner table, regardless of status (Adamson 2004; Bynum 1988).

At Trino Vercellese, previous archaeobotanical and stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analyses attest to dietary differences among status and sex groups (Reitsema and Vercellotti 2012; Reitsema et al. 2016; Vercellotti et al. 2015; Vercellotti et al. 2011). The greatest differences in isotopic indicators of diet at Trino Vercellese are status differences among males: diets of low-status males comprised more plants with relatively high $\delta^{13}C$ ratios, and less animal protein. However, intrapopulation differences in medieval menus pertain not only to what foods were consumed but also to how foods are prepared. Food preparation techniques are virtually invisible isotopically but are socioculturally significant. For example, meat may be prepared in many ways, but boiling or stewing is better at retaining juices, and thus characterizes meat consumption among lower classes, whereas roasts are more common among medieval elites (Adamson 2004). Grains are ubiquitous in the medieval menu in the forms of porridges or bread (Adamson 2004).

At Trino Vercellese, where diets of low-status males comprised significantly more millet and less animal protein than diets of females and high-status males, low social status for men may have entailed work outside the home and consumption of different foods. For females, whose isotopic ratios were not socially differentiated, social status divisions may have had fewer dietary consequences. Nevertheless, similarities in isotopic ratios among females and high-status males, while indicating similarities in menu ingredients, may conceal other forms of dietary variation that may have had nutritional and social importance in the medieval period. DMA can be used as a complementary analysis of diet by providing information about food preparation, which potentially could be more influenced by social status and wealth compared with menu ingredients.

We explore the potential applicability of DMA as a complement to $\delta^{13}C$ and $\delta^{15}N$ analyses by analyzing within-group variation in microwear patterns among medieval Italian residents of Trino Vercellese. DMA has the potential to provide information about food preparation and mechanical properties but has rarely been used as a complement to other techniques of dietary reconstruction (Garcia-Gonzalez et al. 2015; Grine et al. 2012; Hogue and Melsheimer 2008). The purpose of this study is to explore the possibilities that diets of high-status males and females at Trino Vercellese differed despite having similar $\delta^{13}C$ and $\delta^{15}N$ values, and that the isotopic differences of low-status males also are reflected in dental microwear features. We test the null hypothesis that microwear features agree with earlier isotopic results in terms of the similarities between subgroups with regard to the number of features and variance in those features. Previously published $\delta^{13}C$ and $\delta^{15}N$ values of teeth and bones from the Trino Vercellese cemetery found that low-status males consumed more millet than all other subgroups (Reitsema and Vercellotti 2012). Millet could have been consumed as gruel or bread, and was considered a low-status food in this region of Italy (Nada Patrone 1981). Our first hypothesis is that microwear features of

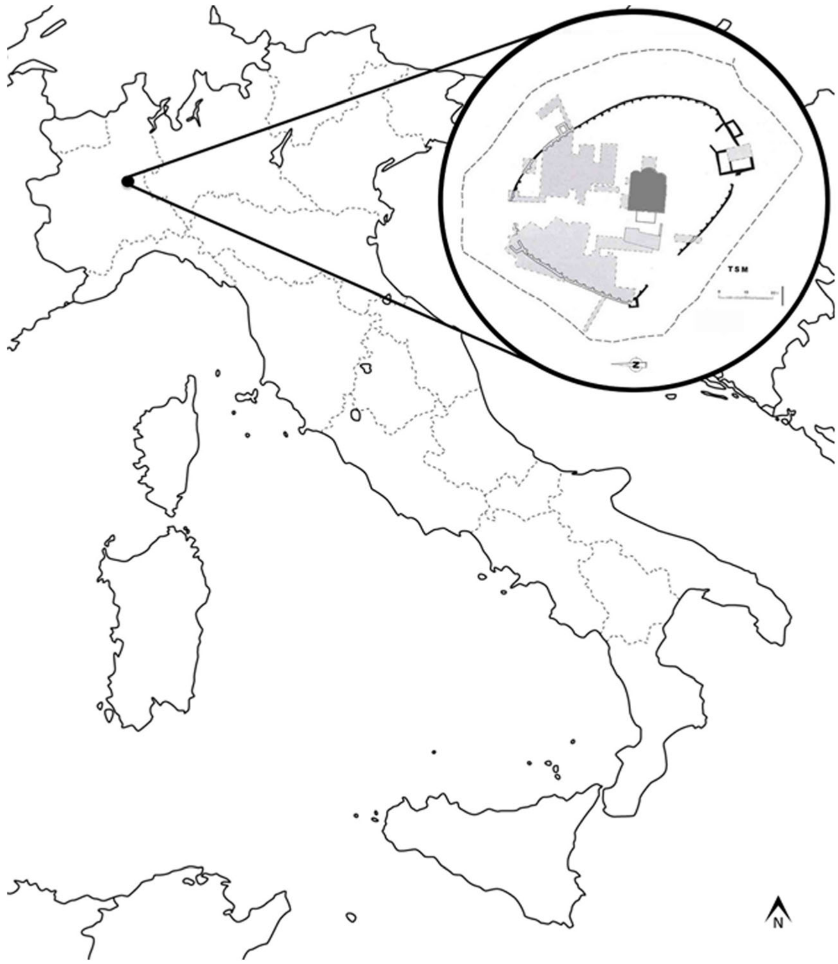

**Fig. 1** Map of Trino Vercellese

low-status males are significantly different compared with high-status males and all females in terms of numbers and variance. Previous $\delta^{13}C$ and $\delta^{15}N$ data did not identify status differences among the diets of females at Trino Vercellese. However, it is entirely possible that while high-status males and females and low-status females do not exhibit any significant $\delta^{13}C$ and $\delta^{15}N$ differences, they nevertheless consumed foods prepared in different ways. We hypothesize that high-status individuals and low-status females will exhibit similar numbers of microwear features and variance in those features. Interpreting microwear results alongside isotopic results helps point to which features or isotopic signatures in human remains.

## Materials and methods

### Trino Vercellese

This research analyzes tooth casts created from skeletal remains recovered from the medieval cemetery of San Michele's church in Trino Vercellese (VC) in northern Italy. San Michele's church is one of the earliest *pievi*, churches granted the ability to perform baptisms and inhumations, in the area surrounding Torino (Vercellotti et al. 2011). The University of Torino excavated the cemetery at San Michele's church between 1980 and 1994, with 749 burials uncovered during the excavation (Vercellotti et al. 2011). The majority of remains ($n = 688$) date from the medieval period (eighth to thirteenth century CE), with the rest dating from the post-medieval period (fourteenth century). Eighty-five percent ($n = 585$) of the individuals recovered were adults, while the remaining 15% ($n = 103$) were juveniles. The skeletal collection from this site is likely representative of the living adult population during the medieval period.

Several lines of evidence, including burial location, burial typology, and grave good typology, point to variation in social status among the individuals buried in San Michele's cemetery (Accorsi et al. 1999; Aimar et al. 1999; Caramiello et al. 1999; Celoria 1999; Ferro 1999; Girotti and Garetto 1999; Negro Ponzi Mancini 1999; Porro et al. 1999). Individuals from the cemetery were buried both inside and outside of the church. During the medieval period, elite community members, including clergy, community leaders, and philanthropists, were frequently honored in death through burial in privileged spaces inside of the church, whereas others of lower social rank were buried in the consecrated ground surrounding the church (Negro Ponzi Mancini 1999). Within the church, single male burials closest to the altar suggest that these individuals were members of the clergy. Burials found further from the altar inside the church were composed of multiple individuals, including women and children, which suggests that these burials are high-status family burials. Differences in burial typology between the internments inside and outside the church also suggest social status differentiation; all the burials inside the church are characterized by well-defined masonry cases, whereas burials outside the church mainly consist of dirt ditches lacking wooden or stone delimitations. Metal grave goods, including brooches, buckles, and gold thread, were more common discoveries among burials inside the church compared with those outside the church, strongly suggesting status differences between these sub-populations (Negro Ponzi Mancini 1999). An extensive review of the determination of status differences at Trino Vercellese can be found in Vercellotti et al. (2011).

Several archaeological, archaeobotanical, and zooarchaeological studies have described the environmental conditions and subsistence strategies during the medieval period at Trino Vercellese (Accorsi et al. 1999; Aimar et al. 1999; Caramiello et al. 1999; Celoria 1999; Ferro 1999; Girotti and Garetto 1999; Negro Ponzi Mancini 1999; Porro et al. 1999; Reitsema and Vercellotti 2012; Vercellotti et al. 2011). Research indicates that livestock breeding was the primary focus of the local economy. Swine, cattle, and sheep/goats were the most abundant domestic faunal species found at the site (Ferro 1999). The remains of horses and domestic fowl also were found, suggesting these species also were domesticated, but were not as important to the local economy (Ferro 1999). Butchery marks and age-at-death profiles indicate that swine and cattle were used for meat and hides, and sheep and goats were primarily bred to produce wool and milk (Aimar et al. 1999). Wild ungulates, mainly red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*), were also found among the faunal remains and were likely hunted regularly as an alternate source of meat. Few aquatic faunal remains were found at the site, indicating that marine and river resources were not a primary part of the diet of the inhabitants of medieval Trino Vercellese. Isotopic evidence indicates the diet was mainly terrestrial and based on $C_3$ plants including wheat or vegetables, but that some individuals consumed $C_4$ plants and small amounts of fish (Reitsema and Vercellotti 2012; Reitsema et al. 2016). Hardwood forests dominated the landscape of the local area but were slowly replaced by pastures and crops over time (Caramiello et al. 1999). Cereals, legumes, and aromatic plants were the primary source of plant remains found in the village (Accorsi et al. 1999). Paleobotanical analysis and historical documentation confirm that millet was cultivated at Trino Vercellese (Accorsi et al. 1999; Caramiello et al. 1999). Interestingly, there is historical evidence that cereals with large grain sizes, such as wheat, barley, and rye, were subject to higher fees in land use contracts than cereals with smaller grains, such as millets and sorghum (Nada Patrone 1981), pointing to a status difference in cereal consumption. Pottery vessels were used for preparing and storing food and for direct contact with fire and cooking. For example, soapstone vessels were suspended over a fire to boil small portions of vegetables and meat. Soapstone tableware and kitchenware were valued at Trino Vercellese, as is attested by several attempts to repair broken vessels (de Vingo 2011).

During the medieval period, high-status individuals tended to have a diet composed mainly of tender meats, with little if any fruits and vegetables (Nada Patrone 1981). Members of the lower classes tended to consume fewer calories overall, but they tended to have a more varied diet compared with elites. Cookbooks from the medieval period geared towards upper-class individuals rarely mentioned millet as an ingredient (Adamson 2004). Millet was consumed mainly in the form of porridge but could also be baked into a bread.

## Methods

The same samples from Reitsema and Vercellotti's (2012) isotopic study were selected for microwear analysis for a complementary data set. Three samples (S80, S56, and S133) were excluded due to poor enamel preservation. In total, second molars (M2s) from three high-status females, six low-status females, eight high-status males, and ten low-status males were analyzed for dental microwear. Most M2s included for microwear analysis are maxillary (81%). Five individuals are included in the mandibular sample: two high-status males (S41 and S166/2B), one high-status female (S73), one low-status female (S207), and one low-status male (S328). A Mann-Whitney *U* test was performed to determine if there were any differences between maxillary and mandibular molar microwear patterns, and no statistical differences were found between these groups (see Appendix Table 4). This result confirms earlier studies that also demonstrate no differences between upper and lower molar microwear (El-Zaatari et al. 2005; Kay and Hiiemae 1977; Semprebon et al. 2004). One low-status male (S-424) was excluded when comparing the $\delta^{13}$C and $\delta^{15}$N data with dental microwear features because the collagen had been deemed to be poorly preserved (Reitsema and Vercellotti 2012).

Dental impressions were taken with Coltène-Whaledent President Light Body/Regular Body polyvinylsiloxane. One molar impression was taken from each individual during the course of the study. A high-resolution positive replica of each molar impression was made using Struers Epo-Fix epoxy resin kit by mixing the hardener and resin together at a ratio of 1:7 by volume. The mixture was centrifuged for 30 s to remove bubbles. The epoxy resin was then poured into the polyvinyl impressions and allowed to cure for approximately 24 h. After curing, the replicas were sputter-coated with a 200-Å gold layer using a SPI-Module line molecular sputter coater and analyzed using a FEI Teneo field emission scanning electron microscope (FE-SEM). For each tooth, one micrograph of crushing/grinding facets (facet 9, 10*n*, or *x*) of the distal-buccal crown was taken at × 500 magnification, at 10 kV acceleration voltage, and 0° of tilt angle (Kay 1975; Kay 1977). The resulting micrograph was a 1536 × 1024-pixel image covering 828 × 553 μm of the surface of the distobuccal cusp of each tooth. In order to avoid the foreshortening of features, a subsection measuring 276 × 184 μm of each micrograph was analyzed using Microwear 4.02 software calibrated to × 500 magnification (Ungar 1995; Ungar et al. 1991) (Fig. 2). Microwear 4.02 uses a length-to-width aspect ratio of 4:1 to differentiate striations from pits. Using the data generated from this software, four variables were analyzed: feature tally, pit width, striation width, and pitting percentage. Previous research indicates that these specific traits are useful for detecting dietary differences from occlusal dental microwear analysis among human and anthropoid subjects (Organ et al. 2005; Teaford et al. 2001; Ungar 1994). To eliminate interobserver error, each micrograph was analyzed by the same observer (A.S.).

The statistical software package R was used to perform all statistical analyses for this project. Statistical significance is set at any probability less than 0.05 ($\alpha < 0.05$). Analysis of variance (ANOVA) requires that three assumptions be met to ensure accurate results: all data are randomly selected, normally distributed, and homoscedastic. All samples were included in this research if they had exhibited minimal dental attrition on a maxillary or mandibular second molar. Variables were assessed for normality using stripcharts, histograms, and qqnorm plots that separated each variable by sex and status. Each variable was found to be either negatively or positively skewed. Consequently, the Kruskal-Wallis test was used to determine if high-status males, high-status females, low-status males, and low-status females exhibit statistically different microwear features. The Kruskal-Wallis rank sum test is the non-parametric equivalent to ANOVA that only assumes random sampling but does not require that the data are normally distributed or homoscedastic. Mann-Whitney *U* tests were used to assess sex and status differences separately. Variance between the subgroups was assessed using Levene's test. Stepwise linear regression was used to determine if $\delta^{13}C$ and $\delta^{15}N$ values have a linear relationship with any specific microwear variables.

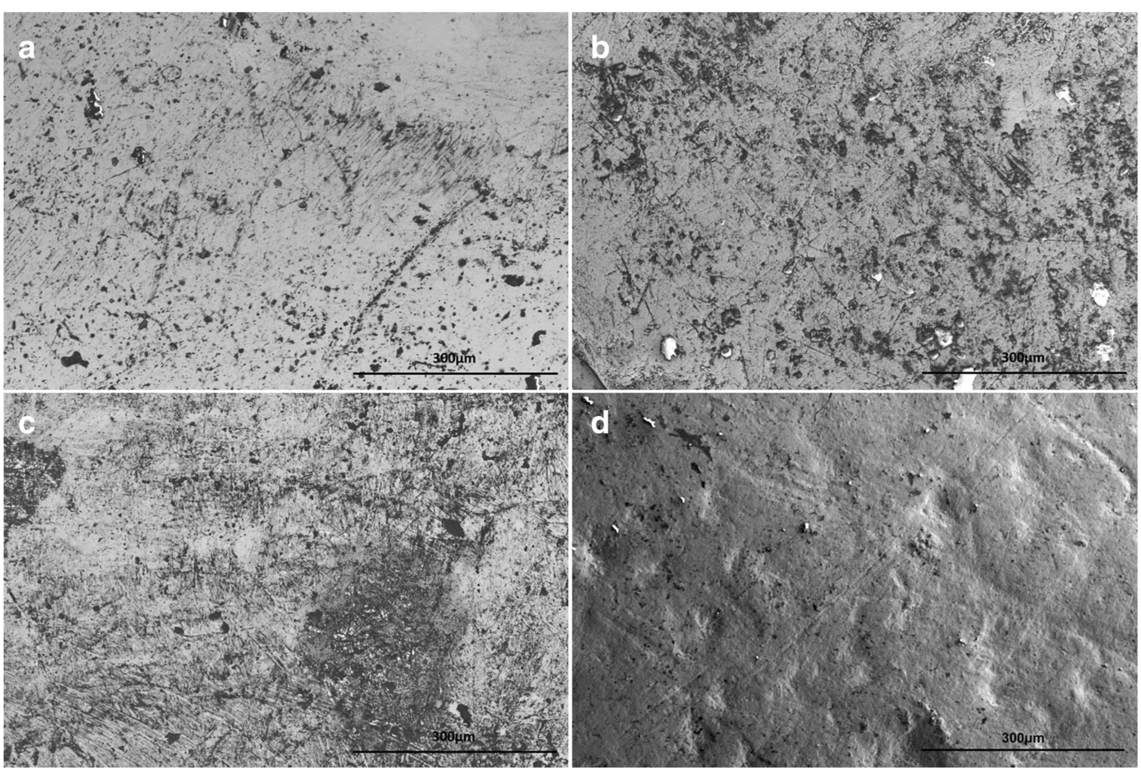


**Fig. 2** Trino Vercellese micrograph images. **a** Individual S46, a high-status female. **b** S166, a high-status male. **c** S528, a low-status female. **d** S456, a low-status male

**Table 1** Summary statistics by sex and status

| | Sex and status | | | | Sex only | | Status only | |
|---|---|---|---|---|---|---|---|---|
| | High-status | | Low-status | | | | | |
| | Females ($n = 3$) | Males ($n = 8$) | Females ($n = 6$) | Males ($n = 10$) | Females ($n = 9$) | Males ($n = 18$) | High ($n = 11$) | Low ($n = 15$) |
| Feature tally | | | | | | | | |
| Max | 119 | 194 | 317 | 272 | 317 | 272 | 194 | 317 |
| Median | 107 | 124 | 173 | 165 | 119 | 142.5 | 119 | 165 |
| Min | 89 | 44 | 18 | 91 | 18 | 44 | 44 | 18 |
| Striation width (μm) | | | | | | | | |
| Max | 2.21 | 3.08 | 2.33 | 3.60 | 2.33 | 3.60 | 3.08 | 3.60 |
| Median | 2.08 | 1.53 | 1.88 | 1.65 | 2.01 | 1.63 | 1.83 | 1.67 |
| Min | 1.83 | 1.05 | 0.55 | 0.95 | 0.55 | 0.95 | 1.05 | 0.55 |
| Pit width (μm) | | | | | | | | |
| Max | 5.79 | 6.69 | 7.48 | 4.65 | 7.48 | 6.69 | 6.69 | 7.48 |
| Median | 5.14 | 3.03 | 4.09 | 3.66 | 4.41 | 3.56 | 3.69 | 3.75 |
| Min | 4.12 | 2.09 | 1.31 | 1.79 | 1.31 | 1.79 | 2.09 | 1.31 |
| Percentage pitting (%) | | | | | | | | |
| Max | 55.06 | 87.7 | 81.90 | 88.02 | 81.60 | 88.02 | 87.70 | 88.02 |
| Median | 49.58 | 64.22 | 54.80 | 77.86 | 51.55 | 71.04 | 56.82 | 69.00 |
| Min | 47.66 | 37.50 | 16.67 | 48.67 | 16.67 | 37.50 | 37.50 | 16.67 |

## Results

### Sex- and status-based differences

Table 1 provides the descriptive statistics for the microwear features when the sample is divided into high- and low-status males and females, sex-based groupings, and status-based groupings.

Feature tallies for all groups overlap, although low-status individuals exhibit higher feature counts compared with high-status individuals in general. No statistically significant differences in feature tally exist between groups based on the results of the Kruskal-Wallis rank sum test ($df = 3$, $X^2 = 5.7566$, $p = 0.1241$). There are also no significant differences in feature tally when the sample is grouped based on sex (Table 2), but there are significant differences in feature tally between high- and low-status individuals ($W = 43.5$, $p = 0.030$). Low-status individuals ($\tilde{x} = 165$) exhibit significantly more features compared with high-status individuals ($\tilde{x} = 119$) (Figs. 3 and 5). Levene's test revealed that the variance in feature tally was significantly different between all sex- and status-based subgroups ($F = 4.057$, $p = 0.01882$) (Table 3).

Striation width is similar among all subgroups in this population. The Kruskal-Wallis rank sum test reveals that the differences in striation width between high-status males, low-status males, high-status females, and low-status females are not statistically significant ($df = 3$, $X^2 = 1.2042$, $p = 0.752$). No statistically significant differences in medians or variance are found when the population is divided by sex or status (Table 2).

Pit width is consistently similar among all subgroups. The Kruskal-Wallis rank sum test indicates no significant differences between the median pit widths for all four subgroups ($df = 3$, $X^2 = 3.003$, $p = 0.3912$). Additionally, no significant sex-based or status-based differences in medians or variance in pit width are observed within this population (Table 2).

Percentage pitting is calculated by dividing the number of pits by the total number of features. The Kruskal-Wallis rank sum test results indicate that there are no statistically significant differences between groups in terms of percentage pitting ($df = 3$, $X^2 = 7.4147$, $p = 0.0598$). When the groups are pooled by sex, males ($\tilde{x} = 71.04\%$) exhibit significantly higher pitting percentage median or variance compared with females ($\tilde{x} = 51.55\%$) (Figs. 4 and 5). There are no significant differences in pitting percentage between high- and low-status groups (Table 2).

**Table 2** Mann-Whitney *U* test results

| | Sex | | Status | |
|---|---|---|---|---|
| | *W* | *p* | *W* | *p* |
| Feature tally | 70.5 | 0.607 | 43.5 | 0.030* |
| Striation width | 89 | 0.700 | 100.5 | 0.554 |
| Pit width | 107 | 0.194 | 96 | 0.716 |
| Percentage pitting | 35 | 0.017* | 66 | 0.294 |

*$p$ values are significant at the 0.05 level

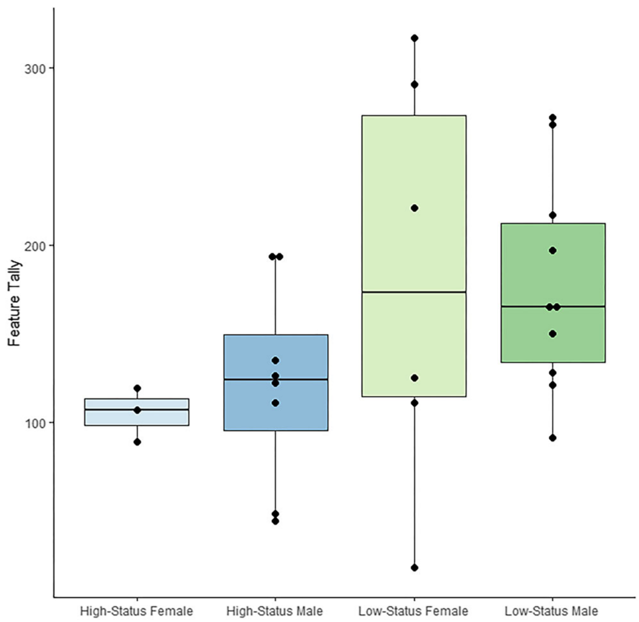


**Fig. 3** Boxplots of feature tally showing medians and interquartile ranges. Low-status individuals (10 males, 6 females) have a significantly higher feature tally compared with high-status individuals (8 males, 3 females) ($W = 43.5$, $p = 0.030$). Variance between all subgroups ($F = 4.057$, $p = 0.01882$) is statistically significant

## δ $^{13}$C and δ $^{15}$N stepwise regression analysis

The stepwise linear regression shows no statistically significant relationships between microwear variables and $\delta^{13}$C and $\delta^{15}$N values (Fig. 6).

## Discussion

Reitsema and Vercellotti's (2012) stable isotope analysis of teeth and bones from the cemetery of San Michele found that low-status males consumed relatively more millet than the rest of the individuals they examined. We hypothesized that high-status males, high-status females, and low-status females would exhibit microwear features similar to each other, and that the microwear features of low-status males would differ from the other subgroups, in terms of numbers of features and variance in those features. When four groups are compared (high-status males, high-status females, low-status males, low-status females), then we find no statistically significant differences in dental microwear at Trino Vercellese. However, when two groups are compared (females vs. males or low-status vs. high-status individuals), our analyses show statistical differences in dental microwear. High-status individuals exhibit a lower median feature tally compared with low-status individuals, and males exhibit a higher percentage pitting compared with females.

Historical evidence could explain and account for the status-based differences in DMA among the medieval inhabitants of Trino Vercellese. Considering that molars of low-status individuals (males and females) have significantly more features than those of high-status individuals, low-status individuals appear to have been consuming a harder diet than high-status individuals. A harder diet for low-status individuals is consistent with historical information about diet in medieval Italy. High-status individuals likely had more access to better quality food, particularly tender meats and grains milled to a fine consistency (Montanari 2001). Among high-status individuals, tender meats, particularly from young animals, were a dietary staple (Montanari 2001; Nada Patrone 1981). Hence, high-status individuals were likely consuming a softer diet compared with low-status individuals, and this difference is reflected in their dental microwear as a lower median feature tally among high-status individuals. Low-status males may also have consumed foods that were contaminated with dirt or grit, which could explain the high number of features among low-status males. Dirt/grit contamination in food was a common occurrence in pre-industrial societies before abrasives were able to be removed using modern food processing methods. Stone grinding of cereals can leave gritty particles in the form of siliceous phytoliths (Gügel et al. 2001; Romero 2012), and low-status males were more likely to consume less finely ground cereals compared with their high-status counterparts in medieval Italy.

Sex-based comparisons suggest that both high- and low-status males in medieval Trino Vercellese may have been consuming harder diets than females. This is an interesting

**Table 3** Levene's test results

| | Sex | | Status | | Sex and status | |
|---|---|---|---|---|---|---|
| | *F* | *p* | *F* | *p* | *F* | *p* |
| Feature tally | 0.8347 | 0.3697 | 3.48 | 0.07389 | 4.057 | 0.01882* |
| Striation width | 0.2689 | 0.6086 | 0.0203 | 0.8877 | 0.6359 | 0.5995 |
| Pit width | 1.5389 | 0.2263 | 0.088 | 0.7692 | 1.5795 | 0.2215 |
| Percentage pitting | 0.0143 | 0.9059 | 0.2566 | 0.6169 | 1.338 | 0.2865 |

*$p$ values are significant at the 0.05 level

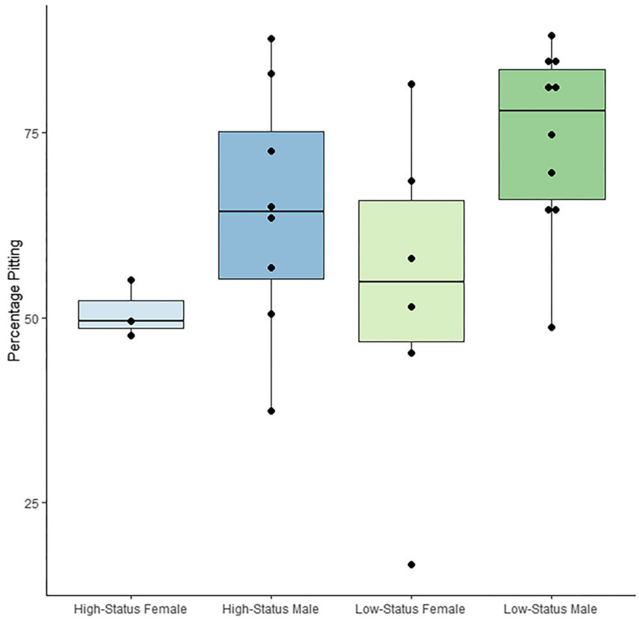


**Fig. 4** Boxplots of pitting percentage showing medians and interquartile ranges. Males have a statistically higher pitting percentage compared with females ($W = 35$, $p = 0.017$)

complement to the isotopic evidence, which did not find that high-status males were dissimilar from females in terms of diet. In the present study, males of both status groups exhibit a significantly higher median percentage of pitting compared with females of both status groups, although there were no significant differences in pit width, striation width, or feature tally between males and females. This result suggests that males of both status groups consumed more of the same pit-producing foods as females in general. While the fact that low-status males exhibit different microwear features than females is unsurprising given the previously reported dietary isotope differences between these groups, the fact that high-status males exhibit microwear features that differ from females, and microwear features that are similar to low-status males, is unexpected. These results suggest males regardless of status may have been eating foods prepared in similar manners despite comprising different ingredients, or perhaps were consuming foods that females did not. Historically, there is precedent for males and females to have slightly different dietary habits that could explain this difference in the amounts of pit-producing food items. Not only may males have had more access to foods of their own choosing owing to higher rank within the household, during the medieval period, high- and low-status women alike were expected to express disinterest in food, especially in public settings, specifically to avoid the sin of gluttony (Adamson 2004; Bynum 1988). The stigma of overeating among women could have caused men to consume a higher proportion of choice foods at the dinner table, some of which could have been pit-producing, such as nuts or seeds. This stigma could have created a situation that allowed men to consume a slightly coarser diet than women, without necessarily consuming higher quantities of food than women. Alternatively, as proposed by Reitsema and Vercellotti (2012), diet differences may relate to whether or not meals were consumed inside the home, or afield, in which case harder foods may be the ones encountered outside the home. Another explanation is that pit frequency is related to the amount of food consumed, and males ate more food regardless of status compared with females.

High-status females also show a statistically lower variance ($s^2 = 228$, CV = 0.14) in feature tally compared with high-status males, low-status females, and low-status males based on the results of Levene's test ($f = 4.057$, $p = 0.01882$). The high-status female group clusters more than all the other groups in terms of pit width and has considerably smaller ranges in all other dental microwear variables as well (see Table 1). The lack of variation among high-status females could be explained by the low sample size for this group ($n = 3$), but low-status females also have a relatively low sample size ($n = 6$) with considerably more variance compared with high-status females. Another possible explanation is that high-status female's diets were highly socially regulated, and therefore the variability of foods consumed by high-status females is more restricted compared with other social groups. The idea that status would canalize diet already is supported by the isotopic evidence from Trino Vercellese, and the dental microwear evidence may be demonstrating this canalization in another dimension (e.g., diet texture) and at a more extreme level among high-status females in particular. Historical sources about

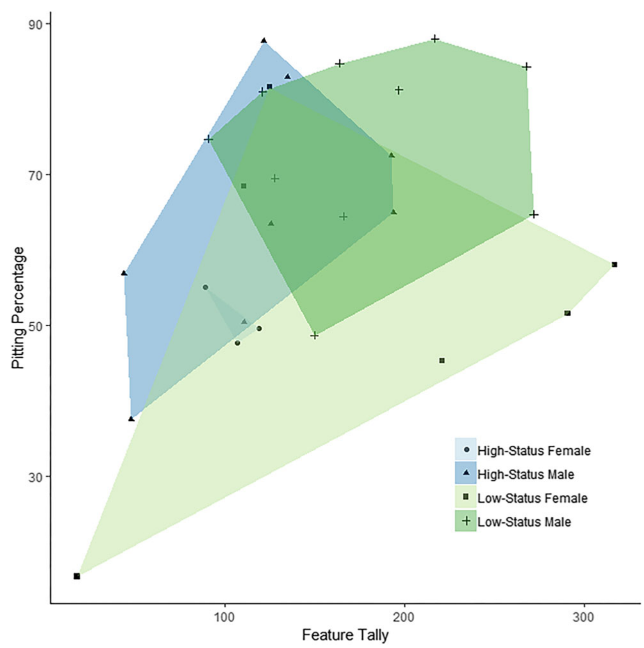


**Fig. 5** Scatter plot of feature tally by pitting percentage. The polygons illustrate the limits of scatter for each subgroup

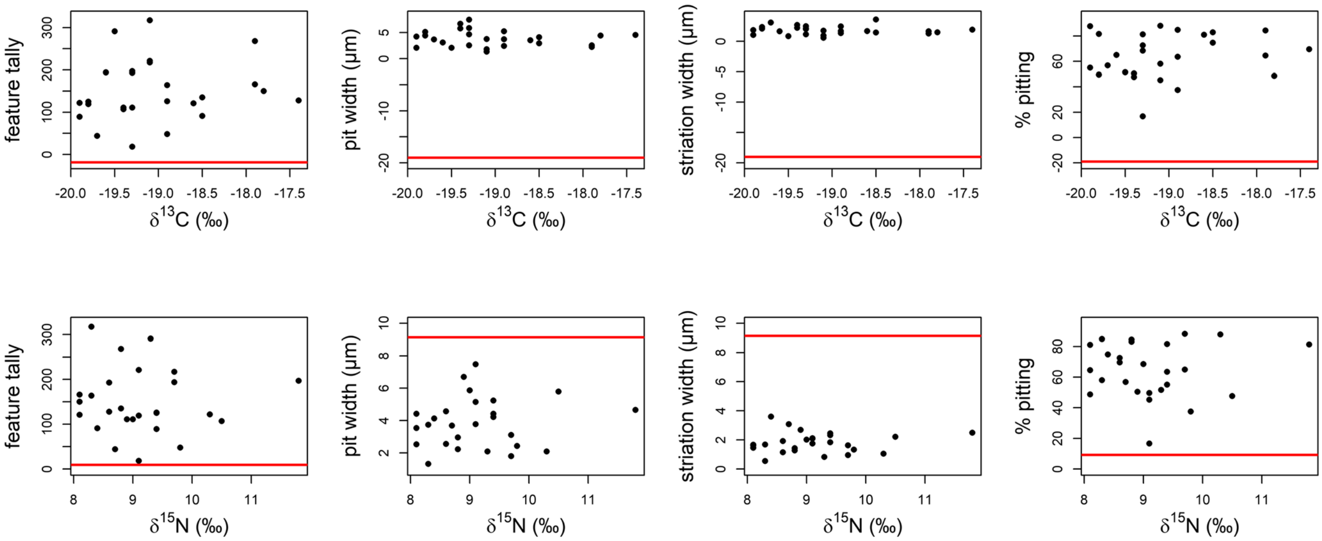


**Fig. 6** Graphs of the stepwise regression analysis comparing carbon and nitrogen stable isotope ratios with dental microwear features. The red line indicates the regression equation for the stepwise linear regression

dietary patterns in medieval Italy also provide several possible explanations for canalization of diet among high-status females. Adamson (2004) discusses how high-status females during the medieval period were expected to avoid appearing gluttonous and therefore restricted their diets, particularly at public events. She also describes how the medieval clergy would recommend religious-based dietary restrictions, particularly against the consumption of meat, which may have been more observed by high-status females because of their increased access to high-quality foods compared with low-status individuals, and due to more social pressure to appear devout.

Since dental microwear is a consequence of attrition and abrasion during mastication, morphological and functional differences between the sexes could influence the microwear signature. Bite force differs between human males and females, with males exhibiting a significantly greater average bite force compared with females (Živko-Babić et al. 2002). Additionally, individuals exhibiting larger mandibular corpora dimensions undergo larger compression loadings compared with individuals with smaller mandibular corpora, resulting in deeper and longer microwear features (Mahoney 2006b). Among *Pan troglodytes*, sex differences have been observed with regard to striation length and feature frequency (Gordon 1982). However, despite these functional and morphological differences among males and females, sex differences in microwear features among human populations have not been consistently observed (Lalueza et al. 1996; Mahoney 2006a; Nystrom 2008; Schmidt 2001), suggesting that dietary sources of microwear variation may eclipse functional and morphological factors. If the sex differences in our sample were the result of sexual dimorphism in mandibular size or bite force, then we would predict that males would exhibit deeper and wider features compared with females. However, we do not observe any statistically significant differences in pit width or striation width between males and females in this population.

There are two possible explanations for the differences in the results obtained in the current study and those obtained through stable isotope analysis by Reitsema and Vercellotti (2012). First, DMA captures information about dietary mechanical properties close to the time of death (Mahoney 2006a). This time-average difference may result in different dietary signatures since DMA captures a shorter window of diet compared with carbon and nitrogen isotope analyses. Second, DMA captures information about dietary consistency, whereas isotope ratios reflect dietary composition. Dietary consistency is influenced by a variety of factors, including ingredient choice, food preparation, and proportion of foods consumed. For instance, individuals may have similar isotope signatures, but may have been consuming similar ingredients that were prepared in different ways, thereby resulting in divergent dental microwear signatures.

The present study found no relationship between dental microwear and $\delta^{13}C$ and $\delta^{15}N$ values. This result suggests that dental microwear features are independent of $\delta^{13}C$ and $\delta^{15}N$ isotope values in humans. Our analysis demonstrates how differences in dietary texture do not necessarily correspond to differences in dietary composition. Individuals at medieval Trino Vercellese may have been consuming different types of foods, but the foods were prepared within the same culinary tradition. The result of this preparation was a similar overall dietary texture between individuals consuming different types of foods.

The dental microwear and stable isotope ratios from the residents of Trino Vercellese indicate that food texture differed based on sex within status groups, and status within each sex. Low-status individuals exhibit a higher median feature tally compared with high-status individuals, indicating that low-status individuals of both sexes consumed a coarser diet. Females exhibit a lower median pitting percentage and thus a softer diet compared with males. No single microwear variable, nor combination of variables, predicted either $\delta^{13}C$ or $\delta^{15}N$ ratios, meaning it is not possible to use microwear features alone to clarify which foods in particular engender which isotope signatures or vice versa. The lack of a relationship between microwear features and isotope ratios suggests individuals consuming different foods may prepare those foods in similar ways, leading to similar dental microwear features despite isotopic differences.

This research demonstrates that intrapopulation differences in dental microwear are observable in populations marked by strongly defined socioeconomic stratification. Several microwear variables indicate subgroup differences that complement other dietary reconstruction methods. In this study, DMA provides information about medieval diet that complements and expands the previous isotopic study of Trino Vercellese (Reitsema and Vercellotti 2012). In particular, the results of this study demonstrate that high-status males, high-status females, and low-status females were not consuming the same diets as predicted by the previously published stable isotope analysis. Instead, diets differed between males and females, and between status groups, in terms of preparation methods, and perhaps ingredients and volume. Additionally, despite low-status males consuming more millet than their high-status counterparts (Reitsema and Vercellotti 2012), this study shows high- and low-status males consumed diets of similar consistency. The results of this study complement prior isotopic and archaeological evidence to provide new information about dietary differences between the sex- and status-based subgroups residing at Trino Vercellese.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

## Appendix. Trino Vercellese

**Table 4** Mann-Whitney *U* test results for upper vs. lower M2s

| | Upper vs. lower M2s | |
|---|---|---|
| | *W* | *p* |
| Feature tally | 41 | 0.3994 |
| Striation width | 60 | 0.7788 |
| Pit width | 66 | 0.5239 |
| Percentage pitting | 59 | 0.8325 |

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