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# A reassessment of the presumed Badegoulian skull from Rond-du-Barry cave (Polignac, France), using direct AMS radiocarbon dating

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**KEYWORDS:** <sup>14</sup>C, diet, Magdalenian, mesolithic, morphology

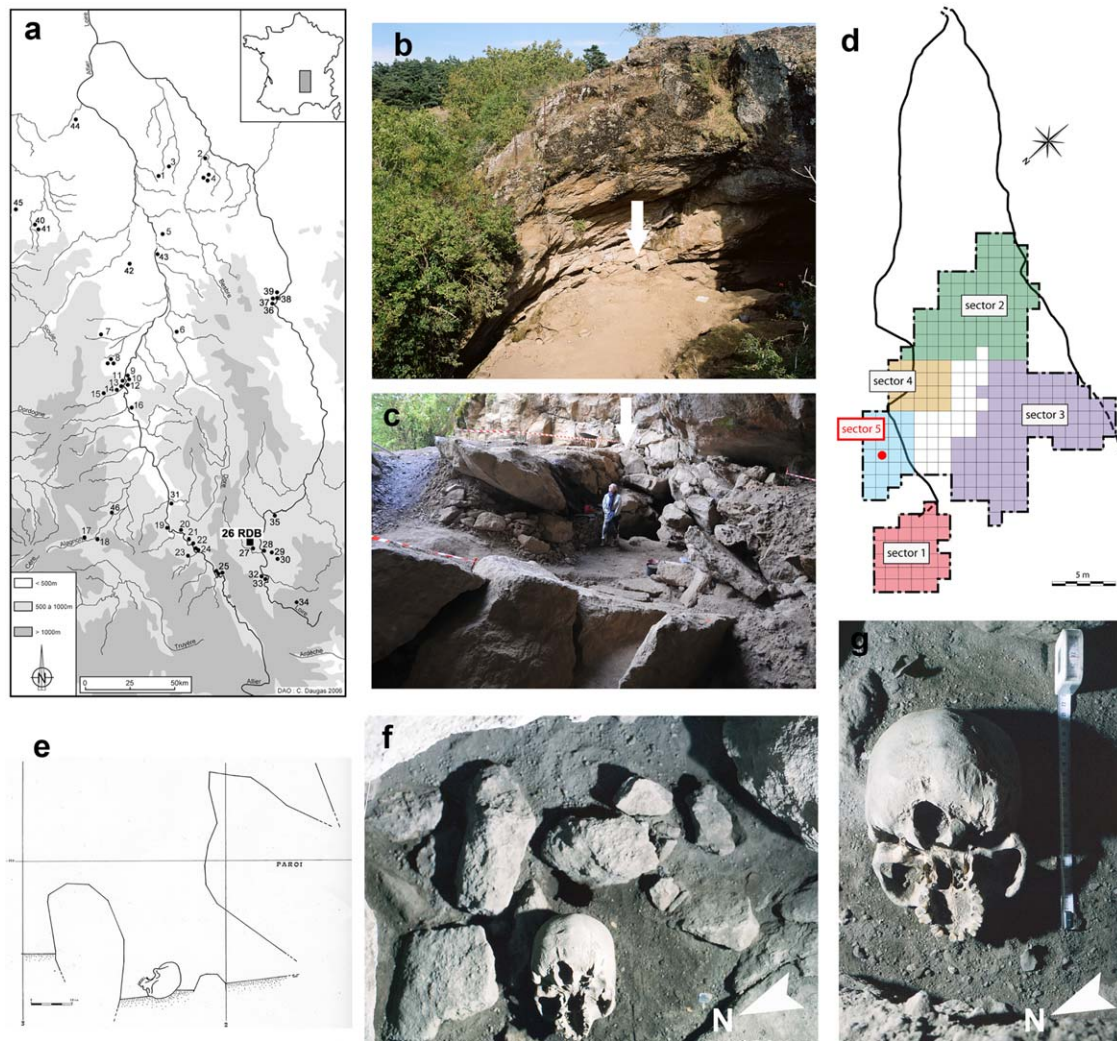
## 1 | INTRODUCTION

Since the 19th century, Rond-du-Barry cave has been documented as one of the largest Upper Paleolithic sites in the Auvergne (Polignac, Haute-Loire, Figure 1). Roger de Bayle des Hermens conducted a rigorous excavation from 1966 to 1987 (de Bayle des Hermens, 1967) and the material he discovered documents different aspects of the management of a middle mountain environment at the end of the Upper Pleistocene. His excavations revealed a Mousterian unit (H) at the bottom of the sequence, followed by several Upper Palaeolithic units (F, E, D), and their respective subdivisions from Badegoulian in F2 to final Magdalenian in D, finished by Mesolithic, Neolithic and Middle Age occupations attested in C, B and A (de Bayle des Hermens, 1979). The Upper Palaeolithic units provided two engraved *bâtons percés*, one featuring a "Venus" (de Bayle des Hermens, 1969) and the second a stylized bird (de Bayle des Hermens, 1986); an abundant bone and antler industry (de Bayle des Hermens, 1974), several beads, perforated shells, as well as striated and used ochre fragments were also found in these layers.

In 1986, a purported burial of roughly rectangular shape, composed of breccia blocks, was discovered in the northwestern part of

the cavity (sector 5, unit F2), containing a perfectly preserved human cranium that seemed to have been placed upside down in a very dry and ashy sediment (de Bayle des Hermens & Heim, 1989) (Figure 1). The cranium was associated with a few Upper Palaeolithic artefacts, suggesting a ritual deposit. The cranium was located in unit F2, and thus assigned to the Magdalenian I period (Badegoulian). Assuming this association, the discovery was significant for expanding the knowledge of the Upper Paleolithic in Massif Central, and represented the oldest human remains known in Auvergne region.

Recently, the revision of the lithic and antler industries of unit F2 demonstrated its techno-cultural heterogeneity (Delvigne, 2016; Lafarge, 2014; Rémy, 2013), suggesting a mix of Badegoulian and early Middle Magdalenian, as defined by Langlais et al. (2016). The spatial division of the unit in different sectors (1 to 5) was proposed on the basis of the techno-typological characteristics of the lithic industries. A 2016 excavation confirmed the complexity of the sedimentation processes close to the cave walls. These walls collapsed into huge megablocks, preserving large voids, and favored the high mobility of sediment and objects from overlying units (Figure 1). Recent radiocarbon dating on charcoals (Supporting Information Table S1) from the



**FIGURE 1** (a) Location of the Rond-du-Barry cave among the Magadalenian sites in the southern Massif Central; (b and c) 2016 views of the cave entrance, arrows plot the skull position (photos by A. Lafarge and J.P. Raynal); (d) position of the skull "burial" in sector 5 (DAO A. Lafarge); (e) South-East section of the skull area (R. de Bayle des Hermens archive); (f and g) pictures of the discovery of the skull (photos by R. De Bayle des Hermens)

sediment surrounding the skull provided Late Mesolithic to Ancient Neolithic ages, and fragments of incised reindeer antler and an ibex tibia fragment, both associated with the skull, gave Magdalenian AMS radiocarbon ages (Supporting Information Table S1) (Raynal et al., 2014). In addition, pollen analysis of sediments of archaeostratigraphic unit F2 (Méon, 2018) reveals local conditions to have been cool to cold with relative humidity favoring a forested cover (Arboreal Pollen ratio (AP) = 55%) of pine, fir and deciduous trees (oak and lime trees) in sheltered and well exposed areas, and an herbaceous cover on the plateau. However, the pollen spectrum of the sediments preserved inside the skull (Vivent, 2018) indicate more temperate conditions, cool and slightly humid, similar to that of the early Holocene: high tree pollens ratio (AP = 74.8%), with *Tilia* (dominant), *Corylus*, *Quercus*, and *Fagus*, while *Pinus* is scarce. These results have shown the need to re-examine the supposed burial and its attribution to Badegoulian.

In this regard, the initial objective of this research was to perform a direct AMS radiocarbon date on the purported Upper Palaeolithic skull. The established age was surprisingly recent and therefore, as observed in other similar situations (Benazzi et al., 2014; Margherita et al., 2016; Talamo et al., 2016), incompatible with the initial stratigraphic assignment.

Because of the new age of Rond-du-Barry cranium, we performed a metric analysis in comparison with a sample from the Magdalenian, the Final Palaeolithic, and the Mesolithic periods as well as analysis of its cranial dimensions in order to provide a sex estimation. Moreover, using the extracted collagen, it was possible to gain insight into the diet of the individual.

By applying radiocarbon dating, morphological study, and the isotopic analysis, we shed new light on other important aspects of Rond-du-Barry individual.

## 2 | MATERIALS AND METHOD

### 2.1 | Radiocarbon and stable isotope analyses

Direct dating was carried out on the root of the second upper left molar of the Rond-du-Barry skull. This tooth was chosen as the most appropriate for destructive sampling since it will have little impact on the work of future researchers. The collagen was extracted at MPI-EVA, Leipzig, Germany for both radiocarbon and isotopic analyses, following the pretreatment protocol based on Talamo and Richards (2011).

Roughly, 600 mg of the root is decalcified in 0.5M HCl at room temperature until no CO<sub>2</sub> effervescence is observed, usually for about 4 h. A 0.1M NaOH is added for 30 min to remove humics. The NaOH step is followed by a final 0.5M HCl step for 15 min. The resulting solid is gelatinized following Longin (1971) at pH 3 in a heater block at 75°C for 20 h. The gelatine is then filtered in an Eeze-Filter™ (Elkay Laboratory Products (UK) Ltd.) to remove small (>80 μm) particles. The gelatine is then ultrafiltered with Sartorius “Vivaspin Turbo” 30 KDa ultrafilters (Brown, Nelson, Vogel, & Southon, 1988). Prior to use, the filter is cleaned to remove carbon containing humectants (Brock, Bronk Ramsey, & Higham, 2007). The sample is lyophilized for 48 h.

To monitor contamination introduced during the pre-treatment stage, a sample from a cave bear bone, kindly provided by D. Döppes (MAMS, Germany), was extracted along with the batch from the human specimen. Elemental and stable isotopic data (%C and %N content, C: N, δ<sup>13</sup>C and δ<sup>15</sup>N) of extracted collagen was measured in-house at the MPI-EVA, and about 5–6 mg was weighed into precleaned tin cups at the MPI-EVA and sent to the Klaus-Tschira-AMS facility (lab code: MAMS). The sample was combusted in an EA, and CO<sub>2</sub> was converted catalytically to graphite and dated using the MICADAS-AMS (Kromer, Lindauer, Synal, & Wacker, 2013).

### 2.2 | Morphometric analysis

From the list of measurements defined by Martin (1928), a subsample of variables were selected following their availability on Rond-du-Barry and their representation in the comparative sample. Supporting Information Table S2 lists the codes and definitions of the 36 retained variables and raw data from Rond-du-Barry. Measurements were obtained on a 3D model of the Rond-du-Barry cranium using TIVMI v.2.1 software (Dutailly, 2016). Data from the comparative sample were mainly collected by one of the authors (MS) from specimens with relatively well-preserved crania from the Late Upper Palaeolithic (Magdalenian and Final Palaeolithic) and the Mesolithic periods in Western Europe, attested by a known context of discovery and/or direct dating. The cranial comparative sample was composed of 63 specimens. Fifty-two of them were used for the analysis of the sexual assessment of Rond-du-Barry cranium thanks to the availability of a sex assessment using methods applied to their *ossa coxarum* (Brůžek, 2002; Brůžek, Santos, Dutailly, Murail, & Cunha, 2017; Murail, Brůžek, Houët, & Cunha, 2005) or their cranial and infracranial sexual dimorphism analysis using logistic regressions (Murail, Brůžek, & Braga, 1999; Santos,

TABLE 1 Cranial measurements of Rond-du-Barry and the Mesolithic comparative sample for sex assessment

Measurements	M N°	Rond-du-Barry	Wilcoxon-Mann-Whitney test: Males vs Females; p value	Mesolithic Males				Mesolithic Females				Adjusted z scores; Rond-du-Barry vs Mesolithic Females			
				Mean	SD	Min.	Max.	N	Mean	SD	Min.	Max.	N	Adjusted z scores; Rond-du-Barry vs Mesolithic Males	Adjusted z scores; Rond-du-Barry vs Mesolithic Females
Maximum length	1	189.8	<0.001	191.0	5.2	185.0	201.0	14	-0.101	182.0	5.0	171.0	191.0	31	0.760
Maximum breadth	8	137.4	0.003	138.8	3.5	131.0	144.0	12	-0.172	132.8	5.9	120.0	142.0	29	0.372
Basion-bregma height	17	141.0	0.008	142.6	4.6	137.0	150.0	9	-0.144	135.5	6.2	126.5	150.0	21	0.411
Auriculo-bregmatic height	20	115.3	0.001	117.3	5.4	108.8	124.9	14	-0.166	111.3	4.4	105.3	124.0	25	0.423
Frontal longitudinal arc	26	134.0	0.001	133.0	6.6	123.0	145.0	16	0.069	126.3	5.7	118.0	139.0	31	0.648
Inner biorbital height	43.1	111.8	0.010	106.2	5.8	97.0	114.0	12	0.421	100.4	4.8	91.8	108.0	22	<u>1.133</u>
Biorbital breadth	44	101.4	0.003	96.8	3.5	92.0	102.9	12	0.588	91.3	4.2	84.3	98.6	20	<u>1.143</u>
Bizygomatic breadth	45	145.3	0.010	140.6	9.1	127.0	153.0	7	0.201	127.4	7.7	116.0	138.0	11	<u>1.005</u>
Naso-alveolar height	48	69.0	<0.001	70.0	4.5	62.8	75.2	10	-0.094	62.5	4.1	52.3	70.5	22	0.741

“M N°” indicates measurements following the Martin system (Martin, 1928). Bold values in the “Wilcoxon-Mann-Whitney test” section show statistically significant differences. Underlined values in the “Adjusted z scores” section are outside the 95% confidence interval of the comparative sample range of variation.

TABLE 2 Radiocarbon dates, isotopic values, % of collagen and C:N ratios of the tooth of Rond du Barry

Site	MPI Code	Anatomical part	% Yield of collagen	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C:N	AMS Nr	$^{14}\text{C}$ Age	Err 1 $\sigma$	Cal BC 1 $\sigma$	Cal BC 2 $\sigma$
Rond-du-Barry	S-EVA 26872	Upper Left 2 <sup>nd</sup> Molar	10.6	-19.4	11.5	45.7	16.9	3.1	MAMS-17748	7864	30	6747-6646	6817-6637

Guyomarc'h, & Brůžek, 2002; Saunders & Hoppa, 1997; Walker, 2008). Eleven additional crania are used in the comparative analysis. To summarize, the Magdalenian subsample includes three individuals (one male and two specimens of indeterminate sex used here in the comparison analysis). The Final Palaeolithic group is composed of height male individuals; 13 females and six males compose the First Mesolithic subsample; the Second Mesolithic group includes 22 females and 11 males. Supporting Information Table S3 lists the 63 comparative specimens with their source publications and details about their sex assessments. As cranial variations in terms of size could be related to sexual dimorphism, we performed a non-parametric Wilcoxon-Mann-Whitney test to determine which measurements show statistically significant sexual dimorphism in the comparative sample ( $p \leq 0.05$ ). We selected nine measurements among those reflecting sexual differences according to their representativeness in the comparative known-sex sample. Results of this test are displayed in Supporting Information Table S2. Adjusted Z scores (Maureille, Rougier, Houët, & Vandermeersch, 2001; Scolan, Santos, Tillier, Maureille, & Quintard, 2012) were computed to compare the adjusted means and standard deviations of these nine measurements in the female and male comparative groups to variables from the Rond-du-Barry cranium (Table 1). The adjusted Z scores indicate the "probabilistic distance" between the Rond-du-Barry (the null

value) specimen and each adjusted mean of male and female comparative groups. For each measurement, a value outside of the interval between  $-1$  and  $1$ , which includes the 95% confidence interval of each of the comparative groups, consequently has a probability  $<0.05$  of being assigned to a male or a female individual incorrectly. Second, missing values were replaced in the comparative sample using the *missMDA* R package (Josse & Husson, 2016) to perform estimations of unknown values only for specimens missing fewer than 30% of their measurements (Brewster, Meiklejohn, von Cramon-Taubadel, & Pinhasi, 2014). A nonparametric Kruskal-Wallis test was performed in the comparative sample, in order to determine which cranial measurements show statistical differences ( $p \leq 0.05$ ) between chronological groups (Magdalenian, Final Palaeolithic, First and Second Mesolithic). Results of this test are displayed in Supporting Information Table S2. To compare the Rond-du-Barry with the reference sample, we performed box-and-whisker plots of the median and range of variation of the measurements showing differences between chronological groups. Analyses were performed with the R statistical software (R Core Team, 2016).

### 3 | RESULTS

#### 3.1 | $^{14}\text{C}$ and stable isotope analysis

The radiocarbon result (MAMS-17748:  $7864 \pm 30$ ) indicates that the cranium is unlikely to belong to an Upper Palaeolithic individual (Table 2). The age range falls within the second part of the First Mesolithic period established for France (Ghesquière & Marchand, 2010). Mesolithic artifacts discovered in unit A of the cave have been attributed to the slightly more recent Montclusien (Houdre, Perrin, & Vital, 2017). As a large part of the cavity remains unexplored other Mesolithic occupations may exist. The presence of the skull only suggests that this dislocated remain was reburied (referred by archaeologists as "secondary burial") and fits well among the great diversity in funerary practices observed for the Mesolithic period (Grünberg, 2000; Meiklejohn, Baab, & Hiebert, 2016; Verjux, 2007). The elemental concentrations (%C and %N), C:N ratios, and the % of collagen yield confirm the good quality and preservation of collagen according to criteria proposed by van Klinken (1999) (Table 2). C and N isotope values of local animals are usually analyzed to interpret human diets. In the absence of associated fauna to the Rond-du-Barry human, we compiled all the C and N isotope values of animals and humans available both in Europe, for the same chronozone (Atlantic period), and for the Mesolithic, from the closest geographical areas for which human and animal isotope data are available (French, Luxemburgian and Belgian sites, Supporting Information Table S4, (Audouze, Drucker, & Valentin, 2009; Bocherens, Drucker, & Taubald, 2011; Bocherens, Polet, & Toussaint, 2007;

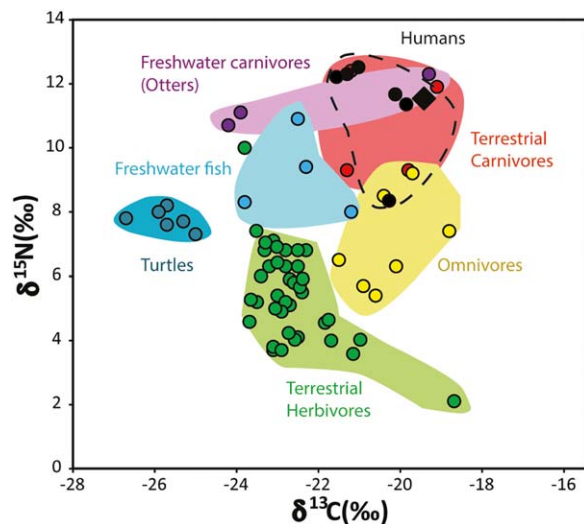
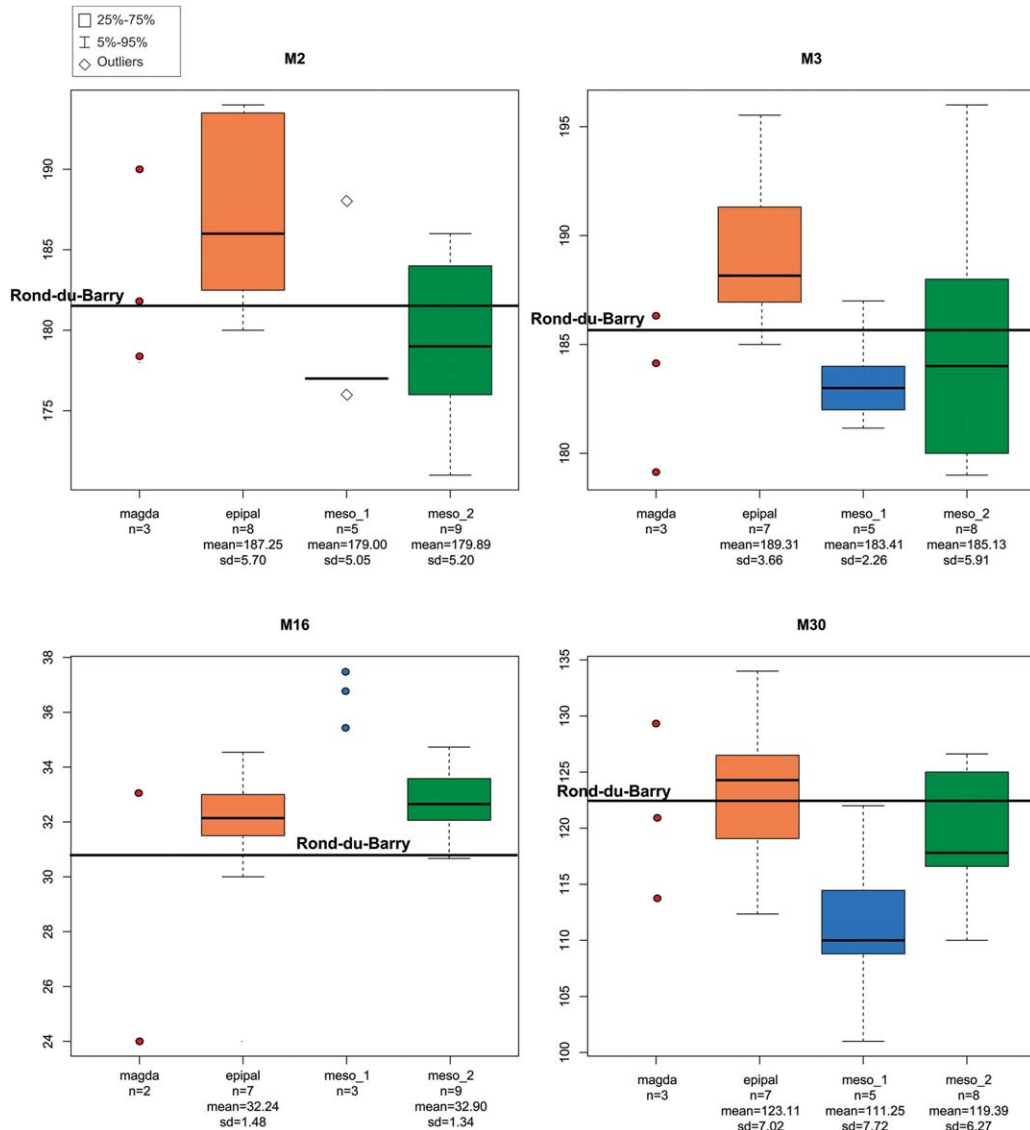


FIGURE 2 Carbon and nitrogen isotope ratios in animal and human bone collagen of North Western European sites for the Atlantic chronozone. The Rond du Barry human is represented with the black diamond symbol. See text and Supplementary data for more information. Data are from this study: Bocherens, Polet, & Toussaint, 2007; Drucker & Bocherens, 2004; Drucker, D. G., Henry-Gambier, D., & Lenoir, M. (2005), Drucker et al., 2003, 2011, 2018



**FIGURE 3** Box-and-whisker plots. Box-and-whisker plots of the median and range of variation of the Glabella-ion length (M2), the Glabella-lambda length (M3), the Maximal breadth of the foramen magnum (M16) and the Parietal chord (M30) for Rond-du-Barry and the comparative samples: Magdalenian group (magda), Final Palaeolithic (epipal), First Mesolithic (meso\_1) and Second Mesolithic (meso\_2). Rond-du-Barry is represented by the black line

Drucker, Bocherens, & Billiou, 2003; Drucker & Célérier, 2001; Drucker, Henry-Gambier, & Lenoir, 2005; Drucker et al., 2018; Schulting, Blockley, Bocherens, Drucker, & Richards, 2008; Schulting & Richards, 2001). Information on site location, species, and associated diets are given in the supplementary information (Supporting Information Figure S1, Tables S4 and S5). The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of Rond-du-Barry are  $-19.4\text{‰}$  and  $11.6\text{‰}$  respectively (Table 2). Similar to the values observed for carnivores in French Mesolithic and European Atlantic sites, the  $\delta^{13}\text{C}$  value of Rond-du-Barry reveals a diet based on terrestrial C3 plants and/or animals that consumed them (Figure 2). As expected considering the cave location (Supporting Information Figure S1), the diet of the individual did not include marine food. The reported  $\delta^{15}\text{N}$  value is typical of those observed for humans in European Atlantic sites (Supporting Information Figure S2), but higher than those of Preboreal humans from Haute Meuse (Belgium, Figure 2), whose diet

relied on terrestrial hunted animals, with the possible addition of fresh-water resources (Bocherens, Polet, & Toussaint, 2007). The herbivore values of French Mesolithic sites tend to be higher during the Atlantic interval compared to the Preboreal period (Supporting Information Figure S2A,B), which is consistent with the warming of the climate throughout the Mesolithic (Drucker, Bridault, Cupillard, Hujic, & Bocherens, 2011; Stevens & Hedges, 2004).

### 3.2 | Morphometric analysis

The Rond-du-Barry cranium is well-preserved and quite complete (Heim, 1992). Twenty-eight of the 36 measurements taken on the Rond-du-Barry cranium were found to differ between males and females in the broader sample, and place this specimen within the range of variation of the male sample but significantly above that of

the female sample (Table 1), in agreement with its robust cranial morphology. The cranial index [M8/M1, (Martin, 1928), see Supplementary Information for abbreviations] calculated from raw data (Table 1) is low (72.37) and indicates a dolichocranic individual. The upper facial index [M48/M45, (Martin, 1928)] is low (47.45) and indicates a wide face.

Second, the 36 measurements were tested for significant differences between chronological periods in the comparison sample. As Rond-du-Barry cranium is beyond the female range, we used only male specimens in the reference sample, and two Magdalenian individuals with an indeterminate sex in order to obtain a larger Magdalenian group. Results indicates significant chronological differences for four variables in the comparison sample (see Supporting Information Table S2 for results and Table S3 for the composition of the comparison sample). Compared with our references groups, the Glabella-inion length (M2) and the Glabella-lambda length (M3) of Rond-du-Barry lie both in the lower part of the Final Palaeolithic variation (epipal) and the upper part of the First Mesolithic (meso\_1) variation, but fall within the Second Mesolithic (meso\_2) dispersion (Figure 3). The maximal breadth of the foramen magnum (M16) of Rond-du-Barry lies in the lower part of the Final Palaeolithic and the Second Mesolithic variation (Figure 3). The parietal chord (M30) of Rond-du-Barry falls within the Final Palaeolithic and Second Mesolithic dispersions. Both maximal breadth of the foramen magnum (M16) and the parietal chord (M30) of Rond-du-Barry stand outside of the First Mesolithic dispersion which seems to differ from the other comparative samples for these variables (Figure 3). Rond-du-Barry aligns with the Magdalenian range of variation characterized by the four dimensions (Figure 3). The Rond-du-Barry cranium does not display peculiar dimensions comparing to the reference sample (Figure 3).

## 4 | DISCUSSION AND CONCLUSION

Radiocarbon dating places the Rond-du-Barry individual in the middle of the seventh millennium cal BC (the calibrated date is provided by OxCal 4.3 (Bronk Ramsey, 2009) using the International Calibration Curve IntCal13 (Reimer et al., 2013) in Table 2) at a time when major changes in stone-working techniques and microlithic traditions characterize the First and Second Mesolithic in Western Europe (Ghesquière & Marchand, 2010; Kozłowski, 2009; Marchand, 2014; Marchand & Perrin, 2017; Perrin et al., 2009; Valdeyron, Bosc-Zanardo, & Briand, 2008). The cranial dimensions and robustness of the Rond-du-Barry cranium are consistent with those of a male, even if the morphological characteristics of the cranium, when considered in isolation, are relatively poor indicators for the assessment of sex. Current analysis on cranial dimensions suggest that Rond-du-Barry stands within the Late Pleistocene and early Holocene range of variation. This comparative analysis was performed for descriptive purposes rather than providing a chronological assessment of Rond-du-Barry individual based on its cranial morphology. Further analyses would be helpful to deepen our understanding of the Rond-du-Barry characteristics in the biological variability during the Late Pleistocene and the Early Holocene.

The isotopic tooth analysis of the Rond-du-Barry individual adds to our knowledge of human diet during the Mesolithic period, as it represents the second report of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  for an adult of a Southern French site dating from the Early Atlantic period (Drucker, Henry-Gambier, & Lenoir, 2005). The tooth dentine is not remodeled after its formation. The analysis of a second molar therefore documents the diet of a few months or years during the childhood of the Rond du Barry individual. Although it is impossible to constrain the dietary sources with more precision in the absence of isotope data available for the associated fauna, these values indicate a diet relying on terrestrial resources, which includes herbivore meat. Freshwater fish might have been eaten, albeit only to a limited extent. This diet is consistent with previous observations made on humans from inland Mesolithic sites (Bocherens, Polet, & Toussaint, 2007; Drucker, Henry-Gambier, & Lenoir, 2005; Drucker et al., 2018; Schulting, Blockley, Bocherens, Drucker, & Richards, 2008).

The new radiocarbon result combined with the isotopic and morphometric studies shed new light on the previous interpretation. In fact, the Rond-du-Barry individual displays a cranial morphology and a diet which are consistent with a Mesolithic sample, in line with the new date. Burials in caves are frequent during the European Mesolithic context, as in calcareous cliffs of the Belgian Meuse River Basin (Toussaint, 2010) and in southern France (Verjux, 2007). However, the Rond-du-Barry cranium represents the only Mesolithic human remains for the French Massif Central area.

We therefore conclude that new techniques in direct radiocarbon dating on specimens yielded by ancient excavations, despite the damage they cause, elucidate invaluable information for the interpretation and study of ancient sites.

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