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Forensic Anthropology

Forensic anthropology casework from Switzerland (Bern): Taphonomic implications for the future

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A B S T R A C T

Retrospective, observational studies of forensic casework enhance knowledge on topics such as postmortem interval (PMI) estimations and search strategies. This 10-year survey of forensic anthropology (FA) casework performed at the Department of Physical Anthropology in the Institute of Forensic Medicine in Bern, Switzerland, provides insights into a variety of human bone cases recovered in different circumstances. In this study, we present 58 cases from our forensic database. The surveyed forensic cases comprise a high proportion of dispersed remains, leading to low recovery rates. In addition, about a third of the cases were discovered in the Swiss Alps. Future studies and research should concentrate on enhancing the recovery rate in outdoor forensic scenes and on research in PMI estimation. This is especially important for remains found in high altitudes, because due to the melting glaciers, we expect more previously covered and frozen remains to be released in the following years. Systematic, longitudinal case reviews further provide a reference that can be used to refer to in FA expertises.

1. Introduction

Forensic anthropology (FA) is the application of physical anthropology and related fields to the forensic context and mainly deals with skeletonised or near-skeletonised human remains of unknown identity and/or resulting from unexplained deaths [1,2]. In Switzerland, forensic anthropologists are generally situated in forensic medicine, therefore, mostly institutionalised at universities. This is also pointed out for most of the other countries in Europe [3,4]. The survey by Obertová et al. [4] further showed that FA is becoming more established in Europe compared to a similar survey from Kranioti and Paine in 2011 [3]. Nevertheless, the FA caseload is still quite small despite the many advantages of the discipline, as following. For instance, faunal bones can be quickly identified and the cases closed early on, reducing time and cost efforts. The same accounts for determining whether human bones are of forensic interest or not – before starting extensive investigative work and genetic analyses, anthropologists provide an expertise on whether the remains might be ancient and recommend suitable dating methods. If the remains are of forensic interest, FA practitioners routinely establish a biological profile to aid identification (sex, age-at-death, ancestry, stature, pathologies and anomalies), assess traumatic lesions and estimate the post-mortem interval (PMI) [5]. Their expertise is especially useful in case of skeletonised, burnt, fragmented and badly preserved remains or where no further bio-(molecular) analysis can be conducted [6,7]. In addition, forensic anthropologists are of value for the search, location and recovery of human remains in a forensic setting [2,8].

Closely related and intertwining with forensic anthropology is forensic taphonomy, the interdisciplinary study of what happens to an organism between its death and recovery (Schotsmans et al., 2017 Introduction). This includes for example the deposition, tissue decay, insect activity and bone weathering. A major challenge in FA is the estimation of the PMI, because of complex processes and influencing taphonomic variables, such as climate and environment [9]. Because of environmental, social, cultural and economic differences between (and within) countries, results and findings published for one country may not account for another. Therefore, case reviews and experimental research can aid many aspects of FA, including PMI estimation methods. However, the use of human cadavers in experiments is difficult to justify in many countries including Switzerland [10]. Pigs (*Sus scrofa*) have been widely used as human analogues, although, it is known that animal models cannot be applied directly to human forensic cases, e.g. [11–13].

A large amount of taphonomic research was established in the United States so far, where FA is more widely integrated within casework compared to Europe [3,14]. For instance, systematic surveys as well as short reports of FA cases in general or about taphonomic features in a

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range of cases have until now mainly been undertaken on the North American continent (Tennessee [15,16]; British Columbia in Canada [17]; Florida [18]; Washington [19]; New York [20]; New Mexico, [6, 21]; Massachusetts [22]; Chico [23]; general US [24,25]), one brief report is published for South Africa [26] and one for Australia [27], whereas none is internationally published yet for Europe. However, there is at least one study conducting a FA case survey in the region around Hamburg, Germany [28].

Switzerland with an area of 41277 km^2 lies in Central Europe and the canton of Bern covers 5960 km^2 of its area (ca. 14%). About 20% of the Alps lie in Switzerland where they cover about 60% of the country, although, only 11% of the Swiss population live in the Alps [29]. A large area of the Canton of Bern is covered by the Alps, their foothills or the Jura mountains. Its largest surface is covered by grass (ca. 40%), followed by trees and woods (30%) and then by vegetation-free land, such as mountains (ca. 11%), waters (7%) and artificially built areas (ca. 6%) [30]. There are 1500 lakes in Switzerland and 48 summits reach an altitude of at least 4000 m, while glaciers cover roughly 1140 km^2 of the Swiss surface [29]. However, the glacier-covered area is decreasing. Approximately 211 km^2 of those glaciers and firns lie in the Canton of Bern.

The Department of Physical Anthropology at the Institute of Forensic Medicine at the University of Bern performs most investigations on archaeological skeletal remains and conducts excavations on human remains and research in physical anthropology, e.g. [31–35]. The department further has the scientific responsibility for a skeletal collection of about 6000 skeletons from various contexts. In addition, forensic casework is one of the tasks, including the recovery of skeletal remains in situ or receiving them from investigative authorities or the forensic medicine department. In the present survey, we reviewed forensic skeletal cases from a 10-year-period (October 2010 to December 2020). Our focus lies on the finding circumstances, taphonomic alterations and individual data of the remains. The cases often derive from particular contexts, such as high altitudes (over 2000 m) and forests (Figs. 1, 2). However, especially PMI estimations are challenging, also because little is published about these circumstances, e.g. [36,37]. References to case reviews where the PMI is known provide a higher credibility for expertises based on similar environmental and/or topographic conditions [38]. Therefore, the aim of our study was to evaluate our FA cases by means of descriptive statistics and to draw conclusions for future casework, in particular PMI estimations. In addition, we provide our anonymised casework data to the scientific community, in particular to colleagues working on related FA topics.

2. Material and methods

We retrieved cases from the FA database of the IRM Bern covering the period August 2010 to December 2020, commissioned by the investigative authorities. Our cases derive mainly from the area of the Canton of Bern, but some derived from adjacent Cantons or such without institutionalised forensic anthropology. For this study, we adduced only cases involving bones or bones with soft tissue remnants from an assumed forensic context, excluding e.g. visual comparisons of imaging material and anthropological investigations on behalf of archaeologists. Besides the expertises and associated photographs, the underlying files may include correspondences, police reports, external expertises (e.g. radiocarbon dating) and in some cases antemortem information of the identified individuals. However, the reporting format as well as the amount of information vary.

We investigated the following categories in this survey.

2.1. Nature of the bones

To determine whether the remains were of human or animal origin, we used size and morphology of the bones [39]. We further distinguished between "archaeological remains" and "forensic remains". The threshold between these two contexts is not legally defined in Switzerland, although, the accountability for homicide currently lapses after 30 years (Art. 97 StGB). To include missing person cases in our database, we used a threshold of 60 years to define forensic interest for

Fig. 1. Human and animal bones were found dispersed in about 2000 m altitude, the bones are indicated by flags. The flag next to number 2 marks the human skull. Photograph with courtesy of the FOR KT AD (Forensic Science Field Service of the Canton of Bern).

Fig. 2. Human remains scattered over a slope in a forest environment, ca. 1300 m altitude. Courtesy of the FOR KT AD (Forensic Science Field Service of the Canton of Bern). Copyright © 2015 John Wiley & Sons, Ltd. [33].

international comparability, see e.g. [40].

2.2. Circumstances of finds

We categorised the discoveries into year and the seasons with spring (March-May), summer (June-August), fall (September-November) and winter (December-February). If known, we listed information about the finder, e.g. walker, construction worker. We further differentiated the depositional environments into indoors and outdoors, the latter into places such as forest surface, subterranean or water environments. For individuals recovered at the Alpine stage (above 2000 m of altitude, height of the tree line), we used "high altitude" as a parameter [41].

2.3. Taphonomic information

We roughly estimated the recovery rate of each individual. In some forensic cases of surface scattered remains, a systematic visual foot search was conducted by the police. When the individuals are represented by more than one case number (three individuals indicated by a, b and c in Table 1), we combined them for this study. We listed particular preservation features such as adipocere, soft tissue or degreased bone. We further noted presence and range of bone dispersal in scattered cases. Additionally, we investigated changes possibly resulting from postmortem animal activity, such as gnawing [42]. We derived information about the PMI from different sources. First, from radiocarbon dating following Szidat et al. [43] with bomb peak modelling where applicable [44,45], second from investigative reconstruction (the time when the individual went missing was taken as time of death) and third, based on anthropological analysis, e.g. tooth restorations or state and presence of soft tissue in comparison with cases of known PMI in similar contexts.

2.4. Individual information

An identification was always confirmed via molecular genetic analysis, e.g. [46]. Anthropological analysis followed recommendations by Buikstra and Ubelaker [47]. The age-at-death estimation by anthropological means was divided into categories of 10 years. Where age-at-death was known due to successful identification of the individual, we used the known age. Due to low representation of skeletal elements, sex estimation was unsure in some cases (indicated with an additional question mark in Table 1). In these cases, the prosecution did not request a molecular genetic confirmation. Trauma was analysed following standard literature, e.g. Reichs [48]. We did not describe the lesions in detail but divided them into ante-, peri- and postmortem.

We followed basic steps in classifying our cases as seen in flowchart Fig. 3. "FA cases" describe all casework of human remains on behalf of investigating authorities in our department. These cases were mostly skeletonised, although, some exhibited varying amounts of soft tissue residues. "Human bone" cases involve all cases with solely human or mixed animal and human skeletal remains. "Forensic remains" only include these found to be of forensic interest, the others were defined as "archaeologic remains". Some of the forensic cases were identified genetically via the Swiss national DNA database and CODIS [49]. The ultimate "number of persons" identified is smaller than the number of cases where identification was possible (see Table 1), because partial remains of one individual may be found distributed over time, resulting in several case numbers for one individual.

The presentation of the cases in our study does not conflict with national legislative frameworks. Most of the cases are animal or ancient human bones without the need for ethical clearance. For the forensic remains, there is an agreement with local investigative authorities enabling us to present anonymized data.

3. Results

During the investigated period, we performed an anthropological analysis on 58 FA cases, all displayed in Table 1.

Table 1
Recorded information of the 58 investigated FA cases. Remains with the same letters (indicated in the column "No.") turned out to be from the same individual, recovered at different occasions. AN: Animal, HU: human, FO: Forensic, AR: Archaeologic, N.d.: not detected.

	Nature		Circumstances of find				Taphonomic information *known from ID (case information) **known from radiocarbon analysis			Individual information *known from genetic ID				
No.	Human, animal	Forensic, archaeologic	Year	Season	Depositional environment	Finder	Recovery rate	Particular preservation features	PMI	MNI	Sex	Age	ID	Trauma
1	HU	FO	2010	Summer (Aug)	Glacier	Mountaineer	Ca. 50%	Adipocere, foot in shoe	40 years*	1	M*	26*	Yes	Perimortem
2	HU	AR	2010	Fall (Nov)	Outdoors surface	Unknown	< 25%	–	Indet.	1	F?	40–60	No	N.d.
3	HU	AR	2011	Spring (Mar)	Water	Walker	< 25%	Adhering algae	> 30 years	1	Indet.	25–40	No	N.d.
4	HU	AR	2011	Spring (Mar)	Outdoors surface	Walker	< 25%	Adipocere	> 100 years**	1–2	M	40–60	No	N.d.
5	HU	AR	2011	Spring (May)	Interred	Construction worker	75–100%	–	> 30 years	2	M, indet.	50–60, 9–11	No	N.d.
6	HU	FO	2011	Summer (Aug)	Forest	Forestry worker	75–100%	Adhering moss, animal scavenging	5*	1	M*	23*	Yes	N.d.
7	HU	FO	2011	Summer (Aug)	Glacier	Mountaineer	< 25%	Adhering sediment, sun bleaching	> 10 years	1	M*	15–25	No	N.d.
8	HU	FO	2011	Spring (Mar)	Forest	Forestry worker	75–100%	Adhering moss, animal scavenging	2.5 years*	1	M*	27*	Yes	Perimortem
9	HU	FO	2012	Spring (Mar)	Outdoors surface	Walker	< 25%	Adhering sediment	56–57 years**	1	M?	20–40	No	N.d.
10	HU	FO	2012	Summer (Aug)	Forest	Walker	75–100%	Partially skeletonised, textile remnants, adipocere	13 months*	1	M	80*	Yes	N.d.
11	HU	AR	2012	Summer (Jun)	Forest	Walker	Ca. 50%	–	> 100 years**	2	–	–	No	N.d.
12	HU	FO	2012	Summer (Aug)	Building	Friend/family	100%	Partially skeletonised, desiccated soft tissue remnants, insects	1 month*	1	M	87*	Yes	N.d.
13	HU	FO	2012	Winter (Dec)	Water	Walker	< 25%	–	Indet.	1	M?	20–50	No	N.d.
14	HU	FO	2012	Fall (Oct)	Forest	Walker	25–50%	Cremated, 1620 g	Indet.	2	Indet.	adult	No	N.d.
15	HU	AR	2013	Winter (Dec)	Outdoors surface	Construction worker	< 25%	–	> 30 years	2	M, indet.	50–70, 18–20	No	N.d.
16	HU	AR	2013	Summer (Jun)	Interred	Construction worker	50–75%	Degreased	> 100 years**	2	M, M	35–55, adult	No	N.d.
17	AN	–	2013	Summer (Jul)	Mountain	Mountaineer	–	–	–	1	–	–	–	–
18	AN	–	2014	Spring (Mar)	Water	Walker	–	–	< 50 years	1	–	–	–	–
19	HU	FO	2014	Spring (Apr)	Forest	Walker	75–100%	Partially burned	1–2 years**	1	M	21*	Yes	Possible perimortem
20	HU	AR	2014	Spring (Apr)	Water	Walker	< 25%	Degreased	> 100 years**	1	Indet.	25–40	No	N.d.
21	HU	AR	2014	Spring (Apr)	unknown	Unknown	< 25%	–	> 100 years**	1	M	50+	No	N.d.
22	HU+AN	AR	2015	Spring (May)	Water	Unknown	< 25%	Degreased	> 30 years	4	Indet.	Indet.	No	Perimortem
23	AN	–	2015	Summer (Aug)	Garden	Unknown	–	–	–	1	–	–	–	–
24	AN	–	2015	Summer (Aug)	Garden	Houseowner	–	–	–	1	–	–	–	–
25	HU	AR	2016	Winter (Feb)	Building	Houseowner	< 25%	Degreased	> 100 years**	1	M	50+	No	N.d.
26	AN	–	2016	Spring (Apr)	Interred	Construction worker	–	–	–	1	–	–	–	–
27	AN	–	2016	Spring (Apr)	Building	Unknown	–	–	–	1	–	–	–	–
28	AN	–	2016	Spring (May)	Forest	Walker	–	–	–	1	–	–	–	–
29	HU+AN	AR	2016	Spring (May)	unknown	Unknown	< 25%	Animal scavenging	> 100 years**	1	F?	adult	No	N.d.
30	HU	AR	2017	Winter (Feb)	Interred	Construction worker	–	–	> 100 years**	8	–	–	–	–
31 (a)	HU+AN	FO	2017	Summer (Jul)	Mountain	Mountaineer	< 25%	Soft tissue remnants, foot in shoe, animal	2 years*	1	M	58*	Yes	Perimortem

(*continued on next page*)

Table 1 (*continued*)

	Nature		Circumstances of find				Taphonomic information *known from ID (case information) **known from radiocarbon analysis			Individual information *known from genetic ID				
No.	Human, animal	Forensic, archaeologic	Year	Season	Depositional environment	Finder	Recovery rate	Particular preservation features	PMI	MNI	Sex	Age	ID	Trauma
								scavenging, dispersal ca. 80 m						
32	AN	–	2017	Summer (Aug)	Interred	Construction worker	–	–	–	1	–	–	–	–
33	HU	AR	2017	Summer (Jul)	Building	Houseowner	< 25%	White-coloured adhesions	> 100 years**	1	F	20–40	No	N.d.
34	HU	FO	2017	Summer (Aug)	Outdoors surface	Mountaineer	< 25%	Insects, foot in shoe	23 years*	1	M	27*	Yes	Perimortem
35	HU+AN	AR	2018	Winter (Feb)	Building	Houseowner	< 25%	Green discolouration (metal)	> 100 years**	1	M	40–60	–	N.d.
36	AN	–	2018	Spring (Mar)	Water	Walker	–	–	–	1	–	–	–	–
37	HU	AR	2018	Spring (May)	Building	Medico-legal examiner	< 25%	–	> 100 years**	1	F	17–25	No	N.d.
38	HU+AN	AR	2018	Summer (Jun)	Mountain	Houseowner	< 25%	–	> 100 years**	1	M?	50–70	No	N.d.
39 (b)	HU	FO	2018	Summer (Aug)	Glacier	Mountaineer	< 25%	Adipocere, dispersal ca. 10 m	53 years*	1	M	22*	Yes	N.d.
40	AN	–	2018	Summer (Aug)	Glacier	Mountaineer	–	–	–	1	–	–	–	–
41 (a)	HU	FO	2018	Fall (Oct)	Mountain	Mountaineer	50–75%	Soft tissue remnants (wet and desiccated), dispersal ca. 450 m aerial distance to case 34	3 years*	1	M	58*	Yes	Perimortem
42	AN	–	2019	Summer (Aug)	Water	Unknown	–	–	–	1	–	–	–	–
43	HU	AR	2019	Summer (Jul)	Unknown	Unknown	< 25%	Adhering sediment	> 100 years**	1	F, F	60+, indet.	No	N.d.
44	HU	AR	2019	Spring (Apr)	Interred	Walker	< 25%	–	> 100 years**	1	Indet.	Adult	No	N.d.
45 (b)	HU	FO	2019	Summer (Aug)	Glacier	Mountaineer	75–100%	Soft tissue remnants (wet and dessicated), foot in shoe, dispersal	54 years*	1	M	22*	Yes	N.d.
46 (b)	HU	FO	2019	Fall (Sep)	Glacier	Mountaineer	25–50%	Adipocere	54 years*	1	M	22*	Yes	N.d.
47	HU	AR	2019	Fall (Sep)	Interred	Construction worker	75–100%	–	> 100 years**	1	F	18–25	No	N.d.
48	AN	–	2020	Winter (Dec)	Water	Mountaineer	–	–	–	1	–	–	–	–
49	HU	AR	2020	Fall (Oct)	Building	Walker	< 25%	–	> 100 years**	2	Indet.	Indet.	No	N.d.
50	HU	FO	2020	Spring (May)	Forest	Walker	Ca. 25%	Degreased, adhering moss, animal scavenging	11 years*	1	F	83*	Yes	N.d.
51	HU	FO	2020	Summer (Jun)	Outdoors surface	Walker	< 25%	Animal scavenging	15 years*	1	M	53*	Yes	N.d.
52	HU	AR	2020	Summer (Aug)	Water	Diver	< 25%	Adhering algae and mussels	> 100 years**	1	Indet.	Juvenile	No	N.d.
53	HU	AR	2020	Summer (Aug)	Interred	Construction worker	< 25%	–	> 100 years**	1	Indet.	30+	No	N.d.
54 (b)	HU	FO	2020	Summer (Aug)	Glacier	Mountaineer	25–50%	Soft tissue remnants (wet and desiccated), adipocere, dispersal	55 years*	1	M	22*	Yes	N.d.
55	HU+AN	FO	2020	Fall (Sep)	Mountain	Police	< 25%	Dessicated soft tissue remnants, greasy, animal scavenging, dispersal	10 months	1	Indet.	59*	Yes	Perimortem, antemortem
56	HU	AR	2020	Fall (Oct)	Compost	Worker	< 25%	–	> 100 years**	1	M	35–55	No	N.d.
57 (c)	HU+AN	FO	2020	Fall (Oct)	Forest	Forestry worker	75–100%		21 months	1	M	65*	Yes	Perimortem

(*continued on next page*)

Table 1 (*continued*)

No.	Nature		Circumstances of find				Taphonomic information *known from ID (case information) **known from radiocarbon analysis			Individual information *known from genetic ID				
	Human, animal	Forensic, archaeologic	Year	Season	Depositional environment	Finder	Recovery rate	Particular preservation features	PMI	MNI	Sex	Age	ID	Trauma
								Partially skeletonised, fully clothed, feet in shoes, insects, dispersal ca. 20–30 m to case 58						
58 (c)	HU	FO	2020	Winter (Dec)	Forest	Walker	< 25%	Wet soft tissue remnants, insects, animal scavenging, dispersal ca. 20–30 m to case 57	23 months	1	M	65*	Yes	N.d.

3.1. Nature of skeletal finds

39 FA cases consisted of human bones only (67.2%), twelve cases were only animal bones (20.7%) and seven cases contained both (12.1%). In total, 46 cases contained human bone. Of the 58 FA cases, 22 were forensic remains (37.9%). Examples of FA cases which comprised archaeological remains or animal bones are shown in Fig. 4a,b.

3.2. Year and season of finds

In average, our department was assigned 5.8 FA cases annually by investigative authorities, with the lowest caseload during 2010 (n = 2) and the highest in 2020 (n = 11). 31% (n = 18) of the remains were discovered during spring, 41.4% (n = 24) in summer, 15.5% (n = 9) in fall and 12.1% (n = 7) in winter months. The forensic remains in particular, were also detected in all seasons, thereof 50% during summer (n = 11), 18.2% during spring (n = 4), 22.7% during fall (n = 5) and 9.1% during winter (n = 2).

3.3. Finders

50% (n = 29) of all FA-cases were discovered by walkers and mountaineers. House owners, construction, forestry and facility workers account for 29.3% (n = 17) of the finds and a police search, a diver, a medico-legal examiner and a family member found one case each, in 13.8% (n = 8) the finder was unknown. Of the 22 forensic remain cases, 77.3% (n = 17) were discovered by walkers or mountaineers.

In the following, we excluded cases with solely animal bones from further evaluation (see Fig. 2) to address particular anthropological questions.

3.4. Depositional environments

80.4% (n = 37) of the 46 human bone cases were found outdoors, 19.6% (n = 9) indoors (e.g. apartments or cellars). Forensic remains were found in the forest or mountains in 37% (n = 17), all finds from high altitudes or glaciers (n = 9) were forensic remains. All finds from subterranean environments (n = 6) were archaeologic remains.

3.5. Recovery rates

39.1% (n = 18) of all human bone cases involved only one skeletal element. Of the forensic remains, one single skeletal element (skull and mandible counted as one) was found in 31.8% (n = 7), either from the skull or the hip region (femur or innominate).

In the following, we excluded archaeologic remains from further evaluation, to concentrate on particular forensic aims.

The recovery rates of the 16 individuals in the 21 forensic remain cases (we excluded one cremated case due to massive fragmentation) are shown in Fig. 5. The skull or parts thereof was recovered of 75% (n = 12) of the individuals, smaller bones such as the hyoid, sternum, hand phalanges and patellae were recovered least frequently in 12.5% (n = 2).

3.6. Particular preservation features

We summarised particular preservation features, resp. taphonomic alterations in Table 2, similar to the table published by Pokines [22].

The distance between recovered scattered skeletal elements of forensic relevance ranged from 1.70 to ca. 450 m. We observed alterations consistent with animal scavenging in 31.8% (n = 7). Moss growth was found in 13.6% (n = 3), all of them from forests. One example of moss growth on forensic skeletal remains is shown in Fig. 6. We found traces of adipocere in 31.8% (n = 7) and six out of those were recovered from high altitudes. Insect remains were present in 18.2% (n = 4), mountain and forest cases only. Also in 13.6% (n = 3), feet and/or hands

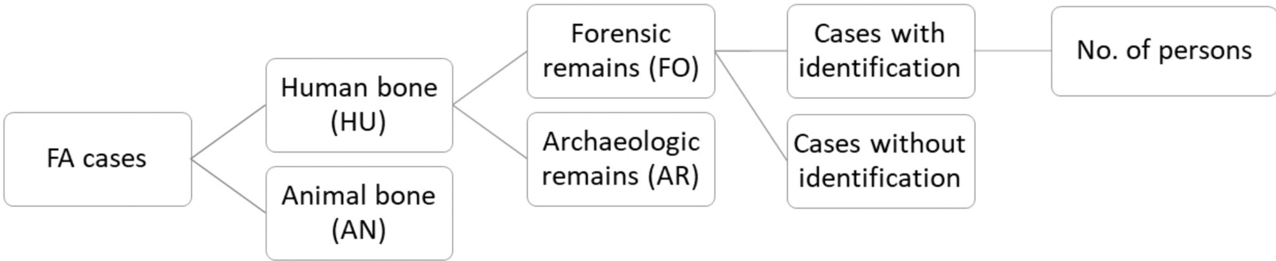

Fig. 3. Classification overview of the FA cases workflow.

were found within boots or gloves (cases 31, 45 and 57).

3.7. Postmortem intervals (PMI)

For the 22 forensic remain cases we determined the PMI by radiocarbon dating in 4.6% (n = 1), by police records after identification in 81.8% (n = 18), and through anthropological analysis in 13.6% (n = 3). PMIs range from 1 month to 56 years, with 45.5% (n = 10) having a PMI of 5 years or less and 45.5% (n = 10) having a PMI of 10 years and more.

3.8. Identifications

18 of 22 forensic remains yielded an identification, all by molecular genetics. Those led to 13 identified persons because the remains of one individual were recovered by four different events over several years (FA case numbers indicated with "b" in Table 1), and the remains of two other individuals were found in two different events (FA case numbers indicated with "a" or "c", respectively). Via molecular genetics, we assigned these multiple cases to each one individual, which lead to the discrepancy between the number of cases with identified remains and the number of identified persons.

3.9. Age-at-death and sex

Males and possible males accounted for 82.4% (n = 14) of the 17 forensic remains, one individual was female and in two cases, sex remained undetermined. For at least 35.3% (n = 6) of the males we assigned an age between 20 and 30 years, 17.7% (n = 3), all male, were grouped between 50 and 70 years and two males and one female were above 80 years (17.7%, n = 3) and 29.4% (n = 5) were "adult".

3.10. Trauma

We detected perimortem trauma in 36.4% (n = 8) of the forensic remains. This comprises fractures from blunt force impacts (n = 6) or associated with fire (n = 2). Two cases (9.1%) presented trauma possibly related to the cause of death. A healed antemortem fracture was detected in one individual (4.6%, n = 1). Postmortem damage was present in all cases, varying from small abrasions to full discontinuations of the bone.

4. Discussion

4.1. Nature of skeletal finds

The animal bone case amount of approximately 21% (plus 12% mixed) would actually be higher, but to save time and resources, we readily identified some of them without creating a case within our database. Nieberg [28] found that 41% of their cases derive from animals of the region around Hamburg, Germany. In the United States, animal bones were reported to be 4% (plus 6% mixed) [50], at least 5% for FA practitioners all over the US [24], 11% in Florida [18], 14.3% at the Smithsonian Institution [19], about 18.9% in New York as well as Chico [20,23] and 17.8%, rising to 30% in Tennessee [16]. Marks [16] explains the high amount of animal bones by the rising public interest in forensic science, which might as well be an explanation for our relatively high animal bone proportion. However, in South Africa, out of 63 cases only one (1.6%) was non-human [26].

According to Evison [51], the frequency and variety of FA casework depends on the homicide rate, population density and environment of a country. In Switzerland, the homicide rate (0.5 per 100,000 people) and

Fig. 4. (a) Human cranium from a subterranean, archaeological context (PMI over 60 years). Note the adhering soil and the rootlets, which grew through cavities. (b) An example of animal bones brought to our department by investigative authorities.

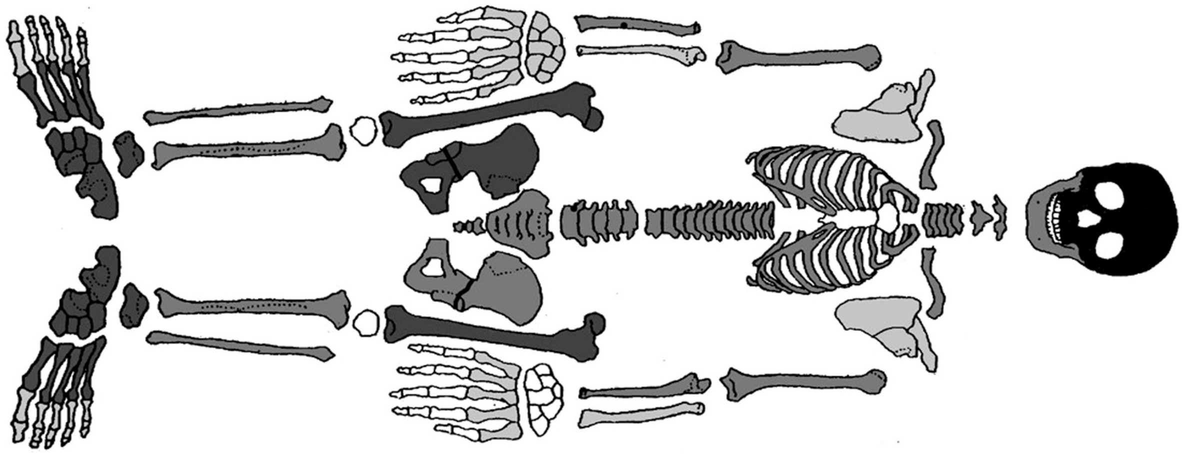

Fig. 5. Numbers of recovered skeletal elements in 21 forensic remain cases (n = 16 individuals). Recovery rate increases with darkness. Even if only a bone fragment was found, the entire bone was coloured. Spine sections were used rather than individual vertebrae. No hand or foot bones were counted bilaterally.

Table 2
Summary of taphonomic aspects in the 22 forensic remain cases and in ten of these from altitudes above 2000 m.

Taphonomic alteration	Forensic remains (n = 22)	Forensic remains recovered over 2000 m altitude (n = 10)
Soft tissue (wet)	6	4
Soft tissue (desiccated)	7	4
Adipocire	5	4
Moss	3	0
Algae	0	0
Plant roots	0	0
Sun bleaching	1	1
Adhering sediment/ humus	2	1
Thermal impact	2	0
Insects/insect casings	4	1
Animal scavenging	7	2
Bone degreased	1	0

the population density (203 people per km^2) are rather low compared to worldwide data [52–54]. This can explain the small case number deriving from investigative authorities in relation to our other anthropological work in archaeological sciences, for instance. Furthermore, medico-legal examiners deal with skeletonised remains themselves, without systematically investigating the bones [6,33]. However, the qualitative assessment of largely skeletonised remains might suffer or left as "undeterminable" when examined by osteologically unexperienced examiners, as also stated by Rhine [6], Cunha and Cattaneo [5] and Kranioti and Paine [3]. In addition, bone finds are directly handed over for genetic analyses with the aim of identification without a prior anthropological examination. Due to the destructive nature of genetic testing, this procedure can destroy information for PMI or trauma assessments, that might have been detected during anthropological examination.

4.2. Year and season of finds

In general, our cases seemed to increase slightly during the past years. A review by Ubelaker [25] includes bone cases from 1938 to 1969, also with an increasing caseload over time. Other authors noted increasing numbers, too [15,16,24,28], while Skinner [17] finds that historic cases increase and recent ones decrease. We think that our increase may be due to a better knowledge of the FA discipline overall and knowledge about the anthropological department in the IRM of Bern. Further, the continuous melting of the glaciers releases increasingly

Fig. 6. Human cranium of forensic interest (PMI = 11 years) found on forest ground with moss growth and adhering leaf litter on the inferior aspect (skull base).

remains of anthropological interest [36]. This also applies to the Swiss Alps as stated by Lösch et al. [33], and is reflected in our data. The majority of our high altitude cases accrued during the years 2017–2020, suggesting that the number of remains from snow or ice covered high altitudes will further increase in the future.

Discoveries of our FA cases occurred mostly during the warm seasons, from March through August, and least often from December through February. This should be true for entire Switzerland since surfaces are often covered with snow in winter, especially in high altitudes. The elevated caseload during warmer months might therefore, be explained by season-related outdoor activities. In addition, snow and leaf litter cover during fall and winter lead to less readily observable skeletal remains (see also [21] Komar 2003). Seasonal patterns were also found in Florida, US and Hamburg in Germany [18,28]. Komar [21] noted no relation between season and number of cases in Mexico, while

Grisbaum and Ubelaker [19] report contrasting results for Washington D.C., with May (spring) and November (fall) having the highest caseload. In addition, Nawrocki [55] states that the discovery of remains in forested areas is most likely during months when the vegetation foliage is low. We argue that the differences between the studies occur due to catchment area-specific environments, including climate and weather conditions in particular.

4.3. Finders

The main finders in our survey were walkers and mountaineers. This goes along with the season of recovery (warmer months) and the depositional environment (outdoors, especially forests and mountains). Only two of the consulted literature included the finder in their survey. Grisbaum and Ubelaker [19] report that there were only information about finders in 40% of their cases: outdoor recreationists accounted for around a third of the finds. Nieberg [28] found construction workers and walkers to be the most frequent finders within her urbanised catchment area. This differs from our study with most cases from rural and suburban regions.

4.4. Depositional environments

The distribution of depositional environments in outdoor forensic remains roughly correlates with the order of geographical properties of the canton of Bern, except for the grass surfaces. This may be explained by the better visibility of bodies on grass, which leads to discovery during early decomposition stages. The larger number of mountain cases compared to forest cases might be explained by the better visibility of remains lying in the open, low vegetation landscapes of high altitudes. Nieberg [28], whose area covers an urbanised region, reports most finds (including archaeological remains) as buried and found during construction works or in gardens.

4.5. Recovery rates

The representation of the recovered skeletal elements is rather poor overall. The skull and the right femur are the bones most often recovered, similar to results from Tennessee [15]. We reason that because most of the population recognises a human skull and because of the relative size of both skeletal elements. Smaller bones such as carpals, patellae, phalanges, hyoid and the sternum were least likely recovered, probably due to their size and lower recognition value. We explain the difference between carpals/hand phalanges and tarsals/foot phalanges by several shoe finds where foot bones were protected from scattering. Another explanation for our poor recovery rate could be that in some cases, no further search mission was conducted after the main portions of a body were recovered. These cases might exhibit higher recovery rates when structured searches are conducted, as shown by Pokines et al. [56].

4.6. Particular preservation features

Desiccated soft tissue remnants, as well as adipocere in various quantities were mostly found on remains from high altitudes (Fig. 7). Adipocere is known to form in wet environments, which indicates that ice and snow around the body were melting at some point, see also [36,57]. Adipocere remnants were reported in several other glacial human remains as well [36,37,58,59]. However, some of these studies noted excellent tissue preservation, which was mostly not present in our cases. This might be due to the circumstance that medico-legal examiners deal with the remains when a considerable amount of soft tissue is present and they were not handed over to our department. Bones recovered at high altitudes were always greasy. The PMI estimation of remains in glacial environments is particularly difficult, as the example of Ötzi, the "prehistoric Iceman" showed. His mummy was treated as a missing mountaineer at first, before he was dated back to about 5200 years ago [60]. This example as well as forensic cases show the need for research in PMI estimation of human remains from glacial environments.

Postmortem animal scavenging has been noted in several other reviews, too. The frequency in our FA cases is higher than the South African example [26] with three cases (4.8%), but similar to the 27% reported by Komar [21], although, her sample size consisted of 596 cases from New Mexico, with apparently other environmental conditions as well as different animal species. Ubelaker and DeGaglia [50] present a survey of 714 FA cases from the US where animal activity was present in 15%. Because of our small data set and our moderate representation, we think it is not useful to perform an evaluation of preferred anatomical regions or the severity of scavenging. However, we found gnawing marks created by rodents as well as carnivores (Fig. 8). Dispersal was always present in the scavenged cases and not solely explicable by topography, which suggests the involvement of animal dispersal agents.

4.7. Postmortem intervals (PMI)

Our forensic remain cases often involve remains with a relatively long PMI of several months to years. Grisbaum and Ubelaker [19] at the Smithsonian Institution in Washington D.C. note 66.2% of the cases having a PMI of less than 10 years. In addition, Komar [21] reports contrary results for New Mexico; the majority of her reviewed cases had a PMI of 1 week or less. We explain this dichotomy with the routine that medico-legal examiners without the involvement of FA mostly handle cases with such short PMIs in Switzerland. Indoors, almost full skeletonization was noted in case no. 12 with a PMI of 1 month during August. Outdoors, excluding the burnt cases no. 14 and no. 19, the case with the shortest PMI exhibiting almost full skeletonization was case no. 55, recovered in an alpine environment after 10 months of exposure between fall and spring. The latter individual was recovered at altitudes of approximately 2100 m, showing preservation of soft tissue remnants due to the cold temperatures. However, it only comprised of single limb bones with lesions from animal scavenging. Both factors might have had accelerated decomposition and explain the short interval for skeletonization, especially since animals have a higher need to scavenge in winter [61]. In particular, we assume that the body must have laid uncovered by snow in the first and later period. In five other cases (no. 1, 31, 34, 45 and 58), a complete foot skeleton with some adhering soft tissue was found preserved within socks and shoes (Fig. 9). One of these cases (no. 58) was recovered in a forest, the other four in high altitudes. We observed, that lower limb bones can be widely skeletonised within 10 months (limb bones) to 2 years (feet in shoes) in Alpine Switzerland.

4.8. Identifications

Our identification rate is very high and all identifications were finally confirmed by molecular genetics. Some of our identified individuals were inhabitants of Switzerland, some were tourists or had a migration background. Komar and Potter [62] report a decreasing identification rate correlating with low recovery rates for New Mexico, US. However, even when in our cases only parts (e.g. lower leg plus foot) were found, an identification was successful. We explain this by good DNA preservation and in most cases, investigative authorities already presumed whom the remains might belong to, leading to a direct genetic comparison. In addition, cases in the American Southwest include large numbers of unknown and undocumented border crossers [57], a circumstance that is comparably negligible in Switzerland. We also noted that molecular genetic analysis is a standard procedure for identification in forensic contexts in Switzerland, which might not be possible (e.g. due to missing reference data, financial and time issues) in other countries or scenarios, e.g. [57], thus explaining lower identification rates. identification rate of 41% reported by Bass and Driscoll [15] might be due to the times the study was done, when molecular

Fig. 7. Human remains recovered from a high altitude glacier environment. Note the adipocere formation and the commingling of the bones.

genetics were not as established yet in forensics as it is today.

4.9. Age-at-death and sex

Males account for about 90% of our forensic remains, while there is only one female (4.6%) in our sample. Preponderances of males have also been observed by Nieberg [28] in Hamburg (including historical remains, 70% males and 30% females), by Komar [21] in New Mexico (76.3% males and 22.4% females), by Marks [16] in Tennessee (ca. 55–75% males), by in Florida (46% males, 33% females, 21% unknown),by Grisbaum and Ubelaker [19] in the Smithsonian Institution (58.1% males, 32.5% females), by Kendell et al. [23] in Chico (43.3% males, 28.9% females) and by Brits et al. [26] in South Africa (60.3% males, 27% females). Furthermore, in our survey all six identified persons recovered from high altitudes were males. Several aspects might be the reason for this male overrepresentation. First, males outnumber females by 60–40% when investigating accidents, suicides and violent deaths in Switzerland, especially between 15 and 44 years of age (years 2000–2017) [63]. Second, the imbalance of sexes in the high altitude cases may be explained by a higher readiness to assume a risk attributed to males, as stated also by Faulhaber et al. [64]. Further, Zürcher et al. [65] analysed hiking fatalities in the Swiss Alps in the Canton of Bern between 2003 and 2018 and found more male victims, below (73%) as well as above (82.5%) 1800 m, too.

Regarding age-at-death, the age category 20–30 years holds the majority of casualties in our survey (50%), similar to Komar [21] with most cases in this age range (25.8%). note peaks in young adults (19–34 years) and middle-aged individuals (35–60 years). Marks [16] reports

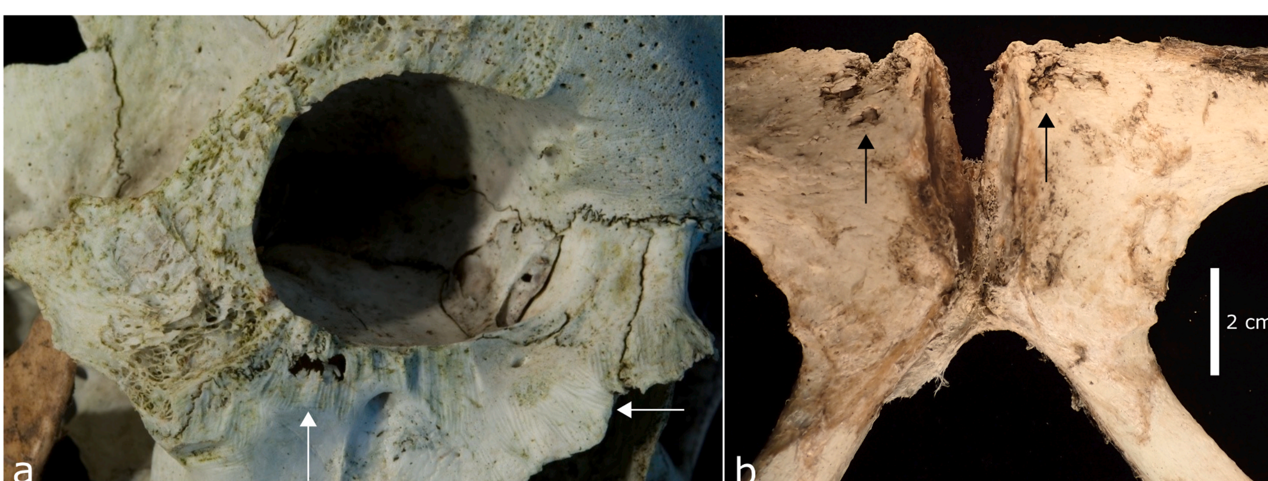

Fig. 8. Animal scavenging on surface deposited human bones. Example (a) shows rodent gnawing (white arrows) around the right orbital and the nasal aperture, example (b) presents carnivore tooth impressions (black arrows) on the posterior-superior aspect of the pubic bones.

Fig. 9. Two examples of articulated foot bones within socks after we removed the shoes, recovered in high altitudes. Example (a) shows the skeletonised talus in the sock entrance and insect larvae on the fabric, example (b) shows soft tissue remnants and adipocere, the toes point towards the bottom right.

the peak between 30 and 39 for males and less than 20 years for females in Tennessee cases.

In our sample, no juveniles below 18 years are present; however, one estimated age between 15 and 25 years might be an exclusion thereof. This is contradictory to studies from the Smithsonian Institution with 15% under 18 years [19], New Mexico with 12% under 20 years [21], Chico with 10.4% subadult [23] and Tennessee with maximum 10% of the individuals below 20 years [16]. Juveniles do account for a low proportion of the cases in these studies; however, the non-appearance in our survey is atypical. The lack of juveniles is also seen within the Swiss death statistics, showing that less than 0.8% of the population dies below 15 years in average [63]. Our results might also be explained by the negligible amount of undocumented (young) border crossers in Switzerland compared to other countries, in particular New Mexico [57, 66].

4.10. Trauma

Compared to our survey, other studies show similar or slightly higher amounts of perimortem trauma: Grisbaum and Ubelaker [19] report them for 38.4% and Komar [21] for 58% of their individuals. However, both their sample sizes exceed ours by far. On the contrary, the sample of Brits et al. [26] present 45 cases (71.4%) with mainly antemortem trauma. In the Alps of the Canton of Bern, 77 fatal hiking accidents were recorded from 2003 to 2018 by the forensic examiners of our institute, all of them caused by a fall from heights [65]. The main causes for traumatic deaths during mountaineering in the Austrian Alps between 2005 and 2012 were cardiovascular emergencies (46%) and different kinds of falls (44%) [67]. Both studies as well as the fracture pattern observed emphasise that some of the trauma in our mountain cases also result from fall impacts, even when we did not receive the entire skeleton for analysis. Fig. 10 presents two cases recovered in high altitudes, exhibiting perimortem bone fractures possibly resulting from a fall. The postmortem damage in most cases was probably due to the depositional environment (e.g. falling stones in high altitudes or glacial load [36]) or animal scavenging.

5. Implications for the future

There is potential for evolvement of the discipline FA in Switzerland. In the context of this survey, we found some issues that should be addressed in future FA casework and research. For example, several regions are not covered by any expert of the field currently. In addition, there is the need for more knowledge in FA, in particular concerning Switzerland's environmental, climatological and topographic conditions. This is true for casework as well as for applied research, e.g. in the field of taphonomy. There is also a need to standardise the data collection and analysis process within and between institutes, nationally and internationally, as also stressed by Alfsdotter [68]. This addresses e.g. the methodology, the recording of taphonomic alterations and nomenclature thereof. In addition, because of the low representation of the remains, more references on sexing and ageing of bones infrequently used for these purposes are needed for contemporary populations. In addition, we recommend that FA practitioners work in bioarchaeology as well to consolidate their experience and knowledge. Besides these needs, two main issues arose:

First, even though the completeness of the skeletons did not affect our identification rate, this is often the case [62]. For the reason of identification, ethical considerations and the interpretation of trauma (cause of death) and taphonomy (time since death), it is important to recover all remains. Further, an intensive search of the region after the recovery of an incomplete skeleton would save the efforts of additional investigations at later stages, as we have encountered. Conducting a search when confronted with incomplete remains has frequently been stressed in the literature as well, e.g. [8,55,69]. Various approaches are suggested for different surface terrains, e.g. a visual foot search in line, grid or spiral patterns [8].

To overcome the fact of our incomplete FA skeletons, we need more knowledge about decomposition, disarticulation and dispersal processes of remains especially in forests, hiking regions, high altitudes, glacier environments and relevant ecosystems, for example by controlled experiments. Currently, eight human taphonomy research facilities exist, distributed in the US (n = 6), Canada (n = 1) and the Netherlands (n = 1) [70]. Most of their environments are not compatible with environmental variables in Switzerland, especially in the high altitudes. To our knowledge, there is currently only one newly established research facility investigating taphonomy in high altitudes in Colorado, US [71].

As mentioned above, we recommend further improvements in search strategies. For instance, experienced practitioners, e.g. physical anthropologists, should be involved in systematic searches for scattered human remains. Ideally, they have knowledge in dispersal processes (including animal ecology) and documentation of scattering, as well as archaeological or police search methods [42]. Several publications point out the advantages of searchers that are trained in osteology and/or postmortem scatter processes, e.g. [2,8,51,55,72–74]. Also, informing the searchers about the taphonomic changes that are to be expected, such as weathering and animal scavenging, enhances the search success [8,69]. Since glacial environments constitute special circumstances, knowledge of their types and movements is important to retrace the scatter pattern as well [36].

Second, the challenges of estimating the PMI are widely known because current methods are still relatively sparse and often insufficient, see e.g. [5,45,75–77]. Anthropologic-morphologic PMI estimations are challenging, especially when the remains are skeletonised, altered through postmortem damage or when recovered in high altitudes with cold temperatures, freezing and thawing events. Research and case studies on taphonomy and PMI estimations are increasing, although, few

Fig. 10. Perimortem fractures in skeletons of forensic interest, both recovered from high altitudes. Example (a) shows a perimortem fracture of the left lateral *Os cuneiforme*, possibly resulting from a fall, example (b) presents a perimortem incomplete fracture of the left lower margin of L4, also possibly due to a fall from height.

particularly address high altitudes and glacial circumstances, e.g. [36,37,59].

In practice, a proper estimation of a PMI into (pre)historic times beforehand will help avoiding cost via genetic testing later on. For forensic purposes, the PMI and the correlated decomposition state is important when conducting searches for presumably dead missing persons [38], but also for checking alibis of potential perpetrators and to include or exclude potential missing persons within the identification process. This is especially true if a molecular genetic identification is not possible or not performed.

Retrospective research involving longitudinal studies of casework is important for establishing and validating PMI estimation methods. Experimental research should be used additionally to gain knowledge about decomposition processes, but also for testing identification methods under certain circumstances and to train forensic practitioners [36,70,78].

6. Conclusions

Our 10-year survey of FA-cases in Switzerland is one of only few worldwide, whereas most of the others were conducted in the US. Because the field of FA is still young, retrospective studies can be of great aid in future cases, since they provide information that cannot be obtained experimentally. Our survey points out issues in casework that should be addressed in future cases and research to enhance the quality and credibility of FA expertises and subsequently the number of cases transferred to anthropologists. Compared to similar studies, this survey is unique because of its cases recovered from altitudes above 2000 m, as well as the multiple recoveries of the same individuals over the course of years. Both aspects are associated with mountains and glacial environment of our catchment area. This retrospective study further highlights the need for more research in the fields of taphonomy, especially PMI estimations and dispersal processes.

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Conflict of interests

We declare that we do not have any conflict of interest.

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