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WIGGLE-MATCH DATING OF A FLOATING OAK CHRONOLOGY FROM AN EARLY IRON AGE GRAVE CONSTRUCTION (ERESZTVÉNYI FOREST, FEHÉRVÁRCSURGÓ, HUNGARY)

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ABSTRACT. Archaeological excavations unearthed three burial mounds between 1983 and 1986 at Fehérvárcsurgó (Hungary). Based on the archaeological determination the site was dated to the Early Iron Age. A complex wooden architecture was observed in the largest tumulus containing inner and outer beam constructions separated by stone blocks. Dendrochronological and radiocarbon (^{14}C) analyses were performed on conserved logs (n=5) to constrain the felling date of the timber, identified as oak, and the construction period of the tumuli. The four longest ringwidth series were synchronized providing a 153-yr-long floating chronology. Five blocks were removed from the cross sections and accelerator mass spectrometry (AMS) ^{14}C analysis was performed on the separated α-cellulose. A wiggle-matching procedure was employed as the ^{14}C ages were in agreement with their relative position in the tree-ring sequence and concurred with the expected archaeological period. The calibrated age range of the last extant ring is 747–707 cal BC (95.4%). The earliest possible felling date of the trees used in the construction was between 735 and 695 BC considering the missing sapwood. This is the first ^{14}C dated tree-ring width chronology from the Early Iron Age in Hungary providing a valuable reference for dendroarchaeological studies along the eastern border of the Hallstatt Culture.

KEYWORDS: dendroarchaeology, grave construction, Hallstatt period, Hungary, wiggle matching.

INTRODUCTION

The Early Iron Age was represented by the Hallstatt culture (800–450 BC), which spread over a wide territory of Western and Central Europe and extended into northern Italy and the northwestern Balkans (Collins 2013). Increasing social differentiation led to an early urbanization (van der Vaart-Verschoof and Schumann 2017).

Western Hungary, so-called Transdanubia, had been part of the Eastern group of the Hallstatt culture, with the Danube as its border in the East (Jerem 2003). The diverse geographical landscape ambience has strongly affected the Early Iron Age network of settlements in Transdanubia. The Early Iron Age aristocracy was living in fortified settlements built mostly on hilltops and they continued basically a Late Bronze Age tradition, as has been documented in excavations made in Sopron-Várhely (Nováki 1955; Jerem 1980; Patek 1982), Pécs-Jakabhegy (Maráz 1979), Süttő (Vadász 1983), Smolenice-Molpír (Dušek and Dušek 1984), Velem-Szentvid (Fekete 1985), Százhalombatta (Holport 1996; Czajlik et al. 2016) and many others. These settlements constituted core centers even in the Early Iron Age, sustaining intense trade relations toward the South and South-East Alps region, as well as the Mediterranean (Fekete 1985; Patek 1993). The aristocracy built rich grave constructions under large tumuli (Ďurkovič et al. 2018). These tumuli graves often had a timber-lined chamber and grave goods set in and around the room (Makarová 2013). All over the neighboring lowland hinterland, there were identified smaller settlements belonging to communities of common people. The location of the open country settlements was mostly dependent on

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their access to natural resources. Such settlement discoveries are known from Sopron-Krautacker (Jerem 1986), Győr-Ménfőcsanak (Ďurkovič 2014), Balatonboglár (Horváth 2014) with the respective cemeteries, like those in Halimba (Lengyel 1959), Nagydém, Süttő (Czajlik et al. 2015). Such cemeteries are usually much more modest in design, poorer in attachments, and generally strictly separated from aristocratic graves. The current stage of research does not allow yet to delineate the exact and direct linkage between the fortified hilltop and the lowland settlements. The process and shaping of the Hallstatt culture needs further research (Nebelsick 1994). However, dating and periodization of the Early Iron Age settlements in the Eastern part of the Hallstatt culture has many disputable issues (Ďurkovič 2017). The reliable chronological constraints on the relative timing of Transdanubian Early Iron Age sites of similar age would be a key requirement in assessing the environmental and social events that can be reconstructed from the archeological material.

Radiocarbon (^{14}C) dating in this period, however, is a well-known challenge due to a plateau feature characterizing the calibration curve resulting almost constant ^{14}C ages between ~800 to ~400 BC (Friedrich and Hennig 1996; Pichler et al. 2011; Jacobson et al. 2018). ^{14}C dating of a single sample from a period of time that coincides with a plateau may lead to similar ^{14}C ages applying to a wide range of calendar dates sometimes greater than a couple of centuries, creating imprecision, ambiguity for archaeological dating (Hajdas 2009; Manning et al. 2020). Development of yearly-resolved ^{14}C datasets for certain parts of this challenging period in order to improve the calibration accuracy is an on-going effort (Jacobson et al. 2018; Jull et al. 2018; Fahrni et al. 2020).

Beside the archaeological interest there are other peculiarities increasing the interest of ^{14}C analysis of the Hallstatt Period. High-resolution ^{14}C datasets revealed the fine structure of the Hallstatt plateau and showed strongly decreasing atmospheric ^{14}C levels at 2625 BP and the subsequent production event at 2610/2609 BP (Fahrni et al. 2020). Evaluating sub-annual resolution for ^{10}Be and and ^{36}Cl data from ice cores suggested that the increased production rate at the 2610/2609 BP event had a solar origin (O'Hare et al. 2019). Due to these features, additional tree-ring data sets from which additional yearly-resolved ^{14}C data can be fitted to the period of the Hallstatt plateau are particularly valuable.

TUMULI IN THE ERESZTVÉNYI FOREST—ARCHAEOLOGICAL CONTEXT AND SIGNIFICANCE OF THE REMAINS

A field of tumuli in the Eresztvényi Forest near to Fehérvárcsurgó (Figure 1) has been known since the 19th century. Some of the grave mounds were disturbed by illegal excavations. Very likely the hill site of Kisvárhegy represents the settlement belonging to these burial mounds (Jungbert 1991), which are separated from each other by the Gaja stream (Figure 1). Preliminary analysis of the archaeological discoveries from Fehérvárcsurgó show as being dated to the HC2 period (700–600 BC) an era with relative intense peopling of Transdanubia (Jungbert 1991). At the final stage of the era, the whole region shows a sudden decrease in habitation, probably as a consequence of external attacks or partial abandon of the territory. Anyhow, the unbroken continuity of peopling in the final phase of the Hallstatt era is evident, but the intensity of documented findings is diverse in each region.

The archaeological excavation of two almost undisturbed tumuli (Nos. 1 and 4) and a third one in a large part disturbed grave (No. 3) took place between 1983 and 1986, in order to prevent further illegal digging (Kovács et al. 1984). The inner grave construction of Tumulus No. 1 was built from logs and covered with stones and earth. The well preserved wood structure of

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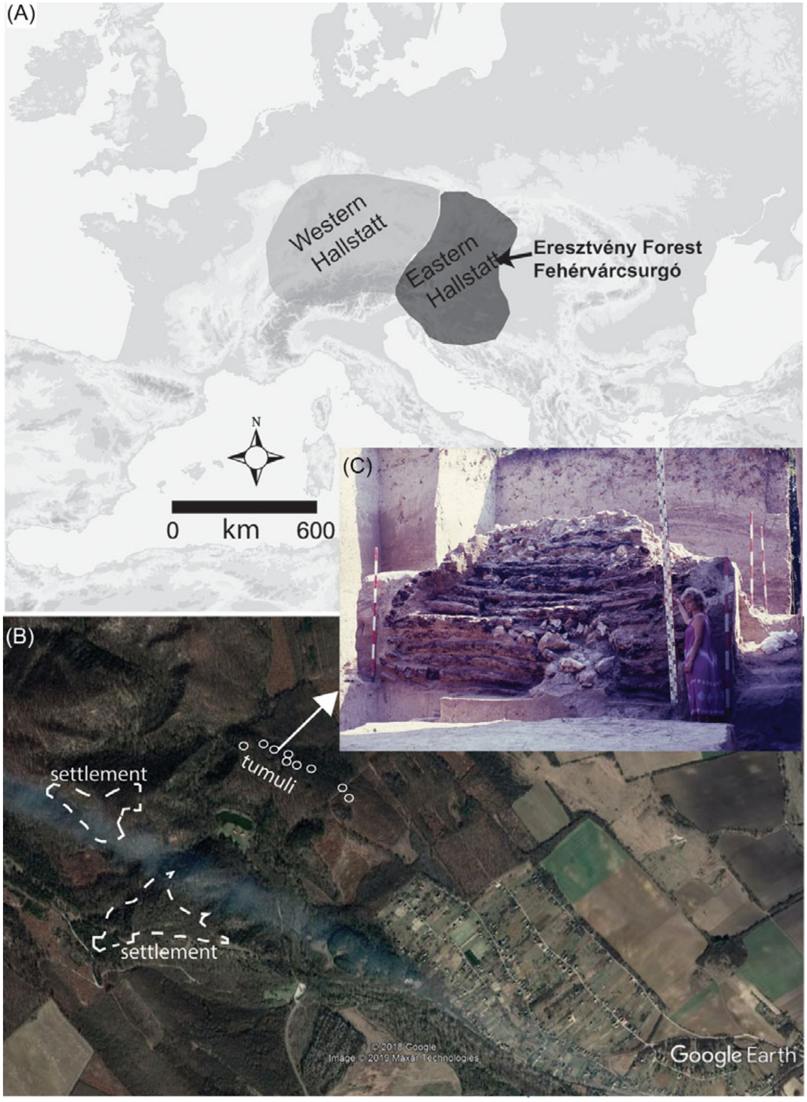

Figure 1 Location of the Iron Age site (Eresztvényi Forest, Fehérvárcsurgó, Hungary): (A) reconstructed geographical range of the Hallstatt culture; (B) location of the study site outline of the Iron Age hilltop settlement excavated south-west of the Gaja stream (dashed line) and location of grave tombs excavated to the east (white circles) of the Gaja stream on a satellite image (image source: Google Earth 2020); C: the excavated Tumulus No. 1. with the wooden grave structure.

Tumulus No. 1 is quite rare across this region in the Hallstatt period (Makarová 2013). The significance of the site is further amplified by making possible to reconstitute basic funeral rite elements of the era (Jerem and Mester 2008).

As elements of the exclusive incinerating rite, the annexed funeral accessories were dispersed on the floor of the chamber, and the ashes deposed in urns. When terminating the burial construction of wood and stone was erected the tumulus itself of several meters high from

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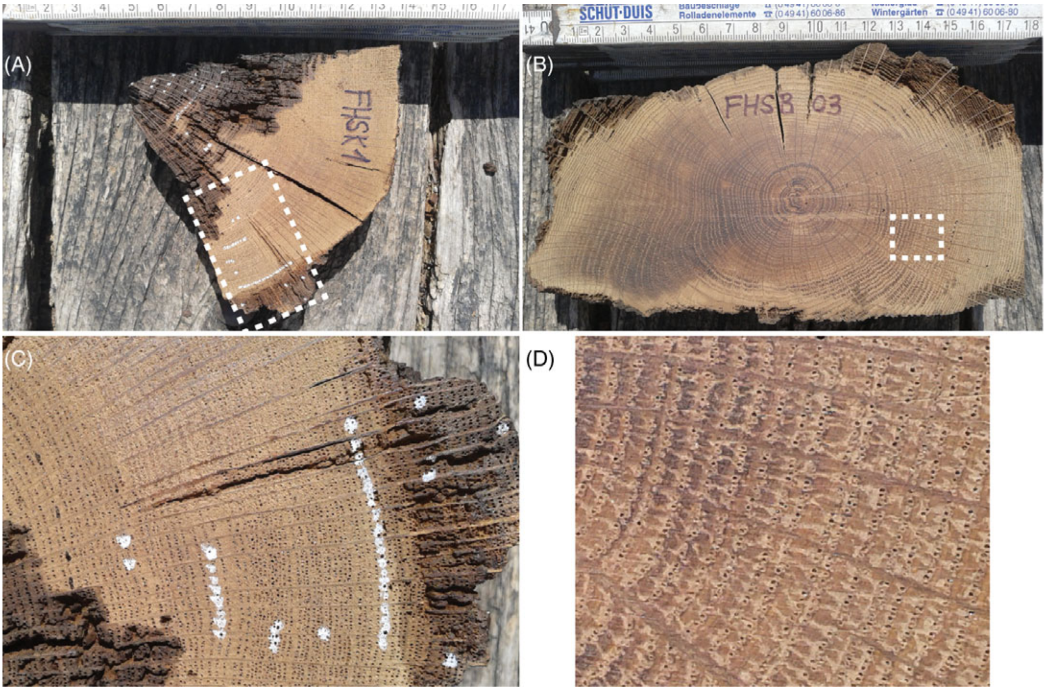

Figure 2 Examples of the polished transects of the dendroarchaeological samples from Tumulus No. 1 Eresztvényi Forest (Fehérvárcsurgó, Hungary). View of the entire cross section of a sample from the inner (A) and outer (B) wooden structure. Parts (C) and (D) are close-up views of the surface indicated by the dashed rectangle in the upper image.

local earth (Jungbert 1991). The rich attachments, like specially decorated ritual and also common use pottery, iron axe and sword, bronze needles, pendants, harness and trappings, and a bronze bowl suggest that a distinguished warrior was buried in Tumulus No. 1. Tumulus No. 4 was much smaller. Its tomb was built entirely of stone and contained a relevant number of pots, lids, small bowls, cups and bronze beading. The significance of the site is further emphasized by the archaeobotanical material placed to the grave as sacrificial donations. A special finding was the beverage residue found in a ceramic pot from the Tumulus No. 1, which could be the earliest known wine residue in Central Europe (Gyulai 2012).

A large amount of wood was recovered from Tumulus No. 1 and a preliminary dendrochronological analysis has been performed already in the mid-1990s. Four wood panels were sampled, three of which came from the inside cover of the tomb and one from the outside structure of the tomb. According to a brief report ring width data sets of the oak samples from its inner cover could be synchronized (Grynaeus 1997). However, the dendroarchaeological investigation could only clarify the relative chronology of the samples and crucial details of the tree-ring analysis are not known from the available brief report published 25 years ago (Grynaeus 1997). In addition, since the research has halted, other scientific dating methods have not been used to improve the age determination of the site. To clarify these issues, the wood material conserved at the Szent István Király Museum (Székesfehérvár) was resampled in 2019 (Figure 2), and tree ring studies were supplemented with ^{14}C dating. The main aim of the work is using a combination of these scientific dating methods to provide a numerical estimate of the age of the archaeological site/material, which will be an important information for the forthcoming publications assessing the archaeological remains from Fehérvárcsurgó, Eresztvényi Forest.

MATERIAL AND METHODS

Tumulus No. 1 and the Dendroarchaeological Material

The excavation of the burial mound of Tumulus No. 1 found a double-walled chamber built in a blockhouse style. An inner log cabin construction was erected from finely finished timbers on all sides with corner joints, standing on the prehistoric ground level of the site and having a side length of about 3–3.5 m. The inner vertical chamber's wall was 0.50–0.70 m high. In this box were ritually placed the burial objects and human and animal funerary ashes. Afterwards, the top of the chamber was horizontally covered by wooden planks. This inner chamber was surrounded by an outer log "cabin" with a side length of 4–4.5 m. This was built from unworked round logs with corner joints. The vertical log wall changed direction and shape after about 1 m forming a truncated pyramid-like shape with a ~2 m^2 opening on the top. The whole interior space between the two constructions was filled up with the remains of the funeral pyre, boulders and soil. As a last act, the mound was covered with layers of soil up to a total height of 4.5–5 m.

Former xylotomical evaluations on the archaeological wood remains identified *Quercus petraea* (Grynaeus 1997) and *Quercus cerris* (É. Petres, personal communication). Urea formaldehyde prepolymer (Conner 1996) was used to conserve the dendroarchaeological material after excavation. This did not affect the dendrochronological examination of the samples at all but caused problems in ^{14}C analyses in certain cases.

Dendrochronology

Five disk samples were collected from the preserved beams of Tumulus No. 1 and used for dendrochronological analysis. Three samples (FHSB01, FHSB02, FHSB03) and two samples (FHSK01, FHSK02) were originated from the inner and outer wooden structure, respectively. Surfaces of the sawn cross sections were sanded with successively finer wood abrasives to expose ring details to the cellular level (Stokes and Smiley 1968). Measurements of the annual growth width, with 0.01 mm accuracy, was done using a LINTAB system and TSAP Win 4.68 software (Rinn 2005). Annual growth widths were measured at least along two radii in each sample and the series were synchronized and averaged. Visual and statistical methods were used to synchronize these individual mean curves. Standard dendrochronological statistics such as percentage of agreement (GLK%, Eckstein and Bauch 1969; Buras and Wilmking 2015) and modified t value (tBP, Baillie and Pilcher 1973) were used to evaluate crossdating results.

Radiocarbon Analysis

Five small blocks, containing 4–7 annual increments, were detached from three disks with the best-preserved physical quality of the timber (Table 1). At the sample selection, the covered span was maximized in order to decrease the probable adverse effects in the wiggle matching results due to some small offset between the ^{14}C levels to the calibration dataset

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Table 1 The results of the ^{14}C analysis and modelled calendar date of the terminal ring of FHS-EIA; the Early Iron age floating oak ringwidth chronology of Tumulus No. 1 (Eresztvényi Forest, Fehérvárcsurgó, Hungary). The unmodelled age range shows the simple calibration, while the modelled one represents the estimated age obtained by wiggle-matching calibration. Calibrated ages are reported with 95.4% (2σ) probability. A: individual agreement percent of the OxCal wiggle-match model

Sample code	Position in tree-ring chronology	AMS lab code[a]	Carbon yield[b] %	^{14}C age BP	Unmodeled cal BC (95.4%) From	Unmodeled cal BC (95.4%) To	Modeled cal BC (95.4%) From	Modeled cal BC (95.4%) To	A(%)
FHSK01-b	52-56	DeA-19521	39.5	2621 ± 31	830 (95.4%)	771	836	796	41.5
FHSK01-a	62-66	DeA-19520	65.4	30809 ± 316		Contaminated			
FHSB03-a	86-89	DeA-20889	42.5	3147 ± 32		Contaminated			
FHSB03-b	101-107	DeA-21939	42.4	2580 ± 32	811 (79.9%)	750	796	756	117.7
					686 (5.0%)	666			
					636 (9.4%)	587			
					581 (1.2%)	570			
FHSB01	129-135	DeA-19518	40.7	2534 ± 30	795 (32.8%)	734	768	728	85.4
					696 (16.3%)	662			
					650 (46.6%)	545			
Last extant ring	153						747	707	

[a]Individual laboratory code of the ICER Centre (Debrecen, ATOMKI) radiocarbon lab (Molnár et al. 2012).

[b]Calculated from the CO_2 produced from the material retained after cellulose preparation.

over its duration (Galimberti et al. 2004) however we had to consider the physical condition of the wood.

As a first step the surface layer most affected by conservation chemicals was mechanically removed, and then subsamples were taken from the inner parts of the samples for ^{14}C analysis. It should be noted that blocks FHSK01-a and FHSB03-a contained the cleaned surface and a few rings directly below it, while the others could be detached from deeper inside of the timber. The α-cellulose was separated (Molnár et al. 2013a) and measured targets were prepared from the material remained after the cellulose separation using sealed-tube graphitization method (Rinyu et al. 2013). ^{14}C analysis was performed at the ICER Centre (Debrecen, ATOMKI) using the EnvironMICADAS facility (Molnár et al. 2013b). The wiggle-matching technique was employed in the calibration of ^{14}C results obtained from dendrochronologically cross-dated tree-ring sequences using the D_Sequence function of the OxCal v.4.4.2. program (Bronk Ramsey 2009) in conjunction with the Northern Hemisphere IntCal20 dataset (Reimer et al. 2020).

RESULTS AND DISCUSSION

Based on the characteristic anatomical features of the timber, such as ring porous structure and wide rays (Figure 2C, D) the wood belongs to *Quercus* sp. (Schoch et al. 2004). This result agrees with previous xylotomy observations (Grynaeus 1997; É. Petres, personal communication). Although oaks are the main species today in the forest of the wider surroundings of Fehérvárcsurgó, they do not create monospecific stands, but are instead typically associated with other species (e.g., hornbeam, ash, elm), and it can be assumed that this was also the case in the Iron Age. The associated species have also been identified as well as the oaks in the timber assemblage of a contemporary wooden structures in Ukraine (Chochorowski et al. 2014). Other species were found beside oak also among the timber of the fortifications of the hillforts of Svržno and Štítary in western Bohemia dated to the Hallstatt period (Pokorný 2004). However, exclusively oak species were identified in the timber material of cremation burials of another Transdanubian Iron Age tumuli site at Érd-Százhalombatta, too (Morgós et al. 2006). These suggest that people of the Northeast Pannonian group of the Eastern Hallstatt Culture selected the oaks for their burial construction and it can be assumed that the associated species could be used as firewood. The results of a detailed anthracological analyses of a burial ground used from the Neolithic until the Iron Age in northern Germany can support this assumption. The overall spectrum of wood species representing the typical species composition of mixed oak forests was found in the charcoal assemblage dated to the Iron Age, however, sorting the charcoal material according to the archeological context showed that only oak was used for grave constructions and the associated species were used as firewood (Jansen et al. 2013).

Counted rings in the samples ranged from 49 to 143. The tree-ring width sequences of the four longest records were successfully synchronized, defining a 153-yr-long floating chronology (Figure 3). The achieved mean ringwidth chronology is coded as FHS-EIA referring to the site code and the abbreviated period. The smaller sample from the outer cover (FHSK02) was the one whose annual ring width data could not be reliably synchronized. For this strongly degraded sample the annual ring widths could only be measured in three non-overlapping short sections (having fewer than 20 rings in each) and these short series could not be fitted to the patterns of the data sets of the longer records with a sufficient certainty, so these small fragments of the FHSK02 were not used in further evaluation. The excellent

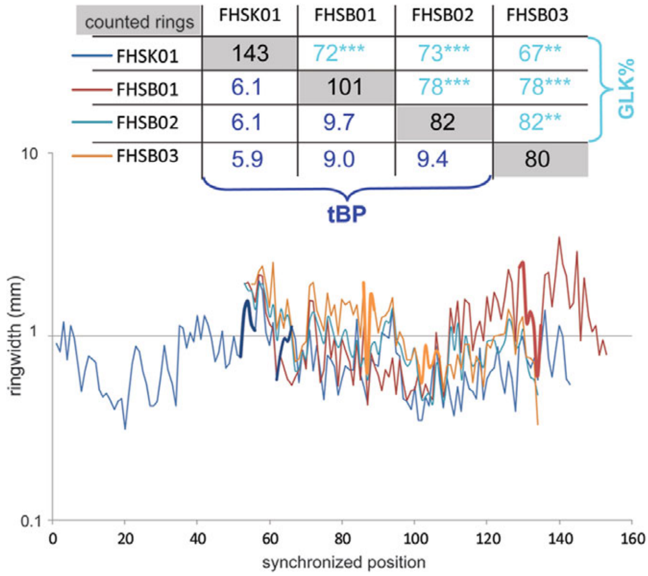

Figure 3 Synchronized tree-ring width series of four oak samples form Tumulus No. 1 of the Iron Age site (Eresztvényi Forest, Fehérvárcsurgó, Hungary). Sections plotted with thicker lines marks the sections removed for ^{14}C analysis. Basic synchronization statistics are shown in the inset table. The lengths of the series are given with a gray background along the diagonal, whereas percentage of agreement (GLK%, Eckstein and Bauch 1969) and t_{BP} (Baille and Pilcher 1973) are shown above and below the diagonal, respectively. The significance of the GLK% is marked as **: p<0.05; ***: p<0.001. Sample codes with FHSB and FHSK show samples taken from the inner and outer beam structure of the grave.

cross-dating statistics of the four longer records (Figure 3) suggest that the trees used for the construction lived very near to each other.

The carbon yield from FHSK01-a (65.4%, Table 1) was well above the maximum expectable carbon yield (44.4%) estimated from the molar mass of carbon ($M_{Carbon} = 12.01$ g/mol) and the molar mass of cellulose ($M_{cellulose} = 162.14$ g/mol) suggesting additional carbon contribution. The ^{14}C age obtained from this sample was much older than the others most strikingly if compared to FHSK01-b which was removed from the same disk just ~10 annual increments preceding the tree rings belonging to FHSK01-a (Table 1). The carbon yield of FHSB03-a was not as anomalous, though the second highest value in the set (Table 1), but the age was also older than the rest of the dataset and similarly in a contrast to the other dated increments of the same disk (FHSB03-b).

These two samples produced much older apparent ^{14}C ages, compared to the others, contradicting with the robust dendrochronological synchronization results, and were detached from the vicinity of the resin-hardened original surface. The unexpectedly old ^{14}C age likely points to a contamination from old carbon which can be originated from the residue from the synthetic resin used for conservation of the archaeological wood. Indeed, the significantly higher carbon yield seen for FHSK01-a and the accompanied strikingly older ^{14}C age (Table 1) supports this explanation. However, the ^{14}C ages obtained from the samples removed apart from the resin-treated surface (FHSK01-b, FHSB03-b, FHSB01) were consistent both with the expected archaeological period and the relative position of the corresponding tree-ring blocks. These samples were used in a wiggle-matching

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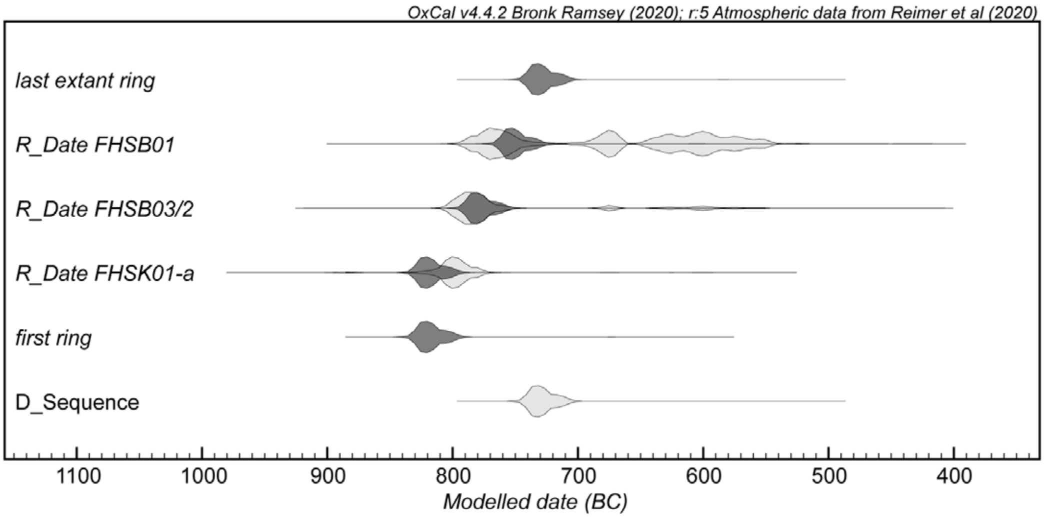

Figure 4 Visualization of the wiggle-matching modeling of the ^{14}C ages obtained from the dendroarchaeological material building the floating oak chronology from Eresztvényi Forest (Fehérvárcsurgó, Hungary). Probability distribution of the single calibration (light gray) and wiggle matching modeling (dark gray) are shown.

procedure to get a calibrated date for the floating oak chronology from this Early Iron Age grave construction (Table 1; Figure 4).

The agreement index (A), which shows how the distributions obtained for the individual samples fit the model, is relatively low in one case (41.5%) but exceeds the critical level of 60% in the other cases (Table 1) and this is also true for the combined index calculated for the whole model ($A_{comb} = 61\%$). The obtained calibrated age range of the last extant ring of FHS-EIA is 747–707 BC (Table 1). Sapwood was not observed on the samples; so assuming a minimum of 12 missing saprings, taking into account the usual range of sapwood rings determined for oaks younger than 150 years in modern forests of Hungary ($17\ ^{+2}/_{-5}$, Grynaeus 2002), the earliest possible felling dates of the trees used in Tumulus No. 1 was between 735 and 695 BC.

The archaeological relative chronology determination of Tumulus No.1 (HC2, Jungbert et al. 1991) is in full accordance with the rating of similar archaeological discoveries in the area (e.g., Százhalombatta Holport et al. 1999). However, the obtained chronological constrains on the probable range of the earliest possible felling date of the trees used for the construction of Tumulus No. 1 just marginally matches HC2 instead cover the preceding HC1 phase (Metzner-Nebelsick 2017). Anyhow, this is a slight but remarkable discrepancy compared to the archaeological determination of the horizon of the tumuli of Eresztvény Forest (Jungbert et al. 1991) and constituting an important starting point for further research and refinement in measurement, observation, and interpretation.

The 153-yr-old floating oak ringwidth chronology from Tumulus No.1 (FHS-EIA) was compared with oak ringwidth chronologies available from the corresponding period from the Czech lands (Kolár et al. 2012; Prokop et al. 2017), Bavaria situated northwest of Transdanubia and from the subfossil driftwood of the Sava river (Pearson et al. 2014) situating south from Transdanubia. However, no reliable synchronicity was found with

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these data (Michal Rybnicek, personal communication; Franz Herzig, personal communication; Charlotte Pearson, personal communication). Consequently, the achieved FHS-EIA will serve as a reference chronology for the (late Bronze Age) early Iron Age dendroarchaeological material of the Transdanubian region of the Eastern Hallstatt Culture which seems to be situating outside of the dendrozone of the above mentioned existing reference oak chronologies of East Central Europe. The most promising target for this endeavor is the rich dendroarcheological material of the above mentioned Iron Age tumuli near to Százhalombatta (Holport 1999) because their conserved timber (Morgós et al. 2006) is still waiting for a systematic dendrochronological analysis.

CONCLUSIONS

A 153-yr-long ringwidth chronology, FHS-EIA, was established from four oak samples of an Early Iron Age burial mound excavated in the Eresztvényi Forest (Fehérvárcsurgó, Hungary). ^{14}C ages, consistent with the dendrochronologically synchronized position of the analyzed tree rings agreed with the archaeological period identified based on the archaeological findings. The earliest possible felling date of the trees used in the construction could be between 735 and 695 BC based on the wiggle-matching calibration results and the sapwood correction. FHS-EIA is the first ^{14}C-dated floating tree-ring width chronology from the Early Iron Age in Hungary which will be a valuable reference in future dendrochronological studies on wood samples from other archaeological sites along the eastern border of the Hallstatt Culture (e.g., Százhalombatta).

This result inevitably places the tumulus burials at Eresztvény Forest to a chronological context to evaluate their connection within the eastern Hallstatt culture and adjacent areas. The chronological constraints on the earliest possible felling date of the trees used in the Tumulus No.1 will apparently make possible a more precise determination of the findings from Fehérvárcsurgó, moreover they will allow a comprehensive and accurate reconsidered phase of the Early Iron age chronological horizon in Transdanubia. The independent confirmation of the archeological age classification, beside the exact dating of the archeological site, will be crucial also for the exploration of environmental historical evaluation of the plant macro-remains, food and beverage residues excavated in Eresztvény Forest.

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