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The monks of San Millán: Investigating the transition between pre-monastic and monastic diet using carbon and nitrogen isotope ratios in incremental dentine

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ABSTRACT

From the early Medieval period, Christian monasteries were wealthy and powerful, and played a central role in both religious and political life. Those who entered the monasteries did so at the age of 7–8 years and were drawn from a wide range of social strata. From that point, they were subject to the dietary rules imposed by the rules of each monastic order. In order to assess the origins and diet of 10 monks who lived in the monastery of San Millán de la Cogolla Yuso (La Rioja, Spain) during the 17th – 18th century, collagen from small sections of human dentine (representing the childhood diet) and from ribs (an average of the last 5–10 years of adult diet) was measured to establish lifetime variations in the isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$). Bulk collagen $\delta^{13}C$ (overall mean = -18.2‰ +/-0.4) and $\delta^{15}N$ (overall mean = 12.6‰ +/-0.8) values from the ribs suggest 2 adult cohorts: one with a diet based on C_3 plants and a high intake of protein from meat or dairy products and some marine resources and a second cohort with some C_4 plant consumption alongside meat and dairy. Data from the dentine sections revealed different dietary patterns during the period of tooth formation among the monks, suggesting that 4 of them entered the monastery after consuming lower status diets during childhood.

1. Introduction

The Christian monasteries played a very important role as centres of knowledge, wealth and power, both religious and political since the beginning of the Middle Ages (Lawrence, 2001). As part of the Church, they had close relationships to Kings, Emperors and the Pope and were influential in the political and social history of Europe until recent times, especially in the Iberian Peninsula where this relationship has been very strong (Lawrence, 2001). Due to their vow of chastity the monks were not allowed to reproduce. During the Medieval period strict class and hierarchy was maintained: one was born as a servant, as a nobleman or a king. A person who became a monk during his life could thus escape his childhood origins.

People of different status, low and high, entered monasteries of the Benedictine order, normally around the age of seven years. According to literary sources, they were the “child oblates”, donated to the order by their parents (Lawrence, 2001). Although this figure disappeared after the 13th century, children continued to enter monastic orders even during the 17th and 18 h centuries (Colombás, 1998). Once admitted, everyone had to follow a strict regime of behaviour (the Rule), including dietary restrictions. Throughout the early period the basic diet consisted of one meal in winter, two in summer, based on white bread, salt and water. During fasting days, which could be as extensive as half of the year (Vandereycken and Van Deth, 1996), they were allowed to consume other foods such as vegetables, dairy products and fish, the latter being the basis of the fasting diet (Lawrence, 2001). Meat was very restricted and only available to the brethren who were very old or in the infirmary. During later periods, monastic orders did not always obey the Rule, increasing the intake of meat even of forbidden animals by following new religious decrees from the Pope (papal bulls) or using different interpretations of the Rule (Vandereycken and Van Deth, 1996). For example, in some orders monks were forbidden to eat meat apart from animals which were hunted, so a monk raised and trained hounds in order to chase the pigs that he also raised, turning them into game meat. Another strategy was to follow the dietary restrictions in the refectory where the brethren ate and build another room where they

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could consume meat (Vandereycken and Van Deth, 1996).

The aim of this study was to investigate the differences in diet during the lifetime of adult males recovered from a monastic cemetery and who were considered from the archaeological and historical evidence likely to have been monks. This was achieved by analysing the isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) of collagen from permanent tooth dentine and rib. A tooth from each of ten individuals was selected to provide information about dietary patterns through the period of childhood, whilst the $\delta^{13}C$ and $\delta^{15}N$ from collagen derived from the rib bone of each individual would represent the diet of the inhabitants of the monastery during their last 5 – 10 years of life (Valentin, 2002).

1.1. Bone and dentine collagen in dietary studies

The measurement of $\delta^{13}C$ and $\delta^{15}N$ in the collagen of human tissues has been shown in numerous studies to allow the estimation of the diet of that individual during the period of tissue formation. Bone, as a living and active tissue, is remodelling continuously, being resorbed, and replaced through the life of the individual once skeletal growth and formation ceases. The rate of turnover varies from one bone to other between 3% – 4% per year, taking from 10 to 15 years to complete the process (Bell et al, 2001; Fahy et al, 2017; Hedges et al, 2007) but rib bone, which was sampled for this study, is considered to have a quicker turnover rate compared with the rest of the skeleton due to the higher proportion of trabecular bone (Valentin, 2002).

Dentine from permanent human teeth has been used to investigate temporal dietary changes during tooth formation. The developmental age of each tooth is well-established (AlQatahtani, 2009; Ubelaker, 1989) and is not affected significantly by sex, geographical origin or even nutritional status (Elamin and Liversidge, 2013; Reid and Dean, 2000; Reid and Dean, 2006). Furthermore, tissues which grow incrementally such as hair and dentine can be used to provide temporal resolution for the changes in diet of an individual (e.g. de Luca et al, 2012; Fuller et al, 2006; Mekota et al. 2006). Method 2 by Beaumont et al. (2013) has been used in previous studies to show short-term dietary changes in the childhood of, for example, Mesolithic individuals from Shetland by Montgomery et al (2013), infant feeding strategies in Roman Bainesse (Cocozza et al, 2021) and in the tissues of individuals during the 19th century Great Irish Famine (Beaumont and Montgomery, 2016). Using this protocol, it is possible to calculate the approximate age at which each section of dentine was formed (Beaumont and Montgomery, 2016). Measuring the isotope ratios in tissues developing at different times offers the potential to follow the diet of an individual through childhood and adolescence, and to then compare with the last few years of life using rib bone collagen (Beaumont, 2013).

In this study we investigated differences in the diets of the putative monks before and after the age at which they should have entered the monastery. Furthermore, it may be possible to identify individuals with different childhood diets and backgrounds, and thus different origins prior to becoming monks.

1.2. Isotopic evidence of monastic diet

Most of the dietary evidence from monastic contexts comes from the Medieval period. Two reviews on this topic can be found in Gowland and Knüsel (2006) and Patrick (2014). The published data suggest two main patterns regardless of the monastic order: 1) a diet based on C_3 resources with consumption of marine and freshwater foods (mainly fish) when the site was close to a water resource and 2) a high trophic level diet more similar to other contemporaneous high-status groups than to the diet of the lay people.

At St Andrew's Priory (Fishergate, York, England) male servants had the same diet as the monks while females consumed fewer marine sources (Mays, 1997; Müldner and Richards, 2007). In the friary of Warrington, in northern England, located near both river and the sea, the friars were indistinguishable from the high-status lay people (Müldner and Richards, 2005). Spencer (2009) studied four English sites: St James abbey (Northampton), Blackfriars Friary (Gloucester), Merton Priory (Surrey) and the abbey of St Mary Graces (London). The isotope data was consistent with a C_3 plant-based diet with animal protein and marine consumption. Similar results were obtained for Scottish bishops (Müldner et al, 2009) and at the medieval hospital of St Giles (North Yorkshire, England) (Bownes et al, 2018; Müldner and Richards, 2005).

At the Dunes abbey (Koksijde, Belgium) (Pollet and Katzenberg, 2003), the data also suggested dietary differences between the brethren and the lay servants. Quintelier et al (2014) analysed a sample of friars and lay males and females from the friary of Aalst (Belgium). The males consumed a higher proportion of meat and marine foods than females with dietary variation suggesting individuals of different status were buried in the same site.

Yoder (2012) studied a sample of monks, peasants, and elites from the medieval monastery of Øm Kloster (Denmark), demonstrating how the monastic diet shifted through the period, from one which was similar to the peasant population to one more similar to the nobility, while there was no dietary change related to the two non-monastic groups (Yoder, 2012). This shift from a low trophic level diet to a higher trophic level was also observed in the monastery of Rennes (Brittany, France) where medieval monks shared the same diet as the secular population while the later early modern monks displayed a diet similar to the privileged class (Colleter *et al*, 2017).

In the Iberian Peninsula, López-Costas et al (2021) showed how the males buried in the Royal Chapel of Lugo Cathedral during Medieval times displayed enriched $\delta^{15}N$ when compared with the rest of the group, suggesting access to higher trophic level foods whether they were members of the Cathedral priesthood or of noble birth (López-Costas et al, 2021). Finally, at the Byzantine community of St Stephen in Jerusalem (Gregoricka and Sheridan, 2013) males (monks and lay) and females were analysed. Although the monks were associated with the Byzantine order, their diet was supposed to be like other monastic orders, following the tradition of not consuming meat, as seen in the $\delta^{15}N$ (Lawrence, 2001).

Recent use of bone collagen and incremental dentine data to investigate monastic burials in medieval English sites have shown significant changes in diet during childhood which suggest a change in diet from lay to monastic at about the age at which the males would have entered the Order (Beaumont et al, 2021; Kancle et al, 2018).

All the data from the medieval studies pointed to monastic fish consumption corresponding to the fasting rules dictated by the Church. In Europe, lay people also started to follow these rules (Salamon et al, 2008) with the proportion of marine consumption increasing over time in medieval populations, especially in higher status communities (Beaumont et al, 2021). The limitations regarding the origin of the animal protein (meat versus dairy products, which can give similar isotopic values) should be considered when interpreting evidence, especially in a population with documented dietary rules which differ from the lay population. As there is little evidence that the elevated $\delta^{15}N$ could be due to malnutrition (Beaumont et al., 2013b) it is assumed that the data represents dietary patterns.

The individuals in this study were buried in San Millán de la Cogolla Yuso in the late 17th – 18th century in the central Iberian Peninsula so cannot be compared directly to the European medieval monasteries discussed earlier. However, a recent study involving 17th –18th century monks buried in Vilnius (Lithuania) revealed a diet based on C_3 vegetables with higher trophic-level protein intake more akin to the contemporary nobility than to lay people, with freshwater fish playing a noticeable role in the diet (Simčenka et al, 2020) which suggests that monastic access to a higher-status diet continued into this period.

The only study that is contemporaneous and comparable in geographical location and monastic context was published by Sarkic et al (2019): bone collagen $\delta^{13}C$ and $\delta^{15}N$ was measured to investigate the diet of nuns from the convent of Santa Catalina de Siena (Belmonte, Cuenca). The study noted the lack of bone isotope ratio studies for the 17th – 18th Iberian Peninsula, and more specifically, women's religious orders (Sarkic et al, 2019). Their interpretations suggest that the diet of the modern period nuns was austere and based on C_3 vegetables, with only minor intake of marine fish and animal protein (Sarkic et al, 2019). From the 19th century onwards, there is evidence for C_4 resources in the diet of the nuns (Sarkic et al, 2019). During the 18th century, the kingdom of Spain experimented progressive economic and technological development which improved the quality of life and access to a more varied diet including imported foods (López et al, 2011).

1.3. The monastery of San Millán de la Cogolla Yuso

The Capilla de San Agustín of the monastery of San Millan de la Cogolla, was chosen for this study because of the high level of archaeological and historical evidence for the presence of monks in the cemetery population, which is all male (Gilchrist and Sloane, 2005; Keevil et al, 2001) buried during the late 17th-18th century (García-Rubio and Martínez Silva, 2010).

The monastery of San Millán de la Cogolla was founded around the tomb of the hermit Saint Millán, a shepherd of the sixth century AD who abandoned his life to live in solitude and teach others the ascetical way of life (García, 1997; Olarte, 2005). In the year 1053 the Saint's remains were to be moved to a new monastery but the oxen which carried them suddenly stopped and refused to travel further. This was interpreted as a miracle due to the Saint's wish to stay in that land, so a new monastery was founded to house his remains. The new site was called San Millán Yuso ("down" in old Spanish) and the older was San Millán Suso ("up" in the same language) (García, 1997; Olarte, 2005).

Until the year 1100 CE the two monasteries coexisted, Suso followed the older Spanish monastic tradition of the Mozarabic rule and a double community (male and female together), while Yuso was founded as a Benedictine community and continued to modern times (Arrúe, 2000; García, 1997; Olarte, 2005; Reinares, 2000). Although Yuso was first built following the Romanesque style, in 1504 the monastery was reconstructed in the Herrerian style, and it is this building which remains in use today. The individuals in this study were excavated from the chapel of Saint Augustine and all the skeletons were males (García-Rubio and Martínez Silva, 2010).

The site is situated 37 km from the city of Logroño in the middle of the north of Spain and is designated an area of Common Heritage of Mankind by UNESCO (Fig. 1). The monastery of San Millán Yuso also houses the Castilian Language Investigation Centre (in English) due to the important role this place has played in the understanding of the evolution of the Castilian and Basque languages. The first evidence of written texts in both languages was found here (García and García, 1995). Nowadays it is occupied by the mendicant order of Saint Augustine.Fig. 2..

2. Material and methods

2.1. Material

The ribs from three individuals from Capilla de San Agustín (late 17th – 18 century) (SM 10, SM 42 and SM 56) had already been sampled at the Dorothy Garrod Laboratory (Cambridge) during 2010 by Professor Luis Ríos Frutos, and isotope data (unpublished) was available. Rib bone was also sampled from each of the other seven individuals in this study.

For each of the 10 individuals a permanent tooth was selected which was growing at the age of 7 years when the children would have entered the monastery. In this case we chose a permanent canine or maxillary first premolar, as both tooth types have relatively long roots which

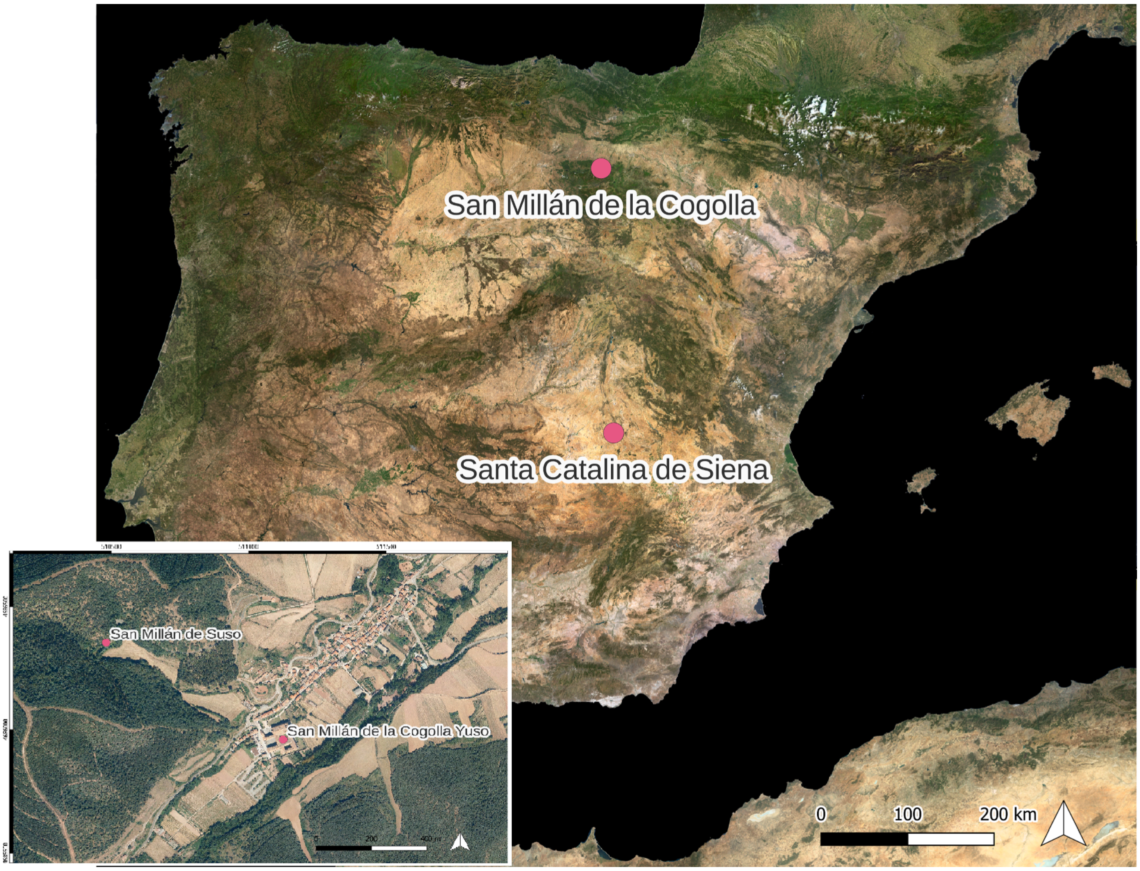

Fig. 1. Location of the site of san millán de la cogolla yuso, along with the other monastic site from the same period, santa catalina de siena, used for comparison later in the discussion of the results.

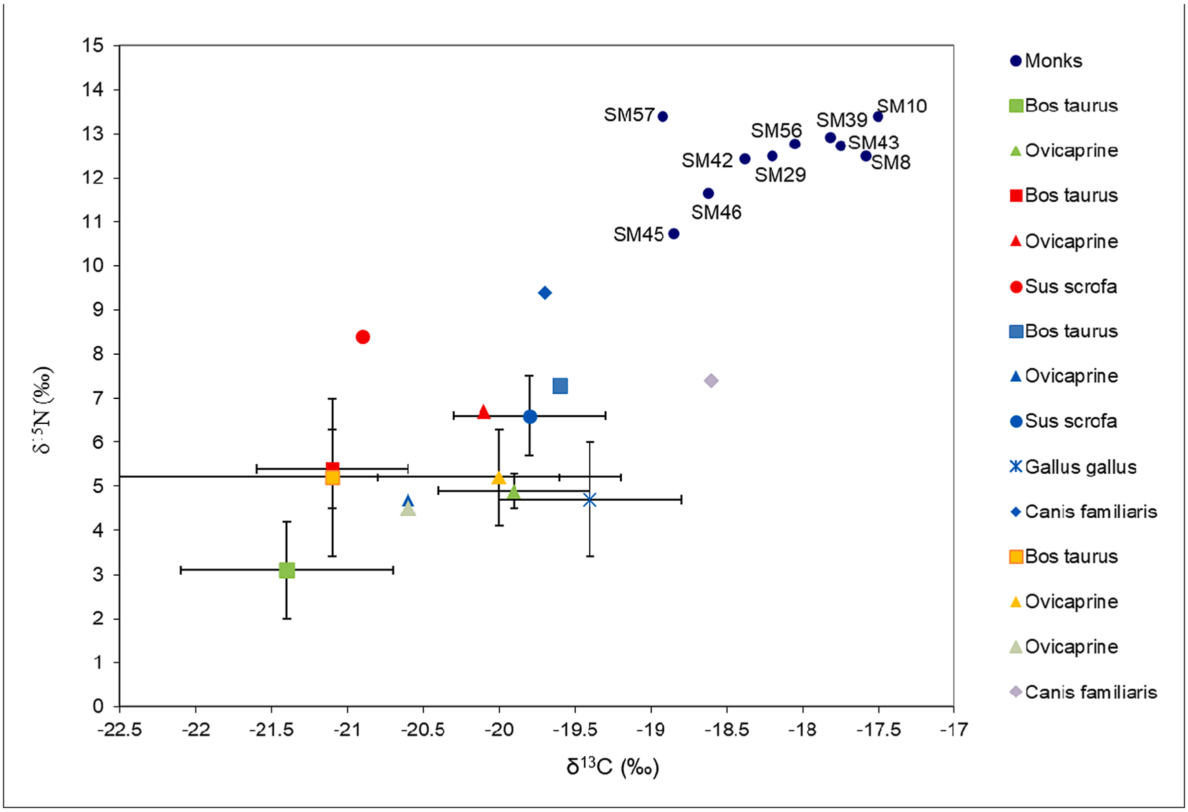

Fig. 2. Plot showing $\delta^{13}C$ and $\delta^{15}N$ of rib collagen for each individual from San Millan de la Cogolla, and faunal data from different sites (Bos tautus as squares, ovicaprines as triangles, Sus scrofa as circles, Canis familiaris as diamonds, and the Gallus gallus as an X). In green, Portales 67 in Logroño (Pérez-Ramallo et al 2022), red is Plaza de San José in Pamplona (Pérez-Ramallo et al 2022), blue for Zaballa, yellow for Zornoztegi, and grey for Treviño (the three of them in Basque Country, by Lubritto et al 2017).

increases the temporal resolution achievable with this method. Each was caries-free and with minimal coronal wear to maximise the isotopic record of the first few years of dentine growth (Tables 1 and 2).

The sex assessment of the individuals was based on morphological and metrical traits of the pelvis (Bruzek, 2002; Murail et al, 2005; Phenice, 1969; Snodgrass et al, 2003) and the cranium (Gülekon and Turgut, 2003; Schiwy-Bochat, 2001; Williams and Rogers, 2006). The estimation of age was more complex. For the subadult and immature individuals in the sample, the fusion of the different epiphysis were recorded (Albert and Maples, 1995; Cardoso, 2008a; Cardoso 2008b; Jit and Kaur, 1989; McKern and Steward, 1957; Owings et al, 1985; Scheuer and Black, 2004). In the case of the adult individuals, a combination of methods was used: pubic symphysis (Brooks and Suchey, 1990), auricular surface (Buckberry and Chamberlain, 2002) ossification of the laryngeal cartilages (Garvin, 2008), development of the dental wear (Hillson, 1996) the changes in the costal cartilage of the fourth rib (Iscan and Loth, 1986) and the cranial sutures (Masset, 1982).

Regarding the palaeopathological conditions of the selected individuals, only one of ten did not show any kind of lesions (SM 42), and another one (SM 46) showed enamel hypoplasia on both lower canines (one of them used in the study). In the other eight individuals there were carious lesions on several teeth as well as dental abscesses, and four of them had signs of arthrosis at different levels (García-Rubio and Martínez Silva, 2010).

Table 1
Age of initiation and of completion from each tooth used in the project (AlQahtani, 2009).

Tooth	Approximate age at initiation (years)	Age of completion (years)
Upper canine	0.6	9.5 ± 0.5
Lower canine	0.9	13.0 ± 0.5
Upper first premolar	3.5	14.5 ± 0.5

2.2. *Methodology*

First, all samples (ribs and teeth) were cleaned by air abrasion to remove surface debris. Then a 0.5 g sample of each rib bone was selected, and each tooth was sectioned longitudinally using a diamond saw. The intraradicular (pulpal) surface of the root canal was cleaned using a small rose-head bur to remove any contamination by secondary dentine.

The collagen was extracted from both the tooth and rib samples by demineralization in 0.5 M HCl at 4°C following the modified Longin method (Brown et al, 1988). Once the dentine was fully demineralized, it was sectioned horizontally at 1 mm intervals using a ruler and a scalpel, following method 2 in Beaumont et al (2013), and placed into individual microtubes. The demineralised bone and all dentine sections were heated in deionised water with HCl at pH3 and 70°C to denature the collagen fibrils and allow them to go into solution. The rib samples were filtered using an Ezee-Filter^{TM} in order to remove any molecules larger or smaller than collagen (Brown et al, 1988). The individual dentine sections were centrifuged to remove debris to the bottom of the microtubes.

All samples were then frozen for at least 24 h and, subsequently, freeze-dried to produce solid collagen samples. 0.5 mg of each sample was weighed into tin capsules. The collagen samples were measured in duplicate by combustion in a Thermo Flash EA 1112 and introduction of separated N_2 and CO_2 to a Finnigan Delta plus XL via a Conflo III interface at the University of Bradford Stable Isotope Laboratory. Internal standards (fish gelatine and BLS) and international standards

Table 2
Sex, estimated age category and tooth sampled from each individual from San Millan de la Cogolla (SM). Source: author.

Individual	*Sex*	*Pubic symphysis*	*Auricular surface*	*Other*	*Age*	*Used tooth (FDI)*
SM 8	Male	*III*	*III*	*Fusing clavicle*	Young adult (late 20 s- early 30 s)	*14*
SM 10	Male	*V*	*V*	*Laryngeal cartilages ossified*	Mature adult (over 40 years old)	*33*
SM 29	Male	*IV*	–	–	Adult (mean age = 35.2 years)	*23*
SM 39	Male	–	*V*	–	Mature adult (mean age = 62 years)	*33*
SM 42	Male	–	–	*Thyroid cartilage ossified*	Adult (over 39 years old)	*13*
SM 43	Male	–	–	*Active epiphyseal fusion in most bones*	Under 18	*14*
SM 45	Male	–	*V*	–	Mature adult (mean age = 62 years)	*13*
SM 46	Male	–	–	*Non active fusion*	Adult (all available epiphysis fused)	*43*
SM 56	Male	–	–	*Non active fusion. Thyroid partly ossified*	Adult	*23*
SM 57	Male	–	–	*Thyroid cartilage ossified*	Mature adult (over 39 years old).	*43*

(IAEA 600, IAEA CH6, IAEA CH7, N1 and N2) were interspersed throughout the run. Calibrated against these standards, the analytical error at 1 standard deviation was ± 0.2‰ or better.

3. Results

3.1. Quality indicators

All the samples fell within the range for the C:N ratio developed by DeNiro (1985) of 2.9 – 3.6, and Van Klinken (1999) of 3.1–3.5. Other indicators such as the %C and the %N were applied (Ambrose 1990), and although some samples fell outside the suggested ranges, all the C:N ratios indicated the good quality of the samples used in the study. The collagen yield for the seven ribs analysed for this study was in the range of 7.8 – 22.3%. The yield is not recorded for the dentine collagen because it is not filtered during preparation.

3.2. δ^{13}C and δ^{15}N from rib collagen

Due to the lack of an animal baseline from the site of San Millán de la Cogolla Yuso, faunal data from other sites was selected, such as Portales 67 (Logroño) and Plaza de San José (Pamplona) due to the geographical closeness, (both in Pérez-Ramallo et al 2022), as well as the sites of Zaballa, Zornoztegi and Treviño (Lubritto et al 2017), which were chronologically closer to the San Millán de la Cogolla Yuso sample, and geographically not very far.

The results obtained for the rib samples are shown in Table 3 and Fig. 1. The δ^{13}C values of the rib samples were between −17.5 and −18.9‰, with a mean of −18.1‰ and a standard deviation of 0.5. The range for the δ^{15}N rib values was 10.7 – 13.4‰, the mean 12.5‰ and the standard deviation 0.8. When comparing with the selected animal baseline, these data suggest a diet with a high intake in animal protein.

3.3. δ^{13}C and δ^{15}N from the dentine collagen sections

The incremental dentine analysis provided δ^{13}C and δ^{15}N results for each 1 mm section was assigned to the approximate age when the dentine was formed using the method outlined in Beaumont and Montgomery (2015). For all the dentine sequences, the mean δ^{13}C value was −18.8‰ with a standard deviation of 0.3, while the mean δ^{15}N value was 11.75‰ and a standard deviation of 1. The range for δ^{13}C was −17.4‰ to −19.5‰ (Fig. 3). The δ^{15}N values ranged from 8.9‰ to 16.2‰ (Fig. 4).

4. Discussion

4.1. San Millán de la Cogolla: The monastic context

Fig. 5 and Table 4 represent the mean and standard deviation of the δ^{13}C and δ^{15}N rib collagen values for this site compared with other Medieval male monastic sites, and one modern site. The mean of δ^{15}N is similar to most of the other sites, with the exception of Koksijde and St Stephen (a lower mean value) and Lugo (the highest mean), while the mean value of δ^{13}C from San Millán is more positive than all of the sites. The standard deviation for both δ^{13}C and δ^{15}N from this study and the geographically closest other monasteries, (Koksijde, St Stephen and Lugo), show very little overlap. This evidence suggests that, despite similar monastic rules, the dietary differences between San Millán and the rest of the sites were large enough to be detected by light stable isotope analysis. These variations appear to reflect the relative status of the communities buried there.

The interpretation was that the diets of individuals from the other sites were based on C_3 plants with some meat/dairy products and fish consumption due to the fasting rules dictated by the Church, suggesting marine sources as the reason for some δ^{13}C values. We have chosen to use the more conservative threshold of −19.1‰ for δ^{13}C for marine consumption following the discussions in Montgomery et al (2013). Looking at the bone collagen mean data from the monastic populations, it appears that only St Stephen, Koksidje, Santa Catalina, San Millán (dentine and bone) and Lugo Cathedral pass this threshold. Of those, only the δ^{15}N values for Lugo Cathedral bone collagen surpass the δ^{15}N of the other monastic communities. Lugo Cathedral is an outlier, which given the high status of the burials suggests the highest trophic-level

Table 3
δ^{13}C and δ^{15}N from rib bone collagen for each individual from San Millan de la Cogolla.

Individual	δ^{15}N values (‰)	%N	δ^{13}C values (‰)	%C	C:N ratio	Collagen yield (%)
SM 8	12.5	12.3	−17.6	32.9	3.1	20.5
SM 10	13.4	14.6	−17.5	39.1	3.1	–
SM 29	12.5	12.4	−18.2	33.2	3.1	14.0
SM 39	12.9	6.0	−17.8	16.5	3.2	10.8
SM 42	12.4	15.3	−18.4	40.8	3.1	–
SM 43	12.7	14.2	−17.8	37.8	3.1	22.3
SM 45	10.7	16.1	−18.9	43.7	3.1	14.0
SM 46	11.7	11.6	−18.6	31.6	3.1	16.9
SM 56	12.8	15.5	−18.1	41.7	3.1	–
SM 57	13.4	3.4	−18.9	9.7	3.3	7.8

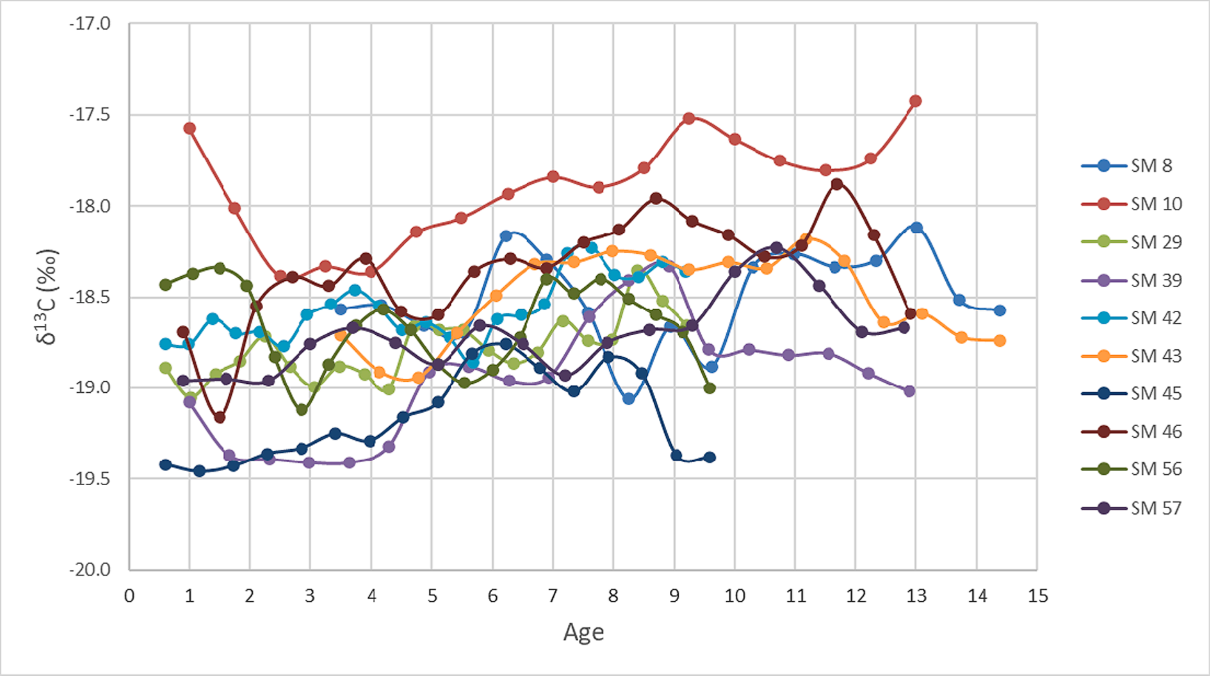

Fig. 3. δ^{13}C dentine collagen profiles from San Millan.

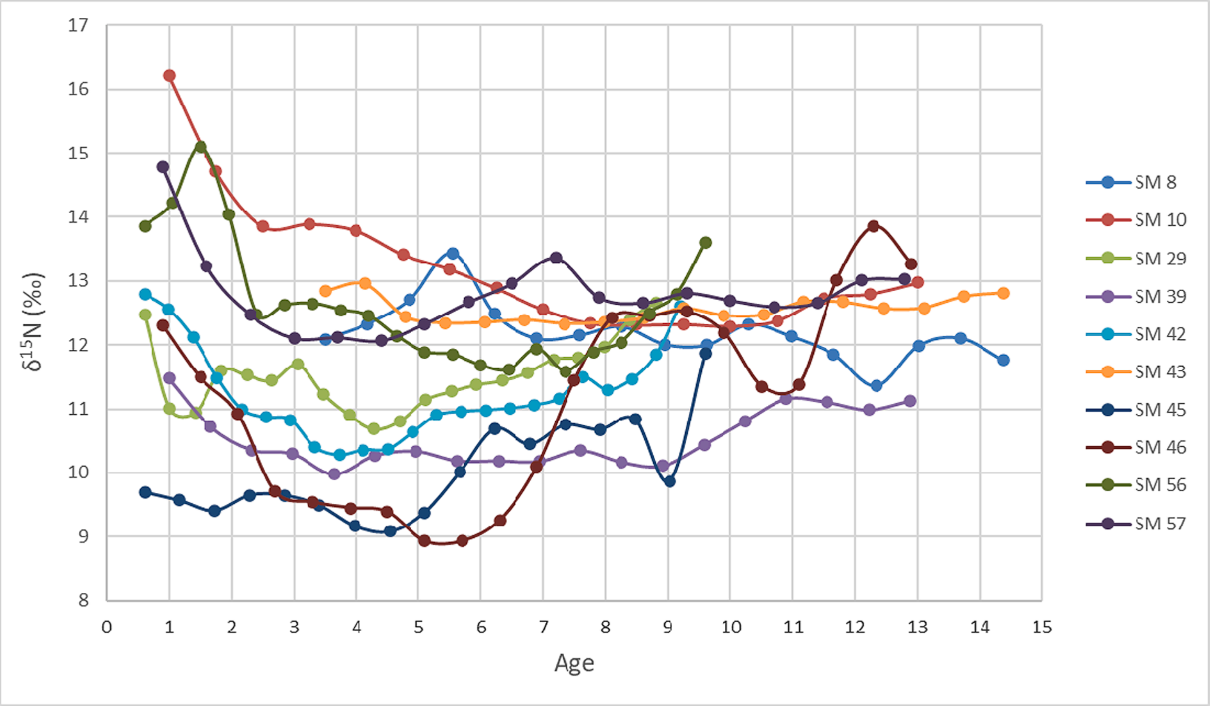

Fig. 4. δ^{15}N dentine collagen profiles from San Millan.

marine diet of the sites, but the diet of the San Millán individuals in the last 5 years of life as recorded in the rib bone appears to show both marine and C_4 dietary intake. This will be discussed further while comparing the dentine and bone collagen data.

All the bone collagen data for δ^{13}C individuals from San Millán is above the −19.1‰ threshold and all the dentine collagen profiles reach this level at some point. For that reason, the δ^{13}C and δ^{15}N data must be considered together. It is apparent that for 4 of the individuals the δ^{13}C of dentine profile does not overlap with the δ^{13}C of the bone collagen data and thus the diet during tooth formation is considerably different to the diet in the last 5 years of life. For SM 29 the bone collagen δ^{15}N is higher than the dentine collagen mean and for SM 39 the δ^{15}N of the dentine profile does not overlap with the higher bone collagen mean. This could be interpreted as a higher marine input to the diet in the last 5 years of life for both. However, for two of the individuals (SM 43 and 56) there is no elevation in the bone δ^{15}N relative to the dentine so this change could be attributed to the inclusion of C_4 plants in the later diet.

The most likely available foodstuffs that could result in these values

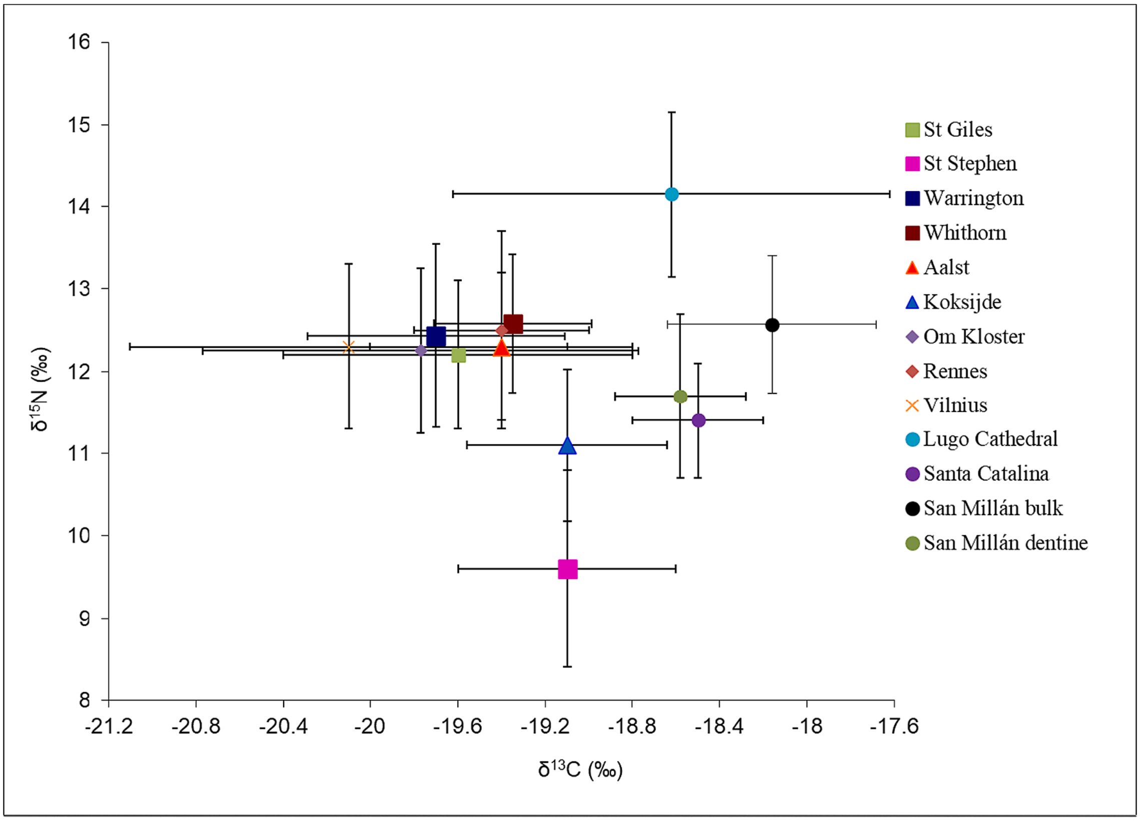

Fig. 5. Comparative plot of bone data means for european monastic sites and dentine mean for San Millán de la Cogolla. Error bars represent 1standard deviation.

were rye (a C_3 plant) and millet and possibly sugarcane and maize (the latter 3 are C_4 plants). Rye and millet were the crops on which most of the population relied and are associated with low status populations (Adamson, 2004; Andrade Cernadas, 2009; Peña-Chocarro et al 2019; Pérez Samper, 2019). In this case the $\delta^{13}C$ values could be the result of consumption of these foods related to the vow of poverty made by all the Benedictine monks and the rejection of luxury items in their diet. However, sugarcane, introduced in the Iberian Peninsula by the Muslims, had been an expensive luxury until this period (17th – 18th century) and only consumed by high-status individuals (Mintz, 1985). If the results were due to this product, it could be interpreted as the consumption of luxury products, a reflection of the richness of the monastery. However, there is a possibility that the impact in the $\delta^{13}C$ values were due to the consumption of millet or even maize. In either case, San Millán de la Cogolla demonstrates an important example of the variability and differences of the monastic diet across Europe during the 17th-18th century and in turn the importance of investigating the individual dietary life histories in a population allowing a much more nuanced interpretation of the data, rather than merely using the mean values from a small sample of 10 individuals. It appears that there are two cohorts in the study with two dietary regimes which could indicate temporal changes in the application of the monastic dietary rules, such as the introduction of new foods arriving from America in the Iberian Peninsula, as in the case of maize.

There may also be geographical differences between sites: for example, Vilnius (Lithuania) as compared to San Millán. While the bone collagen $\delta^{15}N$ values are similar (12.3‰ for Vilnius, 12.5‰ for San Millán), there is a difference in their respective $\delta^{13}C$ values (-20.1‰ for Vilnius, −18.2‰ for San Millán). Several reasons could explain this: first, the dietary norms that each monastery followed were different as applied to the daily life of the monks; second, an environmental one, as C_4 plants are mainly cultivated in arid environments (Herrera, 2008), the weather in Vilnius was not suitable to grow these crops; and finally, that Lithuania did not establish any colony in America that would allow the trade of these new C_4 foods (as maize) directly into the country.

4.2. *Life-histories in the dentine profiles and bone collagen data*

Plots have been produced using the $\delta^{13}C$ and $\delta^{15}N$ dentine profiles against age for each individual, with the bone collagen for that individual plotted as a solid line for each isotope ratio (see Supplementary data).

They are very variable: the profile for SM 43 is the flattest, and this suggests that his childhood diet was consistent in quality and sufficient to avoid any markers for nutritional stress. He is the youngest individual in the study and appears to have had a high-status diet throughout his childhood, with a similar content in animal protein as the monastic diet, and a dietary change as an adult to C_4 consumption (see below) which may mark him out as a high-status member of the order with access to imported foods. The same flat profile is seen for SM 45 until the age of 6 years suggesting a stable and sufficient diet in early childhood.

Some dentine profile patterns are similar: SM10, 29, 42, 45 and 56 all show an elevation in $\delta^{15}N$ at about the age of 7–8 years. This could be interpreted as a change of diet from lay to monastic rules relating to entering the Order at this age.

A change in trophic level is usually seen in the covariance of both $\delta^{13}C$ and $\delta^{15}N$, but SM 56 shows elevation in $\delta^{15}N$ but not $\delta^{13}C$. This pattern of *opposing covariance* has been seen where nutritional deprivation causes the recycling of body tissues and the release of fat stores (Beaumont and Montgomery, 2016) rather than a rise in the trophic level of the diet. A similar pattern can be seen in the profiles of SM 45 at age 9 onwards, SM 10 age 2.5 to 5 years, SM 39 from age 9 years onwards, and potentially on 3 occasions for SM 46 (at the start of the profile, at ages 6–10 and then again at the end of the profile). SM 46 appears to have had a very varied nutritional childhood as a result, with a total range of $\delta^{15}N$ of 5‰ which would be approximately two trophic

Table 4
Mean values and standard deviations, expressed in ‰, of bone collagen δ^{13}C and δ^{15}N reported in studies from European monastic sites.

Site	Number of individuals	Mean δ^{13}C (‰)	SD (‰)	Mean δ^{15}N (‰)	SD (‰)	References
Warrington	18	−19.7	0.5	12.4	1.1	Müldner & Richards (2005)
St Stephen	54	−19.1	0.5	9.6	1.2	Gregoricka and Sheridan (2013)
Koksijde	19 (11 adults, 8 children)	−19.1	0.4	11.1	0.9	Pollet and Katzenberg (2003)
Aalst	39 (mixed population)	−19.4	0.6	12.3	0.9	Quintelier et al (2014)
Whithorn	14 (6 priests, 8 lay people)	−19.3	0.3	12.5	0.8	Müldner et al (2009)
San Millán bulk	10	−18.2	0.4	12.5	0.8	This study
Rennes	82 (bone and tooth, mixed population)	−19.4	0.4	12.5	1.2	Colleter et al (2019)
St Giles	13	−19.6	0.8	12.2	0.9	Bownes et al (2018)
Om Kloster	98	−19.7	0.4	12.2	0.8	Yoder (2012)
Lugo Cathedral	12	−18.6	0.7	14.1	0.3	López-Costas et al (2021)
Vilnius	40	−20.1	0.3	12.3	0.8	Simcenka *et al* (2020)
Santa Catalina	58 (49 from 16th-17th cent, 9 from the 19th-20th)	−18.0	0.3	11.4	0.7	Sarkic et al (2019)
San Millán (dentine)	194	−18.5	0.3	11.7	1	This study

levels if not interpreted as nutritional stress, possibly related to the signs of enamel hypoplasia in both lower canines, one of them used in this study. This was the only individual who showed this condition.

The comparison between the dentine and bone δ^{13}C and δ^{15}N shows that for four individuals the childhood dentine δ^{13}C does not overlap at all with the later bone data. For SM 29 and 39 this is accompanied by a rise from the childhood δ^{15}N to a higher bone δ^{15}N suggesting that this is caused by an increase in the consumption of higher-trophic level marine resources. For SM 43 and 56, there is no corresponding rise in δ^{15}N between childhood and adulthood and would be consistent with a rise in the consumption of C_4 plants. There is evidence for an increased consumption of C_4 over time in the contemporaneous population of nuns from Santa Catalina (Sarkic et al, 2019).

Overall, the dietary patterns suggest varying origins for the monks during childhood with some experiencing periods of nutritional instability. SM 10 and SM 39 appear to have had low-status origins and this is consistent with the high δ^{15}N and subsequent fall of 4.9‰ in early childhood for SM10 and the presence of opposing covariance patterns for both. However, the individual with the most perturbations in childhood δ^{13}C and δ^{15}N (SM 46) was deemed high-status but has the second lowest δ^{15}N in the adult bone. The evidence from the archaeological excavations and the δ^{13}C and δ^{15}N data thus may suggest that an individual from a low-status origin can still reach high-status as an adult in this population (Fig. 6).

4.3. *The modern Spanish Context: San Millán and Santa Catalina*

Fig. 7 represents the combined the δ^{13}C and δ^{15}N data from the San Millán de la Cogolla monks and Santa Catalina de Siena nuns (Table 4). This comparison merits a discussion on its own due to the chronological and geographical similarities between the two sites.

An ANOVA test comparing the means of bulk collagen δ^{13}C and δ^{15}N from Santa Catalina, and the mean bulk collagen and dentine values from San Millán showed statistically significant differences. For δ^{13}C values, the discrepancy was between Santa Catalina bone collagen and the San Millán dentine mean ($p = 0.0003$), while for the δ^{15}N values the difference was between the adults of Santa Catalina and San Millán bone collagen ($p = 0.0011$).

The most probable reason for the difference in the δ^{15}N values is the distinction between their status. As discussed above, San Millán de la Cogolla is a key high-status historic site in Spain. Santa Catalina de Siena was much humbler than San Millán de la Cogolla, and although the dentine data suggests that some monks from a low-status origin entered the order, the dietary differences between the two populations are visible in the data. Sarkic et al (2019), stated that the nuns' diet was low in terrestrial animal protein consistent with the dietary restrictions imposed on them by the monastic rules of the Dominican order.

5. Conclusions

The combination of rib bone and dentine collagen δ^{13}C and δ^{15}N data

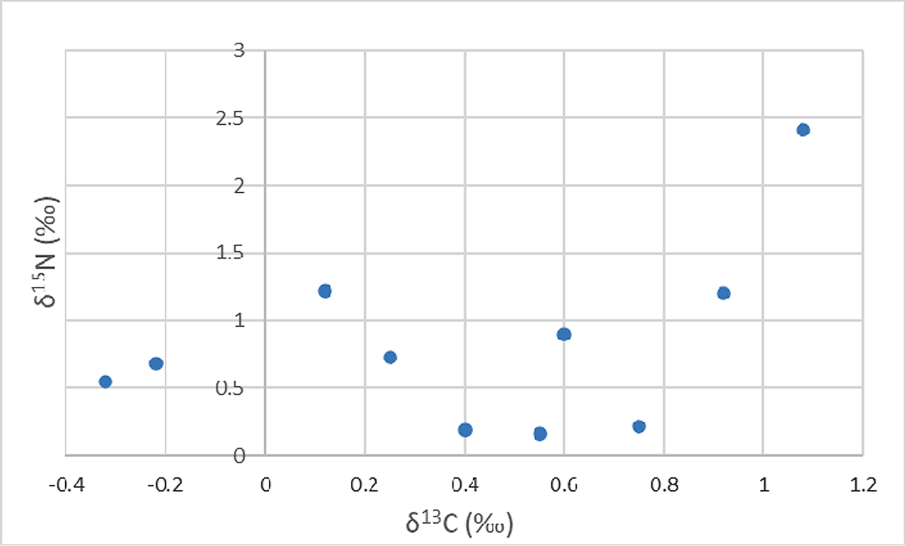

Fig. 6. $\Delta_{\text{bone-dentine}}$ variation among the San Millán monks. All the individuals show a higher δ^{15}N value in the adult diet once they became monks.

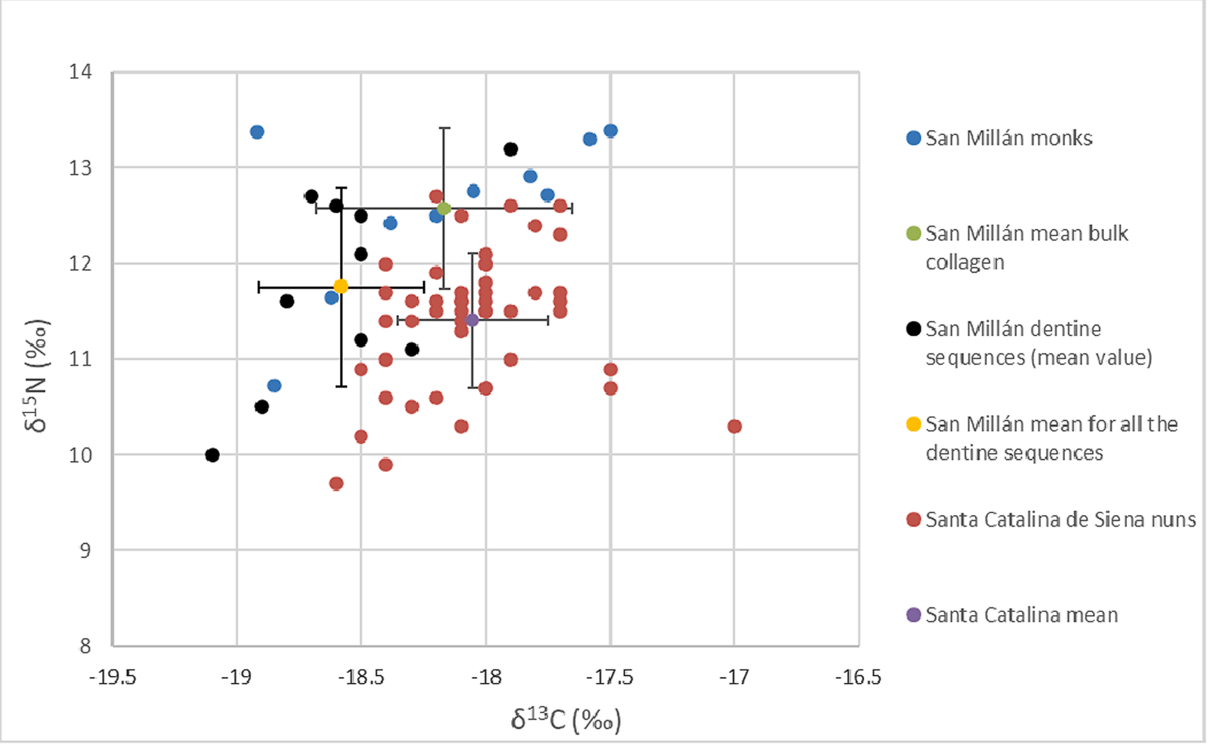

Fig. 7. Comparative plot of individual bone collagen δ^{13}C and δ^{15}N values from the San Millán monks(n = 10) and Santa Catalina nuns(n = 47) with mean bone collagen δ^{13}C and δ^{15}N for both sites and mean dentine collagen δ^{13}C and δ^{15}N from San Millán. Error bars represent 1 standard deviation.

allowed us to identify different dietary patterns that can be interpreted as giving information not only about the site, but also the life-histories of each individual and the age at which that person may have entered the monastic order. Two potential temporal cohorts were identified based solely on the isotope data which suggests differences in the consumption of C_4 within this monastic community.

The site of San Millán de la Cogolla Yuso allows a unique insight into an important Iberian monastic community. Comparing the site with European medieval monasteries it becomes apparent that there are differences in the δ^{13}C values, probably due to consumption of C_4 resources in San Millán de la Cogolla Yuso, which could relate to the later date of the site and the consumption of these resources by some individuals (Fig. 5). However, the δ^{15}N values echo patterns seen in earlier European monastic communities where a high-trophic level diet with consumption of meat is evident and similar to higher-status contemporary lay populations. This is in contrast with the dietary restrictions which were supposed to followed by different monastic Rules. The variation in the high-quality diet/protein intake also applies when comparing the data to other Iberian monastic sites, as the mean δ^{15}N from San Millán de la Cogolla Yuso is situated between low-status sites St Stephen and Koksijde and high-status Lugo Cathedral (Fig. 5).

Finally, the results from incremental dentine δ^{13}C and δ^{15}N profiles during childhood and from rib collagen showed that people with different dietary patterns and backgrounds entered into the same monastery and subsequently adopted a similar dietary regime. A consistent age of entry into the order could not be identified for all the individuals analysed: this may be because some were already consuming a higher-status diet during childhood which is borne out by the relative lack of perturbations in their dentine profiles.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.103981.

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