Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-023-02002-4 OPEN

Slaughtered like animals. Revealing the atrocities committed by the Nazis on captives at Treblinka I by skeletal trauma analysis

Joanna Drath [1,2]✉, Joanna Jarzęcka-Stąporek[3], Dagmara Lisman[1], Maria Szargut[1], Marek E. Jasinski [4,5], Kate Spradley[6], Mirosław Parafiniuk[2] & Andrzej Ossowski [1]

The infamous Treblinka camp was one of numerous extermination camps throughout Poland, where Germans carried out mass killings of Jews. There were two camps in Treblinka, AL Treblinka I, a forced labor camp, and KL Treblinka II, the site of the extermination camp. Treblinka I held captives of various origins and ethnic backgrounds who were serving their sentences by working in a pre-existing gravel pit. Many of those prisoners perished in the camp, and it was believed that the principal causes of their death were attributed to the horrific sanitary conditions in the camp as well as the strenuous hard work of daily life. In 2019, archaeologists uncovered a clandestine mass burial pit that contained commingled human skeleton remains at the Execution Site of the former Treblinka I camp. It was estimated that there were a minimum of forty-nine people in the pit. Within months, an anthropologist performed biological profile assessments and detailed trauma analysis on the recovered skeletal parts. The main goal was to study perimortem trauma patterns to infer the cause and manner of death of the victims. We hypothesized that the victims did not die solely because of the camps' conditions but were brutally slaughtered by the camp guards. Our results were later compared with the survivors' written testimonies. As a result of our research, we were able to show that the Treblinka I captives' death was extremely brutal and that the killing methods were varied. This led us to conclude that multiple assailants were involved in the killing spree. All of our results were consistent with the written witness testimonies, which concurs with our skeletal material analysis that proves the atrocities committed by the Nazis on their civilian prisoners during the war took place.

[1] Forensic Genetics Department, Pomeranian Medical University in Szczecin, Szczecin, Poland. [2] Forensic Medicine Department, Pomeranian Medical University in Szczecin, Szczecin, Poland. [3] Museum of the Second World War, Gdańsk, Poland. [4] Department of Historical and Classical Studies, Norwegian University of Science and Technology, Trondheim, Norway. [5] Falstad Center for Human Rights, Ekne, Norway. [6] Department of Anthropology, Texas State University, San Marcos, Texas, USA. ✉email: joanna.drath@pum.edu.pl

Introduction

In any murder case, the victim's body is regarded as hard evidence of a crime (Hopping, 2007). Without it, the case could only be circumstantial, and it is usually very difficult to prosecute the perpetrators in question (Moran, 2003). With this in mind, Heinrich Himmler ordered the bodies of the dead to be incinerated and commingled, including most of the corpses that were previously buried in mass burial pits (Spector, 1990a) in all the concentration and extermination camps across Europe. As a result, the only existing proof of mass killings is the survivors' testimonies that were written shortly after the end of the war.

Approximately six kilometers away from Treblinka railway station in Sokołów County, Poland lay a gravel pit that was controlled by the German forces from September 1939 (Różycki et al. 2017). Gravel was an important resource for implementing the so-called "Otto Program", a plan for building strategic roads to attack the Soviet Union (Mierzejewski, 2003). The biggest obstacle Germans had to overcome was the labor shortage. To solve this, they constructed a forced labor camp, Treblinka I, where they imprisoned mainly people from the nearby villages and forced them to work in the pit. Germans reported that the people sent to the Treblinka camp were solely criminals. However, many civilians were punished for resisting the occupation, ignoring the curfew, and armed attacks on the Polish underground (Kopówka, 2002).

By 1941, the first prisoners arrived there to serve their sentences. In the first year of the camp's existence, there was no division of Jewish prisoners from Polish ones (Różycki et al. 2017). In mid-1942, around two kilometers north of Treblinka I, the extermination camp Treblinka II was erected, as a part of Operation Reinhard (Arad, 1999). After the construction of the extermination camp, some of the Jewish captives were still sent to the penal labor camp (which in the German announcement of 16th December 1941 is defined as *Arbeitslager Treblinka*) and their physical work conditions served as means of annihilation. The daily strenuous physical work combined with low nutrition rates, diseases, and beatings from the camp guards contributed to the early demise of a significant number of prisoners. It is estimated that a total of 20,000 prisoners passed through the Treblinka labor camp, and 10,000 of them died in the camp. The bodies of the dead were buried in a forest near Maliszewa village (Abate and Sturdy-Colls, 2018). In contrast to other forced labor camps, such as KL Auschwitz, there are few survivors of imprisonment in Treblinka camps (Rajchman, 2011). Therefore, the testimonies on the cause and manner of death for the inmates are vague. The witness' statements report on the camp guards' cruelty and also state the variety of killing methods. The weapons used for killing, according to the Treblinka survivors, include, for example, bats, planks, bayonets, axes, hammers, mallets, sabers, guns, and many others (Kopówka, 2002; Różycki et al. 2017; Wiernik, 1944). However, those statements were never supported by any other physical evidence.

One of the first examinations of Treblinka camps was undertaken on 24 August 1944 by an ad-hoc Soviet-Polish Commission consisting of five officers of the Red Army and four representatives of local Polish inhabitants, including one medical doctor. At that time, it was revealed that the Germans buried their victims in various locations in the camps. About fifty-eight burial pits were discovered, measuring 10×5 m and 2–2.5 meters deep. Three of those graves were excavated for a total surface area of 15×5 m; 305 corpses were exhumed. Twenty-five of them were women. The bodies were interred only 50 centimeters from the surface. It was calculated that around 10,000–12,000 people rested in the graves. Fourteen bodies were subjected to an autopsy. The medical examination showed that the victims' skulls were pierced after the blow of an axe and other similar objects (found in the copy of the deed dated 24 August 1944 translated from Russian into Polish and stored in the Institute of National Remembrance archives, accessed on 15th February 2022; Central Commission for the Investigation of German Crimes in Poland (Kononiuk et al. 1944)).

After 1946, no detailed, professional investigations into the Treblinka camps were carried out until 2007, when scientists from Staffordshire University began work on archaeological and historical research on the Treblinka camps. The researchers obtained permission to study the site with the use of a minimal invasive methodology. They had been instructed not to exhume the bodies from the graves. Combining LiDAR survey, walkover survey, and archival map research, six potential mass burial pits were detected in the area of the Execution Site near the former labor camp (Sturdy Colls, 2012). Three of those sites were excavated using minimally invasive techniques (Sturdy-Colls, 2016). In the 1960s, a Museum of Struggle and Martyrdom was established to protect the victims' memory.

In 2019, a previously unknown burial pit was discovered at the bus station car park that belongs to Treblinka I camp. The pit contained the commingled remains of nearly fifty people. Neither their identities nor their cause and manner of death were known. Following DVI standards (Interpol, 2018), the interdisciplinary team was engaged in the process of the remains recovery and personal identification. The team consisted of experts in forensic archaeology, forensic anthropology, forensic medicine, and forensic genetics. The fieldwork was overseen by the Rabbinical Commission for Jewish Cemeteries in Poland.

We assumed that the victims were the Treblinka I captives who were killed by the camp guards. Our main focus was to analyze the skeletal remains, in particular, concentrating on perimortem trauma analysis. We hypothesized that the trauma pattern would allow us to infer the most prevalent killing method applied by the guards and the positioning of the assailants in relationship to the victims. By comparing our results with the survivors' testimonies, we hoped to identify specific camp guards responsible for the crimes that had been committed, which in turn could help in legal actions, to bring closure to the victims' families. Our secondary goal was to explain the state in which the remains were found. The archaeological evidence points to secondary burial, but it is unknown why the skeletons were commingled or who was responsible for the commingling.

Material

When the Germans retreated from Treblinka, they tried to hide all the evidence of their atrocities, so most of the buildings were destroyed (Sturdy Colls and Colls, 2020) and the victims' bodies were buried in undisclosed locations. Sadly, there were no structures of cremation pyres nor any buildings from the extermination camp that had been preserved. Only the building foundations in the labor camp remained intact. In the summer of 1944, some of the mass graves were found, together with individual burials (Kopówka, 2015). At that time, it was established that the bodies from the extermination camp had been disposed of indiscriminately. Some were interred in mass burial pits, some were cremated and buried, and others were scattered on the ground after cremation. In contrast, the bodies from the labor camp were not cremated, but instead buried in mass burial pits. Those observations were taken into account by Staffordshire scientists when they prepared the survey (Sturdy Colls and Colls, 2020; Sturdy-Colls, 2016). The place where most of the graves were revealed was named the Execution Site (Remiszewska, 2020). It is located to the south of the gravel pit and the labor camp. It was there, where the wounded and exhausted were shot,

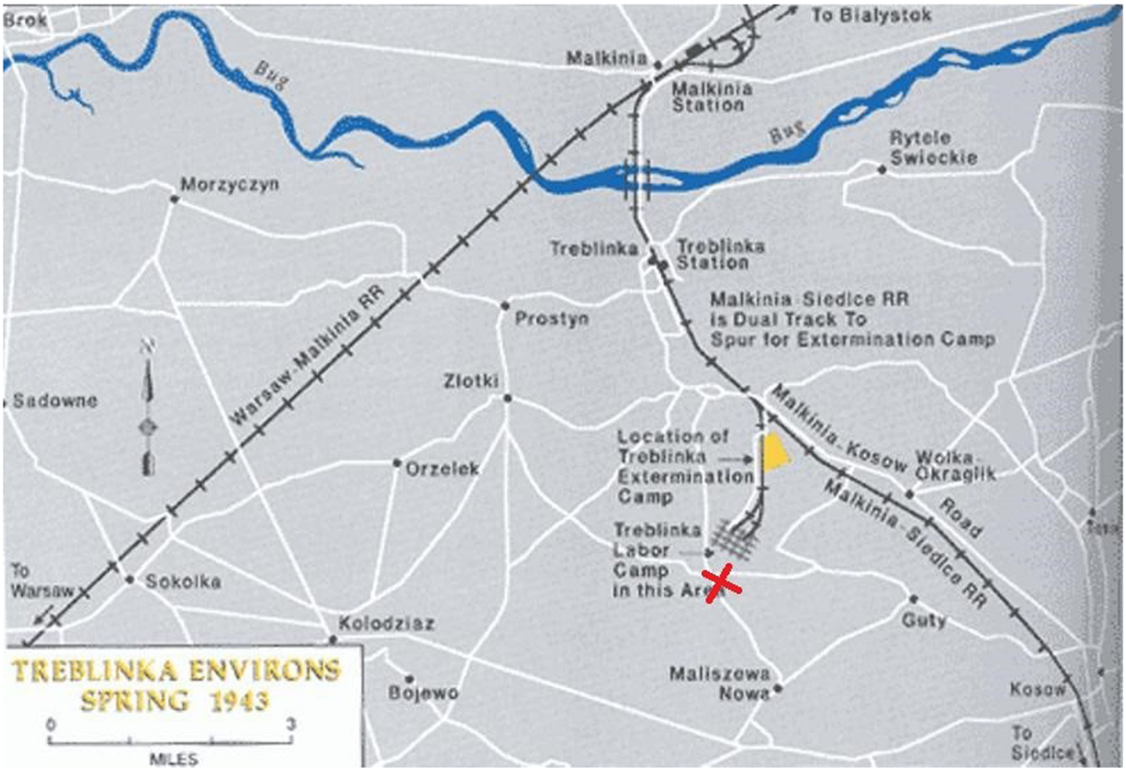

Fig. 1 The map showing the search place. Red "X" marks the location of the search (www.museumtreblinka.eu).

along with those sentenced to death for camp offenses, as well as Poles transported from Warsaw and Sokołów Podlaski. On 2 March 1942, around a hundred people from the prison in Pawiak Szucha alley were taken there and shot to death. Executions of Jews from the Warsaw Ghetto and Romanis and Sinti were also carried out at the same place. It was also possible that the Italian officers and soldiers had died there as well (Kopówka, 2002).

In November 2019, human bones were discovered at the Execution Site (Koschalka, 2019; Remiszewska, 2020) in a burial pit sized 4.5 × 3.4 m. The skeletal remains were resting only 15 cm from the surface, so many skeletal elements were highly fragmented. Upon the decision of the National Institute of Remembrance prosecutor, the pit containing the remains was excavated with the use of forensic archaeological methods. The skeletons were already extremely commingled in the grave; none were in the anatomical position. Each skeletal element was cleaned on-site, tagged, and wrapped. The material was sent to the Forensic Genetics Department of Pomeranian Medical University in Szczecin for detailed anthropological and genetic analysis that would lead to personal identification and cause and manner of death determination.

Fig. 2 Location of site 1- eastern orientation. Marked in red circle.

Methods

The archaeological methodology used for localization and exhumation of the graves. The archaeological survey began prior to the planned modernization works in the forest car park carried out by Treblinka Museum. The main goal of the archaeological survey was the search for clandestine burials of victims who died in the forced labor camp, as well as other victims transferred here from Warsaw for execution. The search took place in the vicinity of the Execution Site, in the forest parking lot (site 1), and to the west of it, behind the road leading from the camp to the monument commemorating the camp victims (site 2). Two sites were designated for archaeological surveys (Figs. 1 and 2). Site 1 encompassed an area of 930 m^2, and site 2 was an area of 1300 m^2. The exploration area of site 1 was divided into sectors. The applied methodology was a combination of the demirant and quadrant excavation method (up to the primary trench marks) and the stratigraphic excavation method with a single context recording system.

Firstly, the surface of the site was examined with Ground Penetrating Radar to detect any anomalies that would indicate the existence of the graves below the surface (Różycki et al. 2020). The GPR is a kind of geophysical survey that is most frequently used in searching for clandestine burials (Fiedler et al. 2009). This research was added to the Historical-GIS-Treblinka system, which was created between 2016 and 2018. The system was the result of a project aimed to commemorate the Treblinka camps' history. The analysis took place in Maliszewa Forest, where many of the death pits were previously located (Abate and Sturdy-Colls, 2018). Presently, the area is overgrown by thick pine woods. The area of 15 hectares was cleared of trees, permitting the GPR research. In previous research campaigns (2016–2018), the analysis included extended spatial data, geophysical measurements, and excavation work. These results were used to select research areas and conduct geophysical and excavation surveys in 2019 (Różycki et al. 2020). The GPR equipment used in the 2019 campaign was SIR 3000, which has an antenna placed on a special cart with a system for calculating distances. The antenna used was a 400 MHz shielded frequency. The studied area of site 1 was named GPR3 in geophysical research analysis. Eleven profiles were scanned, each was ten meters long, with a distance of 0.5 m between them. The details of the GPR survey and the Historical-GIS-Treblinka system are provided in a separate paper by Różycki et al. 2020 (Różycki et al. 2020).

Metal detectors were used on the ground of the search area, on the surface of the grave and its surroundings to find and collect relevant artifacts (Figs. 3, 6, and 7). The detectors were used as well, during the grave exploration, after each layer of soil was removed. The equipment used for detection was Manticore Multi-IQ+, which is a waterproof metal detector with operating frequencies from 5KHz to 100KHz. The tool can detect and separate objects, even if they lie next to each other. When the detector rendered a highly pitched audio signal, the manual exploration with the use of a small spade was focused on the scanned area to retrieve the metal object.

Next, the surveys were marked and with the use of a backhoe with a slope bucket, small layers of humus were removed together with the alluvial level of soil up to the level of the bedrock. These activities were carried out under the archaeologists' constant supervision. Once the skeletal remains were visible, the exploration was combined with bone exhumation (Figs. 4 and 5). The exploration was conducted manually with continuous documentation including measurements, photographs, and drawings. The tools used in that stage were made of plastic to prevent any skeletal destruction and to preserve any possible crime evidence that could be relevant in the course of the investigation. The infill of the grave was sifted in an archaeological sieve to retrieve all the small fragments.

The feature was explored in quarters, documenting profiles until the layer was outlined, which was interpreted as the original burial pit fill. It was decided that it would be fully exposed and mapped. After completing the documentation and a small survey, the layer was explored in its entirety, which was also combined with the exhumation of human bones deposited in it without anatomical arrangement. Due to the clear outline of the excavation and the course of the layers, the method of exploration with natural layers was used and the exhumed remains were assigned to them. The skeletal remains were secured with bubble wrap and put in paper bags signed with the date, site number, and layer number. Finally, the packed material was transferred to an anthropologist for osteological analysis. Soil samples were taken from layer 1 for laboratory testing for the presence of explosives. For comparison purposes, soil samples from outside of the grave were also collected for analysis.

During archaeological surveys in 2019, another group of graves (site 2) was discovered and uncovered at a distance of a few meters in the west direction from site 1. An archaeological survey of site 2 showed that this group of graves was diametrically different from the burial pit of site 1. Seven graves at site 2 were singular graves arranged in a regular row with all bodies placed in coffins with some grave goods suggesting a different status of buried bodies. It is possible that the single burials of site 2 belonged to the camp guards, so-called the Watchmen (*SS-Wachmannschaften*). The details of site 2 and the results of the analysis will be the subject of a separate paper.

Fig. 3 A Jewish Ghetto Police badge found on the ground of the studied area.

Anthropological methodology. As the bones were in a very fragmented state, it was necessary to reassemble fractured elements before the analysis began. Every element was labeled with a different tag, measured, and described on a specially created spreadsheet. Elements were segregated in accordance with the body side and for each element the possible components of the biological profile were assessed. The biological sex was estimated by the use of morphological (Phenice, 1969) and metric (Brůžek et al. 2017) methods on the coxal bones. On femoral bones, metric methods were applied (Curate et al. 2016; T. D. Stewart, 1979). A morphological trait assessment method was used for the skulls (J. E., Buikstra and Ubelaker, 1994). The biological age-at-death was

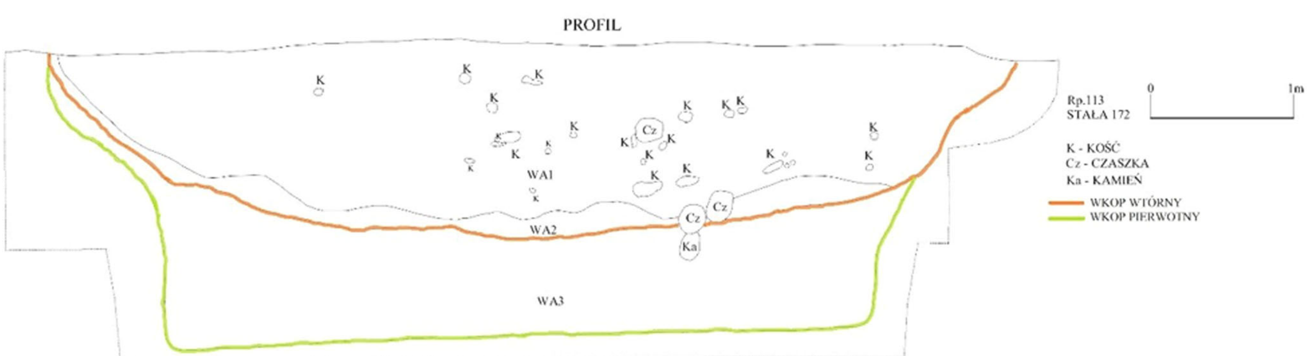

Fig. 4 Western profile of mass burial pit, partly reconstructed based on the archaeological documentation (figure credit M. Wołyńska). K- bone; Cz- skull; Ka- stone WA1- layer 1; WA2- layer 2; WA3- layer 3. Orange- secondary trench; green- primary trench line.

Fig. 5 Western profile of the mass grave pit explored to the level of the original filling. NE view.

estimated on the basis of bone length measurements in subadults (Maresh, 1970), and skeletal ossification stage (Scheuer et al. 2000). In adults, a method based on morphological features of pubic symphysis was applied (Brooks and Suchey, 1990). The stature was estimated with the use of a metric method based on femoral bone measurements and a regression formula with regard to the estimated biological sex and biogeographical origin (Trotter, 1970). Ancestry was evaluated using the skulls' measurements and the software Ancestrees (Navega et al. 2015) and Cranid (Wright, 2008) and a non-metric trait method (Hefner, 2009).

Every pathological condition and traumatic lesion was photographed and described in detail on a spreadsheet. The description included the location of a lesion on a bone, the type of lesion, and its dimensions. The pathological lesions included non-specific stress indicators, such as Cribra Orbitalia, Cribra Cranii, Cribra Femori, and Linear and Punctual Enamel Hypoplasia. Those traits as well as metabolic disorders could reflect the general health status of a person.

Bone fracture descriptions include the type of fracture, mechanism, time of occurrence, and possible direction of the impact. In ballistic trauma, the entry and exit wound location, diameter, and probable bullet trajectory were included in the analysis. Additionally, in every trauma case, a possible weapon responsible for the traumatic mark was inferred. When referring to the timing of trauma, the term perimortem was applied, meaning trauma that happened on fresh, hydrated bone (İşcan & Steyn, 2013).

To resolve the issue of commingling, we tried to follow the methodology described by Adams (Adams and Byrd, 2014). The spatial location of each excavated skeletal element was marked during the exhumation process on tags and later on the spreadsheet, in the hope of possible element association by the proximity of the next skeletal part in the joint (Tuller and Hofmeister, 2014). Moreover, each skeletal element was measured (Byrd and LeGarde, 2014) and in the cases of subadult skeletons, the bones could be matched on the basis of the assessed biological age-at-death (Schaefer, 2014). Other methods include taphonomic changes comparisons of the bone periosteum (Ubelaker, 2008).

The trauma frequency indicator was calculated from the number of cranial impacts and the number of cranial elements that were preserved. The small sample prevented us from obtaining any significant results after applying statistical tests. Therefore, the results were analyzed using empirical and descriptive approaches as opposed to statistical analysis.

Genetic methods used to verify anthropological sex estimates and mt haplogroup determination. Tooth samples were taken for DNA analysis, using modern forensic DNA methodology to obtain genetic profiles that would serve for personal identification once the reference material is provided.

The teeth were cleaned mechanically and chemically, and ground in a cryogenic mill. DNA was extracted and purified from the prepared bone powder with PrepFiler ™ BTA Forensic DNA Extraction Kit (Thermo Fisher Scientific) according to the manufacturer's protocol. Quantitation of DNA extracts using the Quantifiler™ Trio DNA Quantification Kit (Thermo Fisher Scientific) on the 7500 Real-Time PCR Instrument (Thermo Fisher Scientific). STR markers were amplified using a commercially available kit –GlobalFiler (Applied Biosystems), which includes three types of markers that allow for genetic sex determination: a fragment of the amelogenin coding gene, located both on the X and the Y chromosome, with a different allele length for each variant, and two markers located on the Y chromosome exclusively: an insertion/deletion marker and an STR marker. For the analysis of Y-STR markers, the Y-Filer™ Plus PCR Amplification Kit (Applied Biosystems) was used, and the kit can amplify 25 Y-STR loci. Positive and negative controls were prepared for each amplification to assess the performance and purity of the amplification step. The positive control contained the reaction mixture and DNA control, and the negative control contained the reaction mixture and nuclease-free water.

Detection of PCR products was performed on a 3500 Genetic Analyzer sequencer. The results were analyzed using GeneMapper® ID-X Software v1.6. Haplogroup estimation from consensus profiles was performed using the EMPOP database (Huber et al. 2018) and the HaploGrep software (Weissensteiner et al. 2016).

Mitochondrial DNA sequences have been determined for the HV1 and HV2 hypervariable regions. The sequences of the amplification primers used were in accordance with the literature (Nilsson et al. 2010) for primer pairs: 15971 and 16410 for HVI and L15 and R429 for HVII. The hypervariable regions were amplified in two separate PCR reactions using the HotStar Taq Master Mix Kit.

In addition, as no reference material from the families of the victims was obtained to this day, an analysis of kinship between the exhumed remains was performed on the Familias 3[1] software (Egeland et al. 2000; Kling et al. 2014). The Familias program, developed by Petter Mostad and Thore Egeland in cooperation with the Norwegian Computing Center and the Institute of Forensic Medicine in Oslo, is used to calculate probabilities of complex kinships. Moreover, it includes a DVI module, in which two databases are created: the victims' database and the reference families' database. This allows for searching for the highest likelihood ratio (LR) of a victim to be related to any reference family in the database versus not being related to them, as well as to establish the LR for a presence of kinships between individual victims themselves, versus no kinship between them. Because in the mass grave only males were found, when analyzing kinship in the Familias program, three kinship models were assumed:

1. parent-child
2. sibling
3. cousin

Results

Archaeological results. Human remains were encountered in the eastern part survey No. 1 during topsoil removal. They were lying without anatomical arrangement directly under the layer of turf. In order to fully reveal the outline of the excavation, survey no. 1 was extended and widened at this point. An oval-shaped pit, oriented along the north-south axis, measuring 6.5 × 3.4 m was uncovered. The fully explored pit was 205 cm deep. The analysis of the course of layers and the edges of the excavation, clearly

Fig. 6 Polish coin from 1936 found in the explored burial pit.

Fig. 7 A bullet shell found in site 1.

visible thanks to the documented profiles, confirmed that we were dealing with two phases of the functioning of the burial pit: a primary and a secondary trench.

The primary trench consists of bones deposited without a visible anatomical order. The bones were placed without any plan, at various angles, on different levels. They did not form a compact structure but were dispersed in a layer of light brown sand and gravel, which was the filling of the grave (layer 3). These were skulls, long bones, short bones, and others. The width of the pit narrowed in a basin to about half its depth, creating a step from which the walls went vertically down. The minimum length of the pit was about 6 meters, and the minimum width was about 1.5 meters. The maximum depth of the pit was around 200 cm, but the thickness of the layer that was not disturbed by the secondary dig was around 70 cm.

The secondary trench was oval in shape, measuring 6.5 × 3.4 m. Its cross-section, 135 cm deep, was basin-shaped, possibly reproducing the original course of the burial pit, reaching approximately two-thirds of its depth. The backfill of the trench was layer no. 1, 130 cm thick, consisting of brown sand and medium and coarse gravel along with human bones, and layer no. 2, up to 20 cm thick, consisting of sand with a significant content of dark brown humus. In contrast to the original fill (layer 3), the sand and gravel of layer 1 were more saturated with organics, resulting in a more intense brown color. The significant amount of humus visible in layer 2 could have been formed by winding a substantial amount of leaves or as a result of the formation of forest litter.

In addition to bones, single items were found in the backfill, mainly fragments of fabrics and leather, most likely the remains of clothes and footwear, items of clothing such as buttons, belt buckles, but also a Polish coin from 1936 (Fig. 6). The pit also contained elements of ammunition, such as shells and projectiles (Fig. 7). Among the artifacts recovered with the use of metal detectors, a badge of the Jewish ghetto police in Falenica was found (Fig. 3).

In the place where GPR surveys indicated anomalies in the ground, stones were registered, which are natural inclusions in the sand and gravel bedrock. Numerous irregular anomalies were located in the parking lot search area. They served as a basis for digging test pits.

The archaeological results show that the burial pit was not of a regular shape. One hypothesis surmised by archaeologists was that a deep hole could have been created after the detonation of explosive materials. The samples that were collected from the pit for trace element analysis suggested that no explosives had been detected or used. The layout of the skeletal remains in the pit suggested that, without doubt, the grave had been disturbed or the pit had not been the primary burial place for the remains.

Anthropological results. The recovered material entailed more than 8.600 skeletal fragments. The minimum number of individuals (MNI), which was estimated from the preserved skull bones, right ulna, and right coxal bones, was forty-nine people. The number of other preserved elements (Fig. 8) did not depart significantly from the estimated MNI. The poorest preserved were the patellas (forty-one right and forty left bones) and sternum (forty bones). It was impossible to assign each element to a particular skeleton within the given time frame for the analysis. We may only infer the shortest skeletal elements belong to one person and the longest elements to the tallest person. Based on the collected data, it will be possible to match more skeletal elements with particular individuals in future studies.

From the entirety of the studied skeletal material, the biological profile shows that the biological sex of all individuals was male. The estimated biological age in the studied population spans from ~10-years-old to over sixty-years-old at the time of death. The stature ranges from 145 cm to 180 cm (±3.27 cm). It was possible to perform ancestry estimations only for thirty-three skulls. Seventeen of them were estimated as most similar to European, four as Northeast-African, and three as South-Asian. For nine skulls, the analysis executed by two chosen software (*Ancestrees* and *Cranid*) gave contradictory results.

The analysis performed on the skulls (Table 1) showed that the minimum number of individuals was 49. The biological sex estimated from the skulls was male and possible male for 34 people (69%), 1 skull (2%) displayed a few morphological female characteristics, and unknown sex for fourteen skulls (29%). The highest number of individuals were classified in the age category 18–30; thirty-three people (67%); thirteen skulls (27%) had assessed the biological age as 31–55; one skull (2%) was assessed to be over 56 at the time of death. For two skulls (4%) it was impossible to estimate any component of the biological profile.

Trauma analysis results and skeletal pathology. Fifteen skulls were preserved without any visible signs of injuries. Perimortem trauma was observed (Fig. 9) on thirty-four skulls (69%), fifteen mandibles (32%), and on three sacral bones (6%), one left (2%) and four right (8%) ulnas, two left (4%) and two right (4%) coxal bones, one left (2%) and one right (2%) tibia, two left (4%) humerus, one left (2%) fibula, three left (6%) and one right (2%) femur, six left (13%) and six right (13%) scapulas, one right (2%) clavicle, vertebra, ribs, and metacarpals. The types of injuries include blunt force trauma, gunshot trauma, and sharp force trauma.

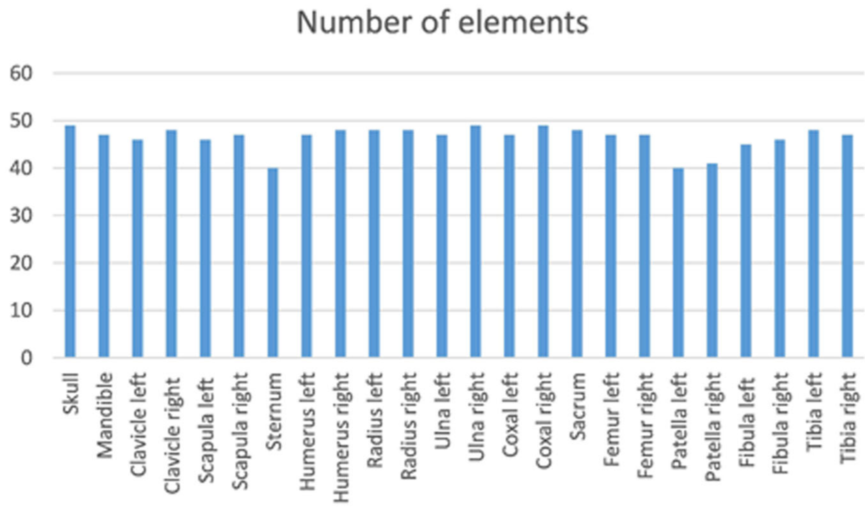

Fig. 8 The number of preserved skeletal elements.

Table 1 Age and sex distribution estimates from skulls.

Age group	Males		Possible males		Possible females		Unknown sex		Total	
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**
18–30	13	26.53	9	18.37	1	2.04	10	20.41	33	67.35
31–55	8	16.33	3	6.12	0	0.00	2	4.08	13	26.53
56+	1	2.04	0	0.00	0	0.00	0	0.00	1	2.04
Unknown age	0	0.00	0	0.00	0	0.00	2	4.08	2	4.08
Total	22	44.90	12	24.49	1	2.04	14	28.57	49	100

In six skulls (12%), sharp force trauma was detected; four skulls (8%) manifested ballistic trauma, and twenty-nine skulls (59%) showed blunt force trauma. Three skulls (6%) have lesions of combined blunt force trauma and ballistic injuries. Two skulls (4%) illustrate a combination of injuries inflicted by a blunt and a sharp instrument. Twelve skulls (24%) demonstrate multiple blunt force trauma impacts (from minimum of two impacts to minimum of five impact points detected). Among the observed perimortem lesions, on twenty-two skulls (45%), trauma could have been lethal. The sharp force injuries on four skulls were located near the foramen magnum rim and occipital condyles but did not affect mastoid processes. That kind of trauma could have led to decapitation and would most certainly cause severe damage to the *Medulla oblongata*. In two cases, sharp force trauma was detected on the maxilla, specifically in the nasal area (piriform aperture).

The highest number of blunt force trauma impacts were localized on the left and right parietal bones (Fig. 10), usually at the top of the head, above the so-called Hat Brim Line (HBL). Many lesions found on parietal bones were of concentric and radiating shapes (Fig. 11). Those traumatic marks that were noticed on occipital bones were mostly linear fractures. The gunshot trauma trajectories went in all cases from the occipital bone to the frontal bone. The entry wound diameter is around 7 mm, which indicates a small caliber bullet.

Within the youngest age category (18–30), twenty-seven blunt force trauma blows were observed on seventeen skulls, three gunshot injuries on three skulls, and five skulls displayed sharp force (Fig. 12) trauma. In the age category 31–55, there were eighteen blunt force trauma impacts on seven skulls and one sharp force injury on one skull. There was no perimortem trauma noticed on the skulls of victims at the age category 56+. There are three blunt force trauma impacts on two skulls and one gunshot trauma on one skull of people of unknown age-at-death. In the middle age-at-death category (31–55), the frequency of blunt force trauma injuries per person is higher than in the youngest age category, but there are no gunshot injuries detected in that age category (Fig. 13). The blunt force trauma types- concentric and radiating, are more prevalent in the youngest age categories than in the middle-aged one.

In postcranial elements, the majority of trauma mechanisms were spiral, transverse and linear, most likely caused by contact with a blunt object. On one left femur there is an entry hole from a gunshot injury, without any exit hole. Apart from the elements listed above, the perimortem fractures are also visible on cervical and thoracic vertebrae, metacarpals, and ribs. The ulna fractures could result from a parry fracture mechanism, but other mechanisms (such as a fall) are also possible. The metacarpals' fractures could result, among many other possibilities, from a physical attack on someone. On the cervical vertebra, there are visible sharp force trauma marks and blunt force trauma.

There were two skulls with Cribra Orbitalia; one skull had Cribra Cranii. There were two right femurs and one left femur with Cribra Femori evidenced in postcranial elements. Two mandibles showed punctual enamel hypoplasia (PEH), whereas thirteen had linear enamel hypoplasia (LEH). The bones of a minimum of two people show signs of pathological bowing, which could be a sign of metabolic disease. The skeletal elements affected by that condition are femurs, tibias, fibulas, humerus, ulnas, and radius, all belonging to adults. On vertebrae and sacrum bones are rather advanced lytic lesions, which could indicate a long-lasting disease such as brucellosis, tuberculosis, or some other parasitic disease, such as malaria.

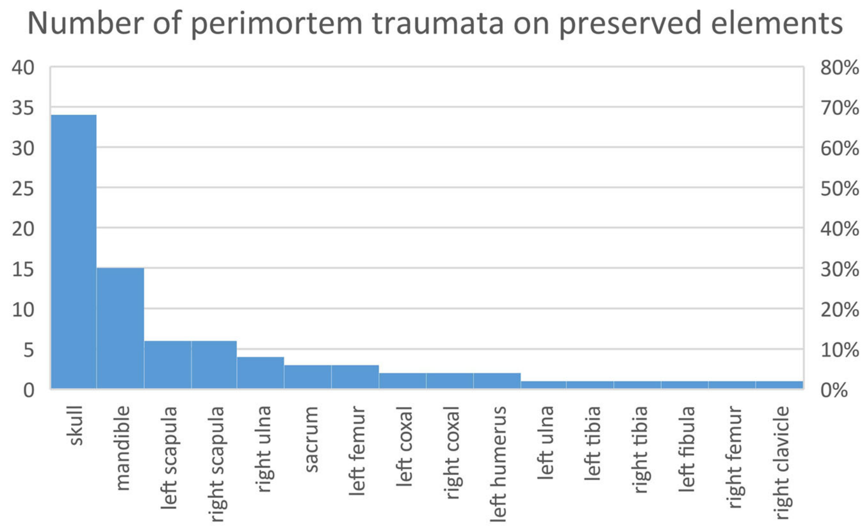

Fig. 9 The number of skeletal elements with perimortem trauma marks.

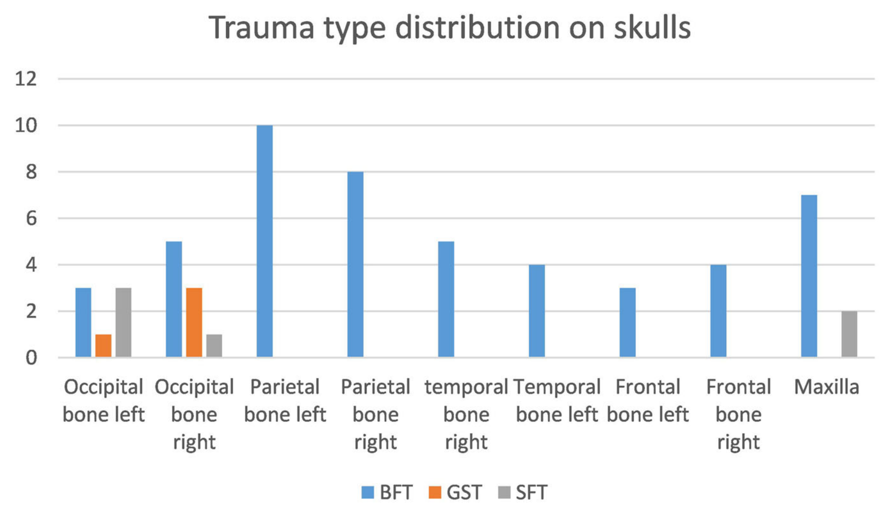

Fig. 10 Distribution of types of trauma on cranial elements.

Fig. 11 Skull No. TI_1069 with perimortem depressed fracture.

Genetic results. Of the teeth collected from 46 individual skulls, only 25 yielded results that allowed for the genetic sex estimation. It was possible to obtain genetic sex results for 25 skulls. All were males. The poor state of preservation of the biological material, which was observed in the results of DNA quantity and quality assessment by Quantifiler TRIO, was also clearly visible in the results of fragment analysis – partial profiles or no profiles were obtained for the majority of victims.

Haplogroups, as a result of the analysis of hypervariable regions of mitochondrial DNA (HV1, HV2) were obtained for 19 individuals. The genetic mtDNA haplogroup estimates are: N1b1b, K, W, J1c7, HV, W3b1, K1a, K1a1b1a, H3p, R0, V7a, K1a1b1a, H2a2a. The obtained mtDNA haplogroups were estimated in the EMPOP database and the HaploGrep program. The results obtained on both software were identical. Those estimates are in concordance with anthropological ancestry estimations.

None of the assumed kinship hypotheses (father-son, siblings, cousins), were confirmed. This could, however, have resulted from the state of preservation of the biological material. All DNA profiles obtained in this study, including partial ones showing signs of strong degradation, were used for the biostatistical analysis. The possibility of the occurrence of drop-out (true alleles not present in a profile) and drop-in (false alleles present in the profile) phenomena, which hinder the result of kinship analysis, can be quite high in such a low-template, highly degraded material (Gill et al. 2012). Thus, the results do not allow us to unequivocally state that no related victims were exhumed from the mass grave in the former Treblinka I penal labor camp.

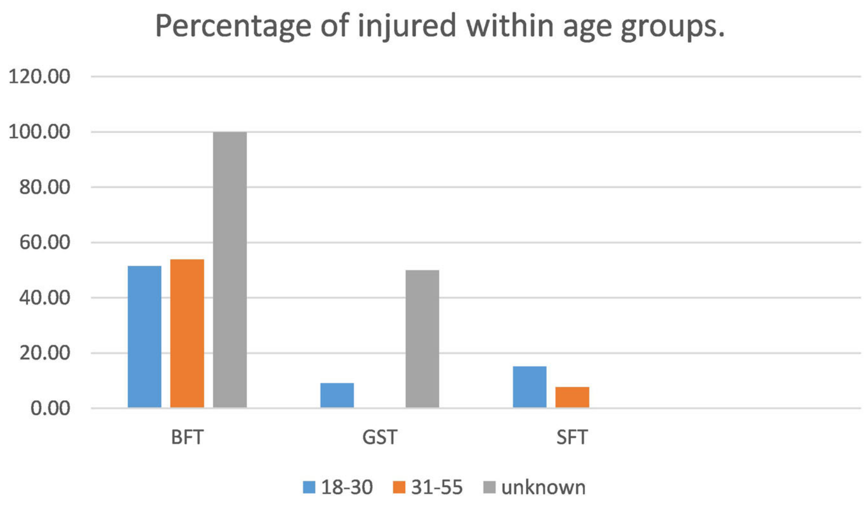

Fig. 12 Percentage of injured people with regard to age category and trauma type.

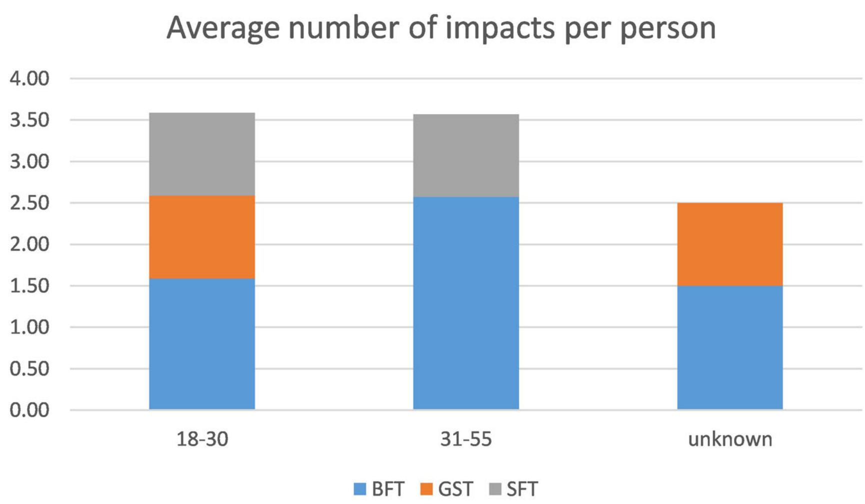

Fig. 13 The average impact frequency of different trauma types per person within estimated age categories.

Discussion

The skeletal analysis of victims killed in World War II concentration camps is very rare, not only because of cultural obstacles regarding the exhumation of the victims' bodies (Sturdy Colls, 2012) but also because many of those bodies were destroyed (burnt and pulverized) during the war to obscure the magnitude of the crimes committed by invaders on civilians (Sonderaktion 1005; (Spector, 1990b)). As a result, many of the genocide survivors, friends, and families of the victims never discovered the truth about the fate of their loved ones. Some of the victim's families are still alive, waiting for any news regarding their kin (Kimmerle, 2012), and that is one of many reasons why the identification process of people killed in concentration camps during the war should be continued. Forensic skeletal analyses include not only the basic biological profile estimated from the preserved victim's skeleton, but also contain medico-legal aspects of perimortem trauma analysis and cause and manner of death inference which can provide clues on how the victim died (Dirkmaat et al. 2018).

The main goal of our research was to analyze the perimortem trauma pattern for the recovered skeletal elements from the burial pit on the terrain of the former German forced labor camp AL Treblinka I. The trauma study results compared with the survivors' testimonies could help in the victims' identification process and could reveal the perpetrators' identity by connecting trauma patterns with the specific camp guards killing preferences.

The skeletal material was found in an already commingled state in one burial pit of irregular dimensions. That certainly hinders the personal identification process. The exact reasons for commingling are unknown, but researchers pose few hypotheses to explain that state. From May 1942 until 1944, upon the orders of Paul Blobel, following the Sonderaktion 1005, the remains of the killed people were exhumed, commingled, and reburied or additionally burned and reburied (Hoffmann, 2008) to hide the evidence of crimes committed on civilians in concentration camps. Historical sources mention that after the camp's liberation, the local people from the villages surrounding Treblinka dug up the bodies in search of treasure (gold, jewels, money, etc.; (Remiszewska, 2020; Różycki et al. 2017; Rusiniak, 2006; Webb et al. 2021)). Those actions surely caused disturbances in the body's organization in the graves as well as the relocation of certain bodily elements, causing commingling. Another possibility is that the culprits for commingling are the Soviets, who used explosive materials in the graves to facilitate their search for valuables on the victims' bodies (Gross and Grudzińska-Gross, 2011). Following that trail, the researchers collected samples of the soil and sent them for trace element analysis, hoping to find traces of explosive materials. That theory would also explain the sill-like shape of the burial pit. However, the results of the analysis show no explosive material elements in the pit.

The interpretation of perimortem trauma patterns from the skeletal remains can provide only partial information on the total injuries inflicted on a victim. The majority of the torso injuries, regardless of the type: blunt force trauma, gunshot trauma, or sharp force trauma, are limited to the soft tissues leaving no traces on the bones (J. E. Buikstra, 2019). However, there are certain skeletal fracture patterns indicative of interpersonal violence, such as cranial fractures, facial bone trauma, zygomatic, maxilla mandible, nasal, orbital rims, etc. (Shepherd et al. 1990) and in postcranial bone fractures of the ribs, metacarpals (Andrearsen et al. 2011) and forearm bones, so-called parry fractures (Judd, 2008). The overall trauma pattern visible on cranial and postcranial bones in our studied sample is consistent with the countless published bioarchaeological evidence of interpersonal violence.

We observed blunt force trauma marks on the cranial vault bones, usually in the form of depressed concentric and radiating fractures. Such fractures frequently occur after a blow with a relatively small surfaced object to the head that rests on a solid surface such as a wooden log or a stone (Moritz, 1954; Ruchonnet et al. 2019) as opposed to blows to a free-moving head, which will form linear or incomplete depressed fracture shapes. From many matching published testimonies of the KL Treblinka survivors: Zdzisław Makowski, Marian Kobyliński, Jan Kiełko, and Antoni Tomczuk, we know that on the terrain of the camp, there was a *Holzplatz*, a place where some of the woodworks were prepared. In that place, Untersturmfuhrer Franz Schwarz and Gruppenwachman Franz Swidersky performed executions on prisoners by hitting them on the head with a mallet with the victim's head placed on a wooden log or a rock (Remiszewska, 2020; Różycki et al. 2017). Those testimonies correspond with our study results of the victims' fracture pattern.

Some sharp force injuries to skulls were found on the maxilla and nasal bones and others were in the area of the foramen magnum or cervical vertebra. Perimortem sharp force trauma located on the skull bones is usually encountered in a manner of death by homicide (Kemal et al. 2013). Stab wounds that include the spinal cord are rarely reported in the literature. Currently, the largest data set on that kind of injury was gathered by Peacock et al. (Peacock et al. 1977) on South African samples. He states that the most common weapon for stabbing through the spinal cord is a knife or an axe, but sickles, scissors, and other sharp instruments are also used. Similar lesions can be found on the skeletal remains of victims of decapitation. The most affected skeletal regions in decapitation cases are the cervical vertebra, occipital condyles, and foramen magnum rim (Boylston et al. 2000; Pitts et al. 2002; Sublimi Saponetti et al. 2008). Various publications report that one of the various Nazi killing methods used on their prisoners was beheading (Czech and Brenner, 2019; Freilinger et al. 2022; Weindling, 2014). They even used a guillotine for that in other locations, such as Plotzensee Prison (Winkelmann, 2021).

The sharp force trauma marks visible on the maxilla and nasal bones could have been inflicted most probably by a knife, a sword, or a saber. From the survivors' testimonies, we learn that one of the camp guards had a saber that he used to mutilate the prisoners by cutting off their ears and noses and women's breasts (McFadden, 2012). The camp guards were equipped with bayonets and knives that could easily create most of the aforementioned sharp force trauma lesions (Różycki et al. 2017). From these testimonies, we also know that in most cases the killings were done by a weapon of opportunity, for example, a bat, a rock, or a pickaxe. A pickaxe could match the bone marks found on some occipital bones.

AL Treblinka I was a forced labor camp set up to recover the precious resource for concrete road construction, gravel. The work in the gravel pit was extremely hard, many prisoners died of exhaustion every day of the camp's existence. However, the amount of perimortem trauma on the recovered skeletal material suggests that the majority of people buried in the exhumed burial pit did not die of natural causes but were instead murdered.

It is estimated that around 800,000 people died in both Treblinka camps. The provenance of the victims varied; some prisoners were from the surrounding villages, and others had to be transferred from countries as far as France, Germany, Austria, Belgium, Czechoslovakia, USSR, Greece, Yugoslavia, and Macedonia. The assessed biological profile includes the ancestry component. The majority of the assessed ancestry was European after the application of both free-to-access software (Ancestrees and Cranid). Four skulls were estimated as Northeast African by both computer programs. The programs used cannot pinpoint the skulls to a specific country, where the person's ancestors lived, but provide the researcher with information on the broader geographical area. Here Northeast Africa refers to the MENA demographic region (Middle East and North Africa), which includes countries such as Israel (Keddie, 1973). From historical sources, we know that many Jews died in Treblinka, and the Jewish ghetto police badge from Falenica found among the artifacts supports the claim that Jewish people were present among the victims. Three skulls were assessed unequivocally South Asian. Again, it is a quite broad geographic region that encompasses demographic regions of countries such as India, Pakistan, Afghanistan, Nepal, Sri Lanka, and others. From various interdisciplinary research (Kalaydjieva et al. 2005; Piccolo, 1996; M. Stewart, 2013; van Loghem et al. 1985) we know, that the origin of Romani populations was from India, and the historical sources demonstrate that Romanis also died in Treblinka. Moreover, when we compare anthropological results with genetic results we notice that for the skulls assessed anthropologically as NE African, haplogroups are N1b1b, and the subclades of R0, those are frequently present in populations of North-East Africa and Ashkenazi Jews (Černý et al. 2009; Feder et al. 2008; Hassan, 2009; Stevanovitch et al. 2004). A skull assessed as S Asian is of haplogroup K, which can be prevalent in Polish Roma people (Malyarchuk et al. 2006).

The ancestry of a person is not always correlated with the person's geographical origin (Christensen et al. 2014). For future research, we recommend stable isotope analysis, which could help in narrowing down the geographical provenance of the victims, and thus help in personal identification. Forensic isotope analysis has proven to be very useful in reconstructing a person's geographic life history and dietary habits in many cases of humanitarian crisis (A. Chesson et al. 2018), such as the identification of dead migrant remains on the USA/Mexico border (Ammer et al. 2020) or identification of migrants from Syria in Italy and Greece (Elissavet et al. 2018). Despite the commingling of the skeletons, the overall preservation state of the skulls was rather good, so it is possible to make facial approximations of many of the recovered victims. Even though facial approximation is not considered a primary method of identification (Gupta, 2015), it could benefit the personal identification process in this case, and it should be one of the next steps of the research on the skeletal material, on the land of former AL Treblinka I, recovered from the clandestine burial pit. One of the primary methods of personal identification recommended by Interpol for a mass event (Interpol, 2018) is genetic analysis. The genetic kinship analysis performed did not show any relatedness between the victims of the Treblinka I penal labor camp. Further studies are being conducted to obtain higher-quality DNA extracts, and thus better DNA profiles. However, even after full profiles are obtained, identification cannot be possible without the reference material.

Thus far, no positive identification of the studied victims has been obtained. An ongoing search for the families of Treblinka I victims is being conducted.

Conclusions

This skeletal material represents the hard evidence of atrocities committed by Treblinka camp guards on their prisoners. This is the first time since the first half of the twentieth century that victims' remains have been physically examined. The non-invasive methods applied by scientists from 2007 contributed greatly to the knowledge of the spatial organization of the camp's structure, as well as the possible location of some of the mass graves, but they cannot fully replace the standard archaeological excavation. Thanks to the trauma analysis results, we may infer that the victims were brutally beaten around the time of death. Many of them opposed the attack (as suggested by parry fractures and metacarpals' fractures), which can indicate they knew what was going to happen to them. Some of the victims were likely killed by forcibly having their heads placed on a wooden block or a stone and hitting them with a tool such as a mallet. Others were hit on the top of their heads with a bat or a plank or a similar object. Some were shot in the back of their head and others were cut through the brain stem or beheaded. Interestingly, all of the noticed perimortem trauma lesions were later verified by survivors' testimonies and were proven consistent.

The variety in the manner of death we observed can suggest that there were multiple assailants during the killing, and possibly the murders took place in various locations. The material that we examined was exhumed from only one of many clandestine mass burial pits on the Execution Site of the Treblinka camp. The archaeological survey shows there are several more graves nearby our exhumed pit.

Our research shows that hard physical labor, poor sanitary conditions, overcrowding, poor nutrition rates, and epidemics were not the only reasons for the early demise of hundreds of thousands of people imprisoned by the Nazis during the Second World War in Treblinka. Many of the captives were brutally murdered by their guards, and those crimes deserve to be prosecuted to bring justice to the victims and their families.

Data availability

The data that support the findings of this study are available from the Institute of National Remembrance, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Institute of National Remembrance.

Received: 4 November 2022; Accepted: 31 July 2023;
Published online: 10 August 2023

Note

1 http://familias.no/
2 https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU19990470480/O/D19990480.pdf
3 https://www.babao.org.uk/assets/Uploads/BABAO-Code-of-Ethics-2019.pdf

References

Abate D, Sturdy-Colls C (2018) A multi-level and multi-sensor documentation approach of the Treblinka extermination and labor camps. J Cult Herit 34:129–135. https://doi.org/10.1016/j.culher.2018.04.012

Adams, B. J., & Byrd, J. E. (2014). Commingled Human Remains: Methods in Recovery, Analysis, and Identification. Commingled Human Remains: Methods in Recovery, Analysis, and Identification, 1–519. https://doi.org/10.1016/C2012-0-02768-8

Ammer STM, Bartelink EJ, Vollner JM, Anderson BE, Cunha EM (2020) Spatial distributions of oxygen stable isotope ratios in tap water from mexico for region of origin predictions of unidentified border crossers. J Forensic Sci 65(4):1049–1055. https://doi.org/10.1111/1556-4029.14283

Andrearsen JO, Bakland LK, Flores MT, Andrearsen FM, Andersson L (2011) Traumatic Dental Injuries: A Manual. John Wiley and Sons, West Sussex, United Kingdom

Arad, Y. (1999). Belzec, Sobibor, Treblinka: the Operation Reinhard death camps. 448

Boylston A, Knüsel CJ, Roberts CA, Dawson M (2000) Investigation of a romano-british rural ritual in bedford, England. J Archaeol Sci 27(3):241–254. https://doi.org/10.1006/jasc.1999.0451

Brooks S, Suchey JM (1990) Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Hum Evol 5(3):227–238. https://doi.org/10.1007/BF02437238

Brůžek J, Santos F, Dutailly B, Murail P, Cunha E (2017) Validation and reliability of the sex estimation of the human os coxae using freely available DSP2 software for bioarchaeology and forensic anthropology. Am J Phys Anthropol 164(2):440–449. https://doi.org/10.1002/ajpa.23282

Buikstra, J. E. (2019). Ortner's identification of pathological conditions in human skeletal remains. Ortner's Identification of Pathological Conditions in Human Skeletal Remains, 1–839. https://doi.org/10.1016/C2011-0-06880-1

Buikstra JE, Ubelaker DH (1994) Standards for data collection from human skeletal remains. Arkansas Archaeological Survey Research Series No. 44. Arkansas Archaeological Survey, Fayetteville

Byrd JE, LeGarde CB (2014) Osteometric Sorting. Commingled Human Remains: Methods in Recovery, Analysis, and Identification, 167–191. https://doi.org/10.1016/B978-0-12-405889-7.00008-3

Chesson AL, Tipple JB, Youmans VL, O'Brien AM, Harmon MM (2018) Forensic Identification of Human Skeletal Remains Using Isotopes. In New Perspectives in Forensic Human Skeletal Identification (pp. 157–173). Elsevier. https://doi.org/10.1016/B978-0-12-805429-1.00014-4

Christensen AM, Passalaqua NV, Bartelink EJ (2014) Forensic Anthropology: Current Methods and Practice, 1st ed. Academic Press, San Diego, USA

Curate F, Coelho J, Gonçalves D, Coelho C, Ferreira MT, Navega D, Cunha E (2016) A method for sex estimation using the proximal femur. Forensic Sci Int 266:579.e1–579.e7. https://doi.org/10.1016/j.forsciint.2016.06.011

Czech H, Brenner E (2019) Nazi victims on the dissection table — The Anatomical Institute in Innsbruck. Ann Anat 226:84–95. https://doi.org/10.1016/j.aanat.2019.03.007

Černý V, Pereira L, Kujanová M, Vašíková A, Hájek M, Morris M, Mulligan CJ (2009) Out of Arabia-The settlement of Island Soqotra as revealed by mitochondrial and Y chromosome genetic diversity. Am J Phys Anthropol 138(4):439–447. https://doi.org/10.1002/ajpa.20960

Dirkmaat D, Garvin H, Cabo LL (2018) Forensic anthropology. In The International Encyclopedia of Biological Anthropology (pp. 1–17). John Wiley & Sons, Inc. https://doi.org/10.1002/9781118584538.ieba0183

Egeland T, Mostad PF, Mevåg B, Stenersen M (2000) Beyond traditional paternity and identification cases. Forensic Sci Int 110(1):47–59. https://doi.org/10.1016/S0379-0738(00)00147-X

Elissavet D, George D, Spyridon L, Dimitrios P, Elena K (2018) Isotopic composition of spring water in greece: spring waters isoscapes. Geosciences 8(7):238. https://doi.org/10.3390/geosciences8070238

Feder J, Blech I, Ovadia O, Amar S, Wainstein J, Raz I, Dadon S, Arking DE, Glaser B, Mishmar D (2008) Differences in mtDNA haplogroup distribution among 3 Jewish populations alter susceptibility to T2DM complications. BMC Genomics 9(1):198. https://doi.org/10.1186/1471-2164-9-198

Fiedler S, Illich B, Berger J, Graw M (2009) The effectiveness of ground-penetrating radar surveys in the location of unmarked burial sites in modern cemeteries. J Appl Geophys 68(3):380–385. https://doi.org/10.1016/j.jappgeo.2009.03.003

Freilinger M, Klimaschewski L, Brenner E (2022) Innsbruck's histological institute in the third Reich: Specimens from NS-victims. Ann Anat 241:151890. https://doi.org/10.1016/j.aanat.2022.151890

Gill P, Gusmão L, Haned H, Mayr WR, Morling N, Parson W, Prieto L, Prinz M, Schneider H, Schneider PM, Weir BS (2012) DNA commission of the International Society of Forensic Genetics: recommendations on the evaluation of STR typing results that may include drop-out and/or drop-in using probabilistic methods. Forensic Sci Int: Genet 6(6):679–688. https://doi.org/10.1016/j.fsigen.2012.06.002

Gross JT, Grudzińska-Gross I (2011) Złote żniwa. Społeczny Instytut Wydawniczy Znak, Warszawa

Gupta S (2015) Forensic facial reconstruction: the final frontier. J Clin Diagn Res. https://doi.org/10.7860/JCDR/2015/14621.6568

Hassan M (2009) Genetic Patterns of Y-chromosome and Mitochondrial (Hassan 2009).pdf | DocDroid. https://www.docdroid.net/8GAIp0X/genetic-patterns-of-y-chromosome-and-mitochondrial-hassan-2009-pdf

Hefner JT (2009) Cranial nonmetric variation and estimating ancestry. J Forensic Sci 54(5):985–995. https://doi.org/10.1111/j.1556-4029.2009.01118.x

Hoffmann J (2008) 'Das kann man nicht erzählen': Aktion 1005 - Wie die Nazis die Spuren ihrer Massenmorde in Osteuropa beseitigten, 3rd edn. KVV Konkret, Hamburg

Hopping LJ (2007) The Body As Evidence (Crime Scene Science). Gareth Stevens Pub Secondary Lib, New York, USA

Huber N, Parson W, Dür A (2018) Next generation database search algorithm for forensic mitogenome analyses. Forensic Sci Int Genet 37:204–214. https://doi.org/10.1016/j.fsigen.2018.09.001

Interpol (2018) Disaster Victim Identification. Disaster Victim Identification. https://www.interpol.int/How-we-work/Forensics/Disaster-Victim-Identification-DVI

Judd MA (2008) The parry problem. J Archaeol Sci 35(6):1658–1666. https://doi.org/10.1016/j.jas.2007.11.005

Kalaydjieva L, Morar B, Chaix R, Tang H (2005) A newly discovered founder population: the Roma/Gypsies. BioEssays 27(10):1084–1094. https://doi.org/10.1002/bies.20287

Keddie NR (1973) Is there a Middle East? Int J Middle East Studies 4(3):255–271. https://doi.org/10.1017/S0020743800031457

Kemal CJ, Patterson T, Molina DK (2013) Deaths due to sharp force injuries in Bexar county, texas, with respect to manner of death. Am J Forensic Med Pathol 34(3):253–259. https://doi.org/10.1097/PAF.0b013e31828ced68

Kimmerle E (2012) Forensic anthropology: a Human Rights Approach. In Forensic Anthropology: An Introduction (pp. 1–450). Taylor and Francis. https://doi.org/10.1201/B12920

Kling D, Tillmar AO, Egeland T (2014) Familias 3 – Extensions and new functionality. Forensic Science International: Genetics 13:121–127. https://doi.org/10.1016/J.FSIGEN.2014.07.004

Kononiuk SL, Apresjan WZ, Hołowań ME, Rodionow FA, Kadałow NW, Dydkowski J, Twusz E, Truskolaski K, Skarżyński K (1944) NIR Archives, vol. I, Deed, p 1-19

Kopówka E (2002) Treblinka- Nigdy więcej (Kopówka, E Ed.; 1st ed.). Muzeum Regionalne w Siedlcach

Kopówka E (2015) Treblinka Historia i Pamięć. Treblinka History and Memory (E. Kopówka, Ed.). Muzeum Regionalne w Siedlcach

Koschalka B (2019) Mass grave discovered under car park at former German Nazi camp Treblinka | Notes From Poland. Notes From Poland. https://notesfrompoland.com/2019/11/16/mass-grave-discovered-under-car-park-at-former-german-nazi-camp-treblinka/

van Loghem E, Tauszik T, Hollan S, Nijenhuis LE (1985) Immunoglobulin allotypes in hungarian gypsies. Eur J Immunogenet 12(3):131–137. https://doi.org/10.1111/j.1744-313X.1985.tb00840.x

Malyarchuk BA, Grzybowski T, Derenko MV, Czarny J, Miscicka-Sliwka D (2006) Mitochondrial DNA diversity in the polish roma. Ann Hum Genet 70(2):195–206. https://doi.org/10.1111/j.1529-8817.2005.00222.x

Maresh M (1970) Measurements from Roentgenograms. Human Growth And Development, 157–200. Springfield, IL

McFadden RD (2012) John Demjanjuk, Accused as a Nazi Guard, Dies at 91 - The New York Times. The New York Times. https://www.nytimes.com/2012/03/18/world/europe/john-demjanjuk-nazi-guard-dies-at-91.html

Mierzejewski A (2003) The Most Valuable Asset of the Reich: A History of the German National Railway (Vol. 2). Univ of North Carolina Press

Moran DA (2003) In Defense of the Corpus Delicti Rule. Ohio State Law Journal 64:817–854

Moritz AR (1954) The pathology of trauma. (A. R. Moritz, Ed.). Lea & Febiger

İşcan MY, Steyn M (2013) The Human Skeleton in Forensic Medicine. 3a ed. In Charles C Thomas

Navega D, Coelho C, Vicente R, Ferreira MT, Wasterlain S, Cunha E (2015) AncesTrees: ancestry estimation with randomized decision trees. Int J Legal Med 129(5):1145–1153. https://doi.org/10.1007/s00414-014-1050-9

Nilsson M, Possnert G, Edlund H, Budowle B, Kjellström A, Allen M (2010) Analysis of the putative remains of a european patron saint–St. Birgitta. PLoS ONE 5(2):e8986. https://doi.org/10.1371/journal.pone.0008986

Peacock WJ, Shrosbree R, Key A (1977) A review of 450 stabwounds of the spinal cord. South Af Med J 51(26):961–964

Phenice TW (1969) A newly developed visual method of sexing the os pubis. Am J Phys Anthropol 30(2):297–301. https://doi.org/10.1002/ajpa.1330300214

Piccolo F (1996) A founder mutation in the gamma-sarcoglycan gene of gypsies possibly predating their migration out of India. Hum Mol Genet 5(12):2019–2022. https://doi.org/10.1093/hmg/5.12.2019

Pitts M, Bayliss A, McKinley J, Bylston A, Budd P, Evans J, Chenery C, Reynolds A, Semple SJ (2002) An Anglo-Saxon decapitation and burial at Stonehenge. Wilts Archaeol Nat Hist Mag 95:131–146

Rajchman C (2011) Treblinka: A Survivor's Memory. Hachette UK

Remiszewska A (2020) Plan Symbolicznych Krzyży na Miejscu Straceń w Treblince (I). Muzeum Treblinka Niemiecki nazistowski obóz zagłady i obóz pracy (1941–1944)

Różycki S, Michalski M, Kopówka E, Róycki S (2017) OBÓZ PRACY TREBLINKA I (I). Muzeum Treblinka

Różycki S, Zapłata R, Karczewski J, Ossowski A, Tomczyk J (2020) Integrated archaeological research: archival resources, surveys, geophysical prospection and excavation approach at an execution and burial site: the german nazi labour camp in Treblinka. Geosciences 10(9):336. https://doi.org/10.3390/geosciences10090336

Ruchonnet A, Diehl M, Tang Y-H, Kranioti EF (2019) Cranial blunt force trauma in relation to the victim's position: An experimental study using polyurethane bone spheres. Forensic Sci Int 301:350–357. https://doi.org/10.1016/j.forsciint.2019.05.051

Rusiniak M (2006) Treblinka, podlasie region's el dorado? Kwartalnik Historii Żydow 2(218):200–211

Schaefer M (2014) A Practical Method for Detecting Commingled Remains Using Epiphyseal Union. Commingled Human Remains: Methods in Recovery, Analysis, and Identification, 123–144. https://doi.org/10.1016/B978-0-12-405889-7.00006-X

Scheuer L, Black S, Scheuer L, Black S (2000) CHAPTER THREE – Bone Development. In Developmental Juvenile Osteology (pp. 18–31)

Shepherd JP, Shapland M, Pearce NX, Scully C (1990) Pattern, severity and aetiology of injuries in victims of assault. J R Soc Med 83(2):75–78. https://doi.org/10.1177/014107689008300206

Spector S (1990a) Aktion 1005 - effacing the murder of millions. Holocaust and Genocide Stud 5(2):157–173. https://doi.org/10.1093/hgs/5.2.157

Spector S (1990b) AKTION 1005 — Effacing the Murder of Millions. Holocaust and Genocide Stud 5(2):157–173. https://doi.org/10.1093/hgs/5.2.157

Stevanovitch A, Gilles A, Bouzaid E, Kefi R, Paris F, Gayraud RP, Spadoni JL, El-Chenawi F, Beraud-Colomb E (2004) Mitochondrial DNA sequence diversity in a sedentary population from Egypt. Ann Hum Genet 68(1):23–39. https://doi.org/10.1046/j.1529-8817.2003.00057.x

Stewart M (2013) Roma and Gypsy "Ethnicity" as a Subject of Anthropological Inquiry. Ann Rev Anthropol 42(1):415–432. https://doi.org/10.1146/annurev-anthro-092010-153348

Stewart TD (1979) Essentials of forensic anthropology: especially as developed in the United States. Charles C. Thomas, Springfield, IL

Sturdy Colls C (2012) Holocaust Archaeology: Archaeological Approaches to Landscapes of Nazi Genocide and Persecution. Journal of Conflict Archaeology 7(2):70–104. https://doi.org/10.1179/1574077312Z.0000000005

Sturdy Colls C, Colls K (2020) The Heart of Terror: A Forensic and Archaeological Assessment of the Old Gas Chambers at Treblinka. In Archaeologies of Totalitarianism, Authoritarianism, and Repression (pp. 83–105). Springer International Publishing. https://doi.org/10.1007/978-3-030-46683-1_5

Sturdy-Colls C (2016) Earth conceal not my blood: forensic and archaeological approaches to locating the remains o Holocaust victims. In Dreyfus J-M, Anstett E (eds) Human Remains in Society, 1st ed. Manchester University Press, pp 163–196

Sublimi Saponetti S, Scattarella V, Di Nunno C, Emanuel P, Di Nunno N (2008) A case of decapitation in Canosa, South Italy (5th–6th century a.d.). Forensic Sci Int 176(2–3):e11–e16. https://doi.org/10.1016/j.forsciint.2007.07.015

Trotter M (1970) Estimation of stature from intact long limb bones. In T. D. Stewart (ed) Personal identification in mass disasters (pp. 71–83)

Tuller H, Hofmeister U (2014) Spatial Analysis of Mass Grave Mapping Data to Assist in the Reassociation of Disarticulated and Commingled Human Remains. Commingled Human Remains: Methods in Recovery, Analysis, and Identification, 7–32. https://doi.org/10.1016/B978-0-12-405889-7.00002-2

Ubelaker DH (2008) Methodology in Commingling Analysis: An Historical Overview. In Adams B, Byrd J (eds) Recovery, Analysis, and Identification of Commingled Human Remains (pp. 1–6). Humana Press. https://doi.org/10.1007/978-1-59745-316-5_1

Webb C, Chocholaty M, Lawson T (2021) The Treblinka Death Camp: History, Biographies, Remembrance, 2nd ed. ibidem, Hannover

Weindling P (2014) Victims and Survivors of Nazi Human Experiments: Science and Suffering in the Holocaust. Bloomsbury Publishing, London, UK

Weissensteiner H, Pacher D, Kloss-Brandstätter A, Forer L, Specht G, Bandelt H-J, Kronenberg F, Salas A, Schönherr S (2016) HaploGrep 2: mitochondrial haplogroup classification in the era of high-throughput sequencing. Nucleic Acids Res 44(W1):W58–W63. https://doi.org/10.1093/nar/gkw233

Wiernik J (1944) Rok w Treblince (J. Wiernik, Ed.). Komisja Koordynacyjna w Warszawie

Winkelmann A (2021) Traces of Nazi victims in Hermann Stieve's histological collection. Ann Anat 237:151720. https://doi.org/10.1016/j.aanat.2021.151720

Wright R (2008) Detection of Likely Ancestry Using CRANID. In Forensic Approaches to Death, Disaster and Abuse. https://doi.org/10.3316/informit.804323190860089

Acknowledgements

We thank the National Institute of Remembrance for their permission to publish our study results. The author would like to thank John and Beata Mayston for their thorough proofreading of this article.

Author contributions

J.D. – a corresponding author: conceived and performed the main anthropological research; J.J-S., D.L., M.Sz., M.J., and K.S.- these authors contributed equally to this work: J.J-S. was in charge of the archaeological part of the project, D.L. sampled material and prepared for DNA extraction, M.Sz. was responsible for NGS sequencing, M.J. was archaeological consultant of the project, K.S. was anthropological advisor and proof-reader of the manuscript; M.P. and A.O.- these authors jointly supervised this work: M.P. was responsible for medico-legal aspect of the research, A.O. supervised the project. All the authors discussed the results and contributed to the final version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with living human participants performed by any of the authors. All human samples are more than seventy years old and anonymous, they were subjects of criminal investigation led by the Institute of National Remembrance prosecutors. The criminal cases conducted by a prosecutor do not require ethical approval in Poland[2]. After the submission of our expert opinion we obtained the prosecutor's permission to publish our results. The copy of permission is attached together with this statement. Moreover, we followed guidance for the ethical treatment of human remains following BABAO[3].

Informed consent

This article does not contain any studies with human participants performed by any of the authors. All information reported in this paper is anonymized and the submission does not include images that may identify the person.

Additional information

Correspondence and requests for materials should be addressed to Joanna Drath.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.