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Human Remains Detection Dogs as a New Prospecting Method in Archaeology

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Abstract

Detecting burial sites in archaeology often involves various prospecting methods such as field survey, ground-penetrating radar (GPR), electrical resistivity, and remote sensing. This paper presents the results of utilizing human remains detection dogs in detecting prehistoric burials dated to the Iron Age in Europe. Human remains detection (HRD) dogs or cadaver dogs are commonly used in criminal cases. However, they are used less frequently for detecting historic burials. Our research was conducted at the burial site of the prehistoric hillfort of Drvišica (Croatia) located on the littoral slope of the Velebit mountains. A total of four HRD dogs were used in both a blinded and double-blinded search. Those locations where an HRD dog produced an indication were subjected to both visual inspection and archaeological excavation. This research has resulted in the discovery of five new prehistoric tombs as well as HRD dogs detecting previously excavated tombs. Therefore, in this paper, we demonstrate that HRD dogs are a valuable tool for locating burials like other non-destructive archaeological search methods.

Keywords Human remains detection (HRD) dogs · Cadaver dogs · Burial sites · Prehistoric burials · Archaeological prospection · Detection · Canine reliability

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Introduction

Many non-destructive methods for locating burials are available to archaeologists, including field survey, aerial photography, infrared satellite imaging, GPR (ground-penetrating radar), and resistivity (Conyers 2006; Kennedy 2011; Goodman and Piro 2013). Although all of these methods offer the potential for remotely identifying sites, they all have limitations and do not always yield the desired results. Scholarly literature from the field of forensic archaeology frequently indicate human remains detection (HRD) dogs or cadaver dogs as a useful tool in locating clandestine burials (Komar 1999; Rebmann et al. 2000; Lasseter et al. 2003; Hunter and Cox 2005; Dupras et al. 2006; Oesterhelweg et al. 2008; Furton 2010; Judah and Sargent 2015; Alexander et al. 2016) or mass graves (Schmitt 2001). Nevertheless, this investigative tool is less frequently employed in prehistoric or historic archaeological contexts.

HRD dogs are trained to find, locate, and indicate the strongest concentrations of human specific odor at various stages of decomposition and in different geological settings (Alexander et al. 2016). Properly trained HRD dogs are capable of detecting human decomposition compounds in gravesoil and water extracted from contaminated gravesoil even in the absence of any visual cues (Alexander et al. 2015). The dogs are trained to emit a clear signal to the handler. The handler is then in a position to interpret the signal as a definitive finding of a specifically human decomposing odor.

Many studies have identified numerous volatile organic compounds (VOCs) associated with buried decomposing human remains. Vass et al. (2008) detected 478 individual VOCs produced from the decomposition process of human remains. Human remains have been demonstrated to have a characteristic, specific odor (Vass et al. 2008) which differs from other decomposing mammals (Rosier et al. 2015) and more than 30 of those VOCs are identified as human specific (Statheropoulos et al. 2007; Vass et al. 2004, 2008; Vass 2012; Hoffman et al. 2009). Although domestic swine are still used in some European countries as a training aid for cadaver dogs, a study which compared human, chicken, pig, and cow cadaver tissues showed that the human and chicken odor profiles had the most similarities with 60% of VOCs detected in common, whereas human and pig were only 23% similar (Cablk et al. 2012).

A body laid in the ground creates a cadaver decomposition island (CDI), the form and size of which is contingent upon the geomorphic and chemical structure of the surrounding soil and the action of scavengers (Aitkenhead-Peterson et al. 2012). HRD dogs can differentiate between soils where decomposition of a human body has taken place from soils where such processes have not occurred. Gravesoil retains VOCs with a specific human decomposition odor profile (Alexander et al. 2015). These VOCs with a specific human decomposition odor profile are absolutely crucial for HRD dogs to detect and indicate precise burial locations.

Human decomposition odor can be preserved in the soil, under favorable conditions, for several millennia. In a wet and humid environment, adipocere can be formed on the body as a product of body fat conversion into a lipid mixture in different soil types (Fründ and Schoenen 2009). Adipocere may leak into the surrounding soil and can be detected in gravesoils (Shari L. Forbes et al. 2003; S. L. Forbes et al. 2005). It can make a body almost resistant to decay for hundreds of years (Fiedler and Graw 2003; Ubelaker and Zarenko 2011). A body of a child in a stone sarcophagus dating to the Roman period was found enveloped in adipocere (Fiedler et al. 2009). Additionally, the

Tyrolean Iceman research demonstrated that adipocere can be preserved for up to 5000 years (Bereuter et al. 1997).

However, it has been demonstrated that decomposition smells can be very persistent. New studies demonstrate that trained HRD dogs are able to detect diluted decomposition fluid (Buis et al. 2015) and cadaveric blood (Riezzo et al. 2014). Additionally, they can detect individual human teeth with a high degree of success in a field setting (Cablk and Sagebiel 2011). Research has also shown that trained HRD dogs can detect residual human decomposition odor on textile which has not been in direct contact with human remains (Oesterhelweg et al. 2008).

Research on the use of HRD dogs to detect and locate older historic, or even prehistoric, burials is very limited. Dogs used to locate archaeological burials and human remains are also called "historical human remains detection dogs or HHRD" (Baxter and Hargrave 2015). HHRD dogs were used at Clements Cemetery, where the earliest gravestone is dated to 1810–1820, to locate unmarked graves within a grouping of known graves (Baxter and Hargrave 2015, 41). As a part of the same project, HHRD dogs were used to locate graves which predate 1940 in Gordon, GA, USA (Baxter and Hargrave 2015, 60–90). In both cases, GPR was also employed to verify the location of graves identified by the HHRD dogs. In this research, HHRD dogs indicated at the same locations as GPR anomalies at 60% of the cemeteries and within 1 m of the anomalies at 100% of the cemeteries (Baxter and Hargrave 2015, 92). Cadaver dogs were also used in an attempt to locate World War II mass graves in Austria (Pototschnig 2013). Although graves were not found on that occasion, the dogs did locate areas where human remains were probably laid for several hours prior to being moved to a secondary location (Pototschnig 2013).

This research provides evidence for the ability of HRD dogs to detect human decomposition smell from prehistoric context. The following aims were specified in order to complete our research agenda: (1) deployment of method to locate prehistoric burials using HRD dogs at Drvišica hillfort necropolis, (2) validation of the dogs' indications with archaeological excavation, and (3) evaluation of using HRD dogs as a prospecting method in the search and location of prehistoric burials.

Geological and Archaeological Context of the Drvišica Hillfort

The research area is located on a littoral slope of central Velebit mountain in Croatia. The Drvišica hillfort site is situated in the vicinity of the modern town of Karlobag, just below the Baške Oštarije mountain pass (927 m a.s.l.). The site is positioned on an elongated ridge (167 a.s.l.), rising steeply from the Adriatic Sea (Fig. 1). The geology of the area is characterized by predominance of carbonate rock, typical karst (limestone) relief, and extreme lack of soil cover (Faivre 1994). Therefore, all karst features are clearly visible such as rillenkarrens and grikes particularly accentuated at northern Drvišica slopes, the exact place of the necropolis and our research using HRD dogs. The western ridge slopes contain somewhat more soil cover in the form of anthropogenic terracing at the site.

Climate is affected by the Velebit mountain geographic position and its altitude (1757 m a.s.l.). The littoral slope of the Velebit mountain, where Drvišica is located, is characterized by sub-Mediterranean climate with aridity caused by great insolation and

Fig. 1 The Drvišica hillfort and the position of the burial site

reduced cloud cover (Rogić 1957, 78–79). High evaporation and thermomechanical rock disintegration is caused by high summer temperatures (Perica and Orešić 1999). However, the major climatic feature of the study area is the strong, cold, and dry wind known as "bura." Bura blows from north, east, and north-east on the littoral Velebit slope, often with a force of a violent storm or even hurricane. The greatest effect of bura is in the areas below the mountain passes. Therefore, our study area, positioned below the Baške oštarije mountain pass, is often exposed to violent bura wind.

Natural factors such as sea proximity, Mediterranean climate, and karst base also affect the vegetation cover represented at the site. The vegetation is adapted to the arid environment. Maquis and low bush-like plants predominate, typical for karst environment (Forenbacher 1990). Rocky and barren areas are also quite common at the site.

Drvišica is a complex site, covering an area greater than 30 ha. The site covers a period from the eighth century B.C. to the early Modern period and includes a prehistoric hillfort with a necropolis, a Roman settlement, a Byzantine fort, and a medieval church (St. Vid) (Glavičić 1996; Braut and Majer Jurišić 2017; Brunšmid 1899; Glavaš 2015; Brunšmid 1901). The research using HRD dogs was conducted on the northern slope of Drvišica hillfort where traces of a prehistoric necropolis were documented during previous research.

Systematic archaeological research at the hillfort commenced in 2013. Research has shown that the prehistoric site was continuously inhabited from the eighth until the first century B.C. A massive, drywall rampart (up to 3 m wide) was built to protect the approach to the central settlement area (Fig. 2). The south-eastern part of the site, towards the sea, was extensively terraced (Glavaš 2015). A prehistoric necropolis, positioned on the north-eastern slope of the hillfort, was identified during a systematic field survey and first excavated in 2014. As a result of looting activities, some burial chests were visible or only partially visible on the ground surface. Excavations in 2014 resulted in the discovery of three, previously disturbed, circular, drywall tombs. A burial chest was placed inside the circular structure composed of roughly worked and unworked stone blocks. The deceased was laid in the chest in a fetal position, the

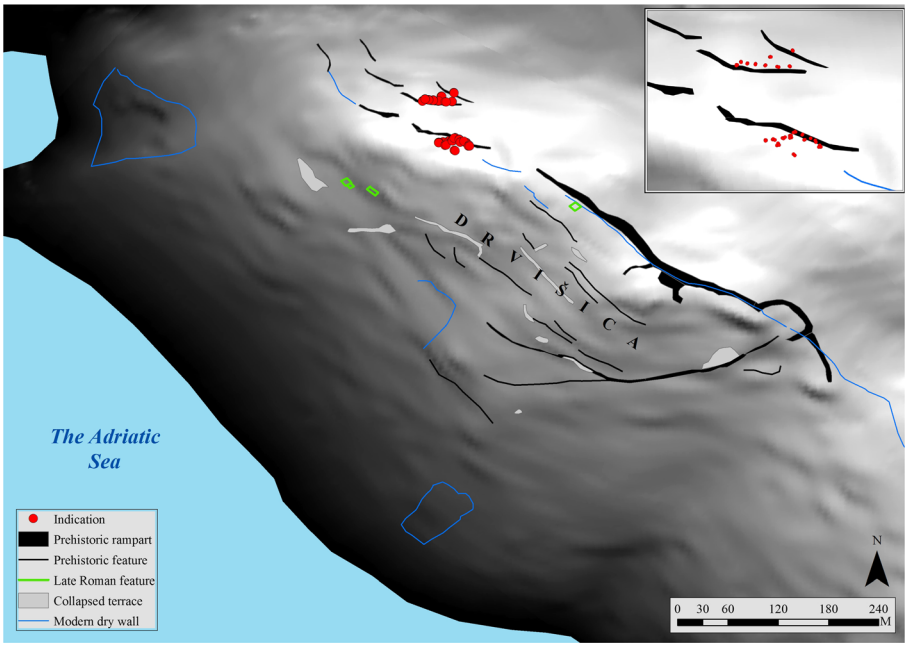

Fig. 2 Indication positions on the Drvišica hillfort

typical style of inhumation in this area during this period (Kukoč 2011). This was also concluded on the basis of burial chest dimensions. The burial chests, incorporated in natural grikes, were mostly uncovered because all burials were previously disturbed.

There was very little soil within the tombs. The bones of the deceased were extremely fragmented with the best preserved material consisting of phalanges and teeth (Glavaš 2015). Based on the number of human teeth within each burial structure, it appears that each tomb contained multiple burials (Glavaš 2015). The preliminary results of the anthropological analysis suggest that each burial contained at least two individuals; an adult and a child (Nystrom 2016). Archaeological finds inside the burial chest indicate that the deceased were interred in the mid-eighth century B.C. This is also confirmed by the results of radiometric carbon dating (Beta-385897, cal BC 770; uncal 2530 ± 30) of human bone from one of the graves.

Materials and Methods

A total of four female HRD dogs (see Table 1) from S.PAS Centre (Special purpose dogs' association, Andraševec, Croatia) and two professional dog handlers were a part of the search effort. The dogs varied both in their experience and age (2–9 years old). Dogs used in this research underwent a training program (Furton 2010; Mine detection dogs: training, operations and odour detection 2003; Abrantes 2010, 2014a, b) common in Europe and the USA (Rebmann et al. 2000; Judah and Sargent 2015). During their training, from puppyhood until maturity, they were exposed to different human remains training aids (Hoffman et al. 2009; Furton 2010). Near the end of their formal training,

Table 1 List of dogs utilized in the research

Dog	Years	Training method	Indication	Breed	Gender
A	9	Air-scenting	Active (barking)	Belgian Malinois	F
B	4	Detection	Passive	Belgian Malinois	F
C	3	Detection	Passive	Belgian Malinois	F
D	2	Detection	Passive	German Shepherd Dog	F

the dogs started to work on real archaeological and forensic sites. During this work, dogs in training were observed, and their behavior and results was always compared with other more experienced dogs.

All dogs used in this research are operational working HRD dogs with a vast experience searching for clandestine and mass graves dating to World War II and the Homeland War (1991–1995) within the Croatian model of searching for missing persons developed by the Ministry of Croatian veterans' affairs. The dogs also have a lot of experiences in criminal cold-cases and operational police cases.

Only the oldest dog used in this research was trained as an air-scenting dog for search and rescue, and she has an active indication by barking (see Table 1). Other dogs were trained as forensic/cadaver detection dogs with passive indication for the purpose of grave searching (see Table 1). They were trained in the same manner as mine detection dogs to achieve greater efficiency for searching the soil surface for the target odor (*i.e.*, human remains).

All dogs were trained exclusively to natural materials of human origin and specific scent imprint of human remains. The training (imprint) material list includes:

- human blood, fresh; dry; decayed;
- human bones, wet; dry; bones from archaeological context up to 3000 years old;
- human muscle, fresh; decayed; mummified;
- human internal organs, decayed;
- human decomposition fluids;
- human fat with skin tissue;
- adipocere (mortuary wax);
- contaminated soil collected from graves of different ages;
- burned human tissue.

The dogs were not exposed to larger quantities of human remains on the surface of the ground such as whole human cadavers or parts of bodies. They were, however, exposed to surface detection of mass graves (World War II, Homeland War 1991–1995) with materials in an advanced stage of decomposition. The dogs were additionally trained using gravesoil samples and bones from historical burials (age > 300–3000 years), which was necessary to prepare them for low concentrations of human-specific decomposition odor which would be associated with prehistoric burials.

The dogs were trained by various handlers. They were also handled by different handlers during this research, which is standard for these dogs in order to decrease handlers' influence and expectations of the dog's work (Lit et al. 2011). The work of

dogs was organized as "blind," but mostly as "double-blind" search. The term "blind" search means the situation when dogs and handlers do not know where the grave is, but the leader of the archaeological excavation can assume the probable position of the grave or can recognize it on the surface. The term "double-blind" describes the situation when the grave is not visible, and when nobody on the site knows whether the target odor is present or not. The same search pattern is usually used within a mass grave search with the same dogs. The third method of searching was "known-target" which means that the handler could recognize the grave on the surface of the ground through observable characteristic changes of the landscape associated with a grave. Known-target searches were performed only on already excavated tombs prior to searching on the non-excavated area of the burial site in order to see if dogs would show any interest or indications.

During the research at Drvišica, the work was always performed using a randomized order of the dogs in order to prevent order effects. Also, the work of the second dog on the same area was always performed by another handler, which was crucial for "double-blind" search. To prevent order effects, dogs and handlers were situated out of sight of the search area while not working. This ensured they could perform their task double-blind since they had no prior knowledge or expectations. The interval between two dogs working was around 15 min.

During the training, as well as within this research, the reward program used for the dogs was various positive reinforcements in intermittent reinforcement schedule. Sometimes, dogs were rewarded with food reward for indications on a blind search in which the handler did not know the position of the grave, but the archaeologists knew. In such cases, the dog would receive the food reward on the burial position. However, in the majority of cases, the dogs were rewarded for their good work at the end of the double-blind search session with a play reward because archaeologists were not always able to recognize the exact burial position.

The search was organized from the upper part of the necropolis and proceeded in a northerly direction, downhill in the direction of the excavation trench. Three burials which were excavated the previous year were also included. The total research area covered was 0.38 ha. Since the site is located on a karstic base and rocky outcrops predominate, it was impossible to test—trench the area prior to survey. The dogs' search was organized in such a manner that each search area segment was covered by at least two dogs led on a long leash or in free search.

The dogs' harnesses contained a GPS device which recorded their movement and allowed us to geolocate the coordinates of each spot indicated by the dogs. All dogs' movement tracks and their indications were entered into a database created within ESRI ArcGIS 10.3 spatial analyst. Every work episode performed by the dogs was also documented with a written description as well as with video recorded from the ground and from the air using a drone. If two or more different dogs indicated within the same area of approximately 4 m^2, this group of indications was considered as marking points (MPs) and therefore the possible position of tomb. If the same dog indicated more than once within one MP, indications were recorded as one by GPS. If different dogs indicated the same position, the indication was recorded each time. Therefore, each MP consists of multiple indications made by different dogs and were flagged as significant for further research (see Table 3).

Marking points (MPs) were tested using two methods: visual inspection and excavation. Since the site is located on karst terrain characterized by a lack of soil, some parts of burial constructions, such as parts of stone burial chests, were readily visible at the surface. However, these features could be recognized on the surface only by an experienced archaeologist who was familiar with the site. Therefore, handlers were not able to recognize these features. All potential burial locations indicated by the dogs were recorded in the sheet as "visible" or "not visible" on the surface. The second method of burial confirmation was archaeological excavation.

Only those MPs that were marked by at least two dogs were selected for archaeological excavation for two reasons. First, due to the availability of only two handlers, any further searching sessions would not be double-blind. The second reason is that multiple indications at the sample location were considered as a confirmation of human decomposition odor. Since the excavation at the burial site started a year prior to the research with dogs, the existing trench on the burial site was extended in directions of dogs' indications to the southern and north-eastern sides. The layers were excavated manually in horizontal, stratigraphic layers. Each layer, as well as the items recovered, was recorded. All soil was sifted during excavation in order to recover the smallest objects and bones. Following the excavation, human bones were analyzed and the results are pending.

Results

The search with dogs on the burial site of Drvišica was performed in three different research campaigns: in June 2015, September 2015, and September 2016. The intervals between the research campaigns were also done in order to prevent a follow-up effect.

The weather conditions during the research varied from warm to very hot with a total temperature range between 22 and 32 °C and no rainfall recorded. During the first trial search in June 2015 on excavated tombs, the temperature varied between 24 and 28 °C with an average of 26.5 °C. During the research, there was no wind. During the search in the non-excavated part of the burial site in September 2015, the range of temperature varied from 22 to 25 °C with an average of 23 °C. The recorded north and northeasterly wind blew up to 40 km/h. The temperature range recorded during the search in September 2016 ranged between 23 and 27 °C with an average of 25.5 °C without any wind. The temperature of the soil was not measured since soil is limited at the site and mostly situated under a layer of rocks. Removing the layer of rocks would cause disturbance of the ground and therefore possibly affect the dogs' indications.

During the search, there was no cloud cover, and therefore, the search area was sunny. The work of every dog was thus reduced to 15–20 min due to the weather conditions. Since during the night stones were getting cooler, and during the morning it started to warm up, to ensure the best thermic opportunity, all searches were done in the morning hours between 7:00 and 11:00 AM.

The search included four HRD dogs, followed by visual inspection of indicated locations, and excavation of five indicated spots.

The first area that the dogs worked included three tombs excavated in 2014: the HRD dogs indicated in all three tomb locations (see Table 2). This search was conducted in June 2015 before the research on the non-excavated part of the burial site in order to see whether the dogs would show any interest in the site. Therefore, the search was a "known-

Table 2 Indications made on known targets by dogs in the previously excavated burial area

Tomb no.	Total number of indications	Burial chest indicated	Dog that indicated burial chest	Inside of circular tomb structure indicated	Dog that indicated inside of the circular structure	Note
1	3	2	C, B	1	D	Burial excavated before testing dogs (tomb 1)
2	3	2	D, B	1	A	Burial excavated before testing dogs (tomb 2)
3	3	3	A, B, and C	0		Burial excavated before testing dogs (tomb 3)
Total	9	7	–	2	–	–

target" search because the handler was told the positions of already excavated graves, which were visible on the surface. Since the burial chests were visible, the dogs were rewarded with play reward, the strongest reward for precisely indicating the position of the grave. For this work, dogs were rewarded with the strongest reward for exactly finding the position of the grave because it was treated as imprint training.

The three previously excavated tombs were indicated by dogs in the following manner: the burial chest which contained human remains or the area within the burial enclosure, immediately adjacent to the burial chest. The position of tomb 1 was marked by the dogs three times: the burial chest was indicated twice while the third indication referred to the area immediately outside the chest but well within the enclosing structure. The same indication pattern was documented at tomb 2. Burial chest of tomb 3 was indicated three times.

The dogs' indications on the non-excavated area of the burial site are presented in Fig. 2, which shows positions that were indicated at least two times during the survey and which were singled out as significant for further research. A total of 19 positions (MPs) were indicated more than once (see Table 3), while the number of single indications was 13. However, single indications were not taken into consideration at this initial phase of the research.

Visual inspection of other locations (Table 3: MP ID 1–19) indicated by at least two dogs was conducted in order to ascertain whether the burial positions could be determined without archaeological excavation. As mentioned previously, the terrain is characterized by an extreme lack of soil. Hence, some of the tombs are readily visible on the ground surface to archaeologists. The HRD dogs indicated a total of 7 locations (MP ID 4, 7, 9, 13, 14, 16, 17) where visual inspection could confirm that tomb structures were present as architectural elements (*e.g.*, segments of circular enclosures or parts of burial chests). The validity of the 12 remaining indicated locations had no visible surface features (MP ID 1, 2, 3, 5, 6, 8, 10, 11, 12, 15, 18, 19) and had to be investigated by archaeological excavations. To date, the excavation of five of these locations (MP ID 5, 11, 13, 15, 17) has been carried out, selected because they were positioned near the existing excavating trench.

Table 3 Indications of dogs made in blind/double-blind searches in unexcavated area, and evaluation of the results

Marking point (MP) ID	Number of indications	Tomb confirmed by visual inspection	Tomb excavated	Burial chest indicated	Dog indicated	Inside of circular tomb structure indicated	Dog indicated	Note	Blind (B) search/double-blind (DB) search
1	2	No	No	–		–		Not excavated yet	DB
2	2	No	No	–		–		Not excavated yet	DB
3	2	No	No	–		–		Not excavated yet	DB
4	2	Yes	No	1	C	1	A	Not excavated yet	B
5	3	No	Yes	1	B	2	A; C	Tomb 4	DB
6	2	No	No	–	–	–	–	Not excavated yet	DB
7	2	Yes	No	1	B	1	D	Not excavated yet	B
8	3	No	No	–		–		Not excavated yet	DB
9	2	Yes	No	1	A	1	B	Not excavated yet	B
10	2	No	No	–		–		Not excavated yet	DB
11	2	No	Yes	–		2	B; D	Tomb 8	DB
12	3	No	No	–		–		Not excavated yet	DB
13	3	Yes	Yes	3	B; C; D	–	–	Tomb 5	B
14	2	Yes	No	–		2	B; D	Not excavated yet	B
15	2	No	Yes	–		2	A; C	Tomb 6	DB
16	2	Yes	No	–		2	A; C	Not excavated yet	B
17	3	Yes	Yes	2	C; D	1	B	Tomb 7	DB
18	3	No	No	–		–		Not excavated yet	DB
19	2	No	No	–		–		Not excavated yet	DB
Total	44	7	5	9		14			

The remaining indications (MP ID 1–3, 6, 8, 10, 12, 18–19) will be tested in subsequent research campaigns. Therefore, since these locations have not been excavated nor recognized on the surface, it was not possible to determine whether the burial chest or the area inside the circular structure was indicated by dogs.

In the non-excavated area of the burial site, the searches were done in blind/double-blind manner, and dogs' indications are presented in Fig. 2 and Table 3.

The excavation of MP ID 5 confirmed the presence of a tomb (tomb 4), built by the same technique as burials known from previous research (Fig. 3). Large, stone blocks were used to construct an outer circular ring measuring 5 × 3.50 m, enclosing a burial chest consisting of three stone blocks placed directly on bedrock. There was a fourth block which was displaced from its original position, probably as a result of grave robbing. Material artifacts recovered from within the chest included a blue glass bead, a bronze pin head, half of a perforated amber bead, and a fragment of bronze wire formed in a tear-shaped coil. Human bones found in the fill were disarticulated and were heavily fragmented. As in previous excavations/tombs, smaller elements, such as phalanges and teeth, were well preserved. Disarticulated human bones and teeth, as well as pottery fragments, were also found upon the removal of gravel between the burial chest and the outer ring. A subsequent comparison of indicated positions and excavated areas demonstrated that the burial chest was indicated by two dogs, while the area inside the circular structure was indicated by one dog.

The second location indicated by three HRD dogs was a burial chest, cataloged as tomb 5 (MP ID 13). Unlike tomb 4, tomb 5 was visible on the ground surface and recognized by archaeologists. The tomb was previously looted and the excavation focused on documenting the burial in its present state of preservation. As visible on Fig. 4, a circular drywall structure was discovered, measuring 4.75 × 3.30 m and an

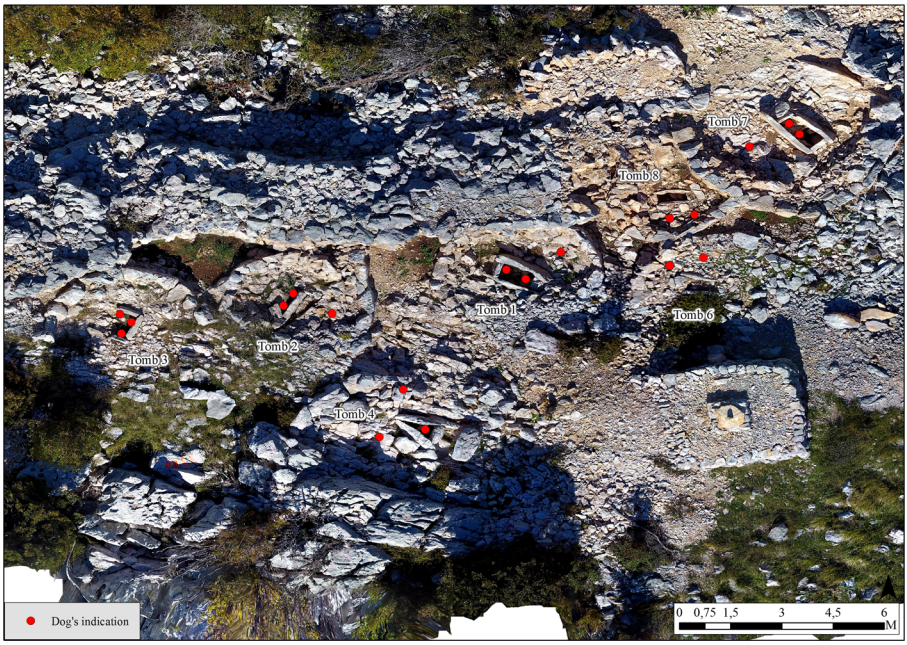

Fig. 3 Excavated part of the burial site and dog indication positions

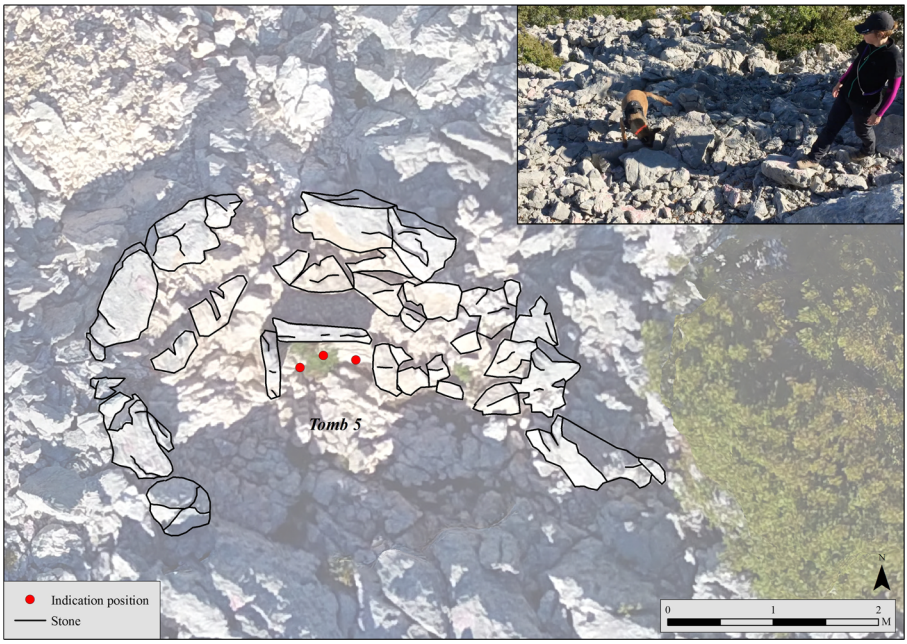

Fig. 4 Tomb 5 and indication of its position by a dog

inner half-ring built with uncut stone. The burial chest is poorly preserved with only two blocks left standing: a lateral block and a block that could have been placed either at the feet or at the head of the deceased. In contrast to tomb 4, there was no soil between the burial chest and the outer circular structure. The fill in the burial chest was 30 cm thick. Only disarticulated human teeth were recovered as well as two bronze pins. The first one is a multi-headed bronze pin which is dated to the eighth–seventh c. BC (Škoberne 2003). This type of pin is a characteristic part of male jewelry spread over central and south-eastern Europe (Škoberne 2003). In Croatia, the greatest number of this type of pin has been found in burials excavated in the territory of Iapodes (Škoberne 2003). A double pin was also discovered in this tomb 5. It may also indicate a male burial. This pin type is characteristic for the wide Balkan region but also for the period between the eighth and second c. BC (Blečić Kavur and Miličević-Capek 2011; Radić 2017; Radić et al. 2017). On the basis of these attire/jewelry finds, this tomb has been dated to between the eighth and second century BC.

Tomb 6 (MP ID 15) was discovered during the "double-blind" search and was confirmed as a grave based on excavation. Both the stone chest and the typical circular structure of the tomb were not visible on the surface, and were both only noticed after removal of the first layer of stones. During the excavation process, it was noticed that previous indications of two dogs were positioned inside of the circular structure of the grave. Tomb 6 was also built in dry wall technique in circular shape 4.27 × 4.08 m in diameter. The burial chest did not have a cover block, which means that the grave could have been previously looted. The chest fill contained disarticulated human bones and glass beads, more than 40 amber beads, as well as a bronze fibula. The bronze fibula is an example of the Beletov vrt type and typically date to the latter half of the second

century until the mid-first c. B.C. (Drnić and Tonc 2014). Since the chest fill contained more individuals, it can be concluded that the grave was used up to the first c. B.C.

The structure defined as tomb 7 (MP ID 17) was indicated by three dogs (Table 3). It was designated as a tomb location during visual inspection because a part of the stone block, assumed to represent the cover stone of a burial chest, was visible on the surface (Fig. 5). This was confirmed by archaeological excavation. As noticed during the excavation, two dogs indicated to the position of the burial chest, and one indicated the area inside circular structure. The structure consisted of drywall construction 4.57 × 4.24 m in diameter. The circular structure was built from unworked stones (Fig. 3). A burial chest, built from four larger blocks of limestone, was placed at the center of the structure. Although previously looted, inside the burial chest, a great amount of disarticulated human bones were discovered as well as remains of attire and jewelry such as glass beads, bone beads, an amber bead, a temple ornament with amber bead, small bronze rings, an ornamented bronze phalera, and a pin. The temple ornament with an amber bead as well as the bronze phalera with the thorn decorated with incised concentric circles and rhomboidal incised decoration can indicate burial of the person of higher status (Blečić Kavur 2014). On the basis of radiocarbon dating, the grave was dated to cal BC 785 (Beta-448437, uncal 2560 ± 30BP, INTCAL 13).

Tomb 8 (MP ID 11) was discovered during the excavation, leaning on the structure of tomb 7. This is the reason why its shape was not circular but semi-circular. The grave was indicated by two dogs: both of them indicated the position outside of the burial chest but within the semi-circular structure. The burial chest was placed inside the structure (Fig. 6). The covering block of the chest was also found *in situ* on the top of it. The chest is much smaller than other chests previously discovered. Its fill contained the bones of children and a bronze fibula. The fibula belongs to the bow type fibulae and is decorated with oblique incisions. It can be dated to the Early Iron Age (Batović 1987). This is also supported by radiocarbon dating of the bone which dated burial at Cal BC 790 (Beta-448438; uncal 2570 ± 30BP, INTCAL 13).

Fig. 5 **a** Indication of the tomb 7 on the position of the burial chest. Cover stone block of the chest can be seen on the left from the dog. **b** Burial chest of the tomb 7 and the same position indicated after removing the first layer of stones

Fig. 6 Tomb 8—drawing of the excavated situation

Out of 19 positions (MPs) indicated by the dogs, 10 of them were confirmed as burials, either by visual inspection or excavation. However, only 5 of them were excavated in this research phase. Tombs 4, 6, 7, and 8 were discovered during "double-blind" search, and tomb 5 through "blind" search. Out of 10 positions confirmed as burials, a burial chest was indicated in 6 tombs (indicated 9 times by different dogs), while within the area of the circular structure 9 tombs were indicated (indicated 14 times by different dogs). The total area of the necropolis, approximately 470 m^2, was defined, combining the results of the HRD dog search and visual inspection of the terrain and zones indicated by HRD dogs, as well as with archaeological excavation.

Discussion

Based on the previous research in which HRD dogs successfully identified historical burials dating back several hundred years (Baxter and Hargrave 2015, 60–90; Pototschnig 2013), the current project was conducted in order to assess the possibilities of using HRD dogs to locate prehistoric and older historical burials. The research was conducted on the Drvišica hillfort in Karlobag (Croatia), which displays distinctive geological and geomorphic characteristics that make both visual inspection and GPR impractical for locating tombs and other structures. In spite of dry karst base, low soil quantity, and exposure to exogenic environmental factors (sun, rain, wind), this research has demonstrated that HRD dogs can be considered as a valid non-invasive search method to locate burial grounds as well as to locate exact burial positions. This is

strongly suggested by a total of 9 indications where the dogs indicated the exact position of the burial chest. At this point of the research, only the positions with at least two indications (*i.e.*, double corroboration of the position of the grave) were taken into further consideration for visual inspection and excavation. Singular indications will be excavated in future research seasons.

Drywall circular tombs 1–8 were positioned on the northern slopes of Drvišica. Tombs 1–4 and 6–8 are positioned at the upper terrace of the necropolis on a similar elevation, but tomb 5 is positioned 8.5 m lower down the slope about 50 m towards the north. However, this position could not be contaminated by decomposition fluids migrating downwards on the slope, because there is no slope wash on well-developed karst surface where vertical runoff prevails (Ford and Williams 2007).

Within the tombs, the deceased were laid in burial chests positioned at the center of circular structures measuring 4–5 m in diameter. A smaller quantity of bones was discovered outside the burial chests, inside, as well as outside the circular drywall structures. The degree of bone fragmentation and poor preservation of archaeological finds suggest that the tombs were most likely robbed. Looting activities could affect the contamination of the surrounding area. However, since within this research, analysis of the soil has not been done, this is not possible to determine. Also, it would not affect the results of significant importance for archaeological research because techniques of the excavation of a burial site will in most cases include digging of a wider trench. Based on dogs' indications, there are several other tombs on the terrace available for future research. Considering the position of the tombs, it is clear that the whole area constitutes a cadaver decomposition island (CDI). That is the principal reason for multiple singular indications recorded during detection. These indications were not taken into consideration for prospective archaeological excavation at this point. However, since the indications do fall within the boundaries of the necropolis, they too will be inspected by archaeological excavation in the future.

The indications in the area of tombs 1, 2, and 3, excavated the year before this research and since then exposed to exogenous factors, demonstrate that the odor profile of human decomposition is preserved even after the soil has been removed from the grave. The excavation cleared all soil to sterile strata, but more commonly to the underlying bedrock. The sterile soil, as previously discussed, is very limited in this region and in most cases soil is anthropogenic in origin. Therefore, there is very little or no sterile strata. Bedrock predominates in the areas where tombs are positioned, which suggests that the rock has absorbed human decomposition odor. The porosity of limestone is the cause for this phenomenon since limestone is a highly porous rock (Ford and Williams 2007). The pores are of great importance in this context, created through deformations during sedimentation, tectonics, or mass removal (Ford and Williams 2007). The fluids generated by human decomposition thus likely entered the pores of limestone rock where the odor has been preserved to the present day. The odor was preserved even after removal of the soil a year ago, suggested by indications at tombs 1, 2, and 3. Therefore, the human decomposition odor is preserved in the soil but also in the rock pores and the rock evaporation commences under favorable conditions. The favorable weather conditions include the periods of reduced aridity but also reduced humidity and wind following the exposure of rock to the sun. Consequently, the evaporation commences making it ideal conditions for HRD dogs to work on.

If we consider indication positions in relation to excavated and visually inspected situation (Table 3: marking point ID 1–19), it is possible to notice that the dogs mostly indicated within the circular structure (14 times), and less commonly on the burial chest (9 times). However, it was noticed that the dogs always indicated with their nose and body oriented in the direction of burial chest, *i.e.*, in the direction of human decomposition odor source. This was noticed in most cases except in the case of tombs 1, 2, and 3 (Table 2), which were discovered before this research, but also in the case of tomb 5 with burial chest almost completely exposed to weathering (Table 3). In these cases, most dogs reacted to burial chests positions. The reason for such indication pattern is that tombs 1, 2, and 3, which were excavated a year before, contain much lower decomposition odor concentration, than other, non-excavated burials. The same pattern was documented in the case of tomb 5, which contained thin burial chest fill, which was mostly exposed to weathering. This was probably the reason why the decomposition odor was not as strong.

In the case of non-excavated graves, the dogs mostly indicated to the edge of the scent area. This is the reason why most indications were situated inside the circular structure and not the burial chest. However, the distance from the burial chest was up to 50 cm, which is negligible in archaeology because the excavation area of a burial site is always bigger. Our interpretation of this indicating pattern is that dogs mostly indicate the edge of the scent pool as this is for them the boundary line between the absence and presence of decomposition odor. Consequently, this "line" for dogs' nose has the strongest scent intensity, which is the reason why dogs mostly decide to indicate there. However, it will be necessary to verify these assumptions with chemical analysis of the soil.

Conclusion

This paper presents the results of testing a search method to locate prehistoric burials using HRD (human remains detection) dogs at Drvišica hillfort near Karlobag in Croatia. Out of five excavated tombs, four of them were found during "double-blind" search and one during the "blind" search. The excavated burials were dated, based on radiocarbon dating and material culture analysis to the eighth to the first century BC.

This research has demonstrated that HRD dogs are able to detect very small amounts of specific human decomposition odor as well as to indicate to considerably older burials than previously assumed. Furthermore, we have argued that the soil, and in this case also the limestone bedrock, preserved the human decomposition odor from the eighth to the first century BC. Hence, the HRD dogs can be used as a part of a non-invasive search strategy to locate burial sites in archaeological research. However, HRD dogs are more important for archaeology to point at the location of a burial ground, rather than individual burials within a particular necropolis.

Locating burial grounds using HRD dogs has great potential in preventive archaeology and archaeological surveys where traces on the ground surface are not readily visible, as is the case with the majority of settlement sites. Therefore, the HRD dogs can be considered as a valuable and usable tool as other non-invasive prospection methods and a valid search method in burial archaeology. However, since dogs are scent

followers, not body locators, their indications have to be analyzed considering geological bedrock, ground slope, and other factors which could have an effect on the position of the scent.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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