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Strategies for the identification of the missing: a review of the contributions of forensic anthropology and forensic dentistry

Rui Filipe Libânio Osório Marta

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STRATEGIES FOR THE IDENTIFICATION OF THE MISSING: A REVIEW OF THE CONTRIBUTIONS OF FORENSIC ANTHROPOLOGY AND FORENSIC DENTISTRY

Dissertação de Candidatura ao grau de Mestre em Medicina Legal submetida ao Instituto de Ciências Biomédicas de Abel Salazar da Universidade do Porto.

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To the Missing and their families

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"To him that will, ways are not wanting."

George Herbert

Abstract

The world is facing a truly unprecedented humanitarian crisis due to the widespread increase in the number of missing persons and unidentified bodies. Several circumstances contribute to this harsh reality, which includes people who have gone missing or died on migratory routes (“the new disappeared”), national and international conflicts, and other large-scale disasters. The forensic investigation into these includes an effective search and identification process of persons (alive or dead), to ultimately clarify their fate and whereabouts. Human identification is a complex and challenging task, but also one of the most dignified in the field of forensic sciences. Identification is crucial for legal, administrative, ethical, and humanitarian reasons, including providing answers to the families and the community, and thus reducing uncertainty and suffering. The process of forensic identification is based on a comparative exercise between all the relevant information on the missing person (often referred to as antemortem data) and all the relevant information on the unidentified remains (often referred to as postmortem data), to determine their level of compatibility or discrepancy.

The overall aim of the present work was to conduct a narrative review of the roles of forensic anthropology and forensic dentistry in the identification of missing persons/unidentified bodies. In particular, the focus of this research was to review published case reports and research studies on the use of identifiers by both disciples in the comparative method towards identification.

Both forensic anthropology and dentistry have witnessed important developments and have made important contributions to resolve missing persons’ cases worldwide. Nonetheless, the successful application of methods and techniques of either of them is not without limitations. The role of forensic dentistry is a well-established, reliable primary method of identification. However, challenges namely related to the conditions in which the remains are often found, as well as the lack of antemortem comparative data or a poor postmortem examination have instigated the search for scientifically sound alternatives. The so-called secondary methods, particularly deriving from the forensic anthropology examination have proven to be valuable contributors towards identification. Together, anthropological and dental identifiers, when adequately identified, documented and interpreted, provide two strong lines of evidence, increasing significantly the potential of success of the forensic human identification process.

Keywords: anthropological identifiers; dental identifiers; antemortem; postmortem; DVI; humanitarian forensic action

Resumo

O mundo enfrenta uma verdadeira crise humanitária sem precedentes devido ao aumento generalizado do número de pessoas desaparecidas e de corpos não identificados. Várias circunstâncias contribuem para esta dura realidade, incluindo fenómenos migratórios, conflitos nacionais e internacionais, e outros desastres em larga-escala. A investigação forense de pessoas desaparecidas ou não identificadas consiste num processo de procura pelos desaparecidos e identificação de indivíduos (vivos ou cadáveres), de forma a clarificar o seu destino e paradeiro. A identificação humana é uma tarefa complexa e desafiante, mas também uma das mais dignificantes no campo das ciências forenses. A identificação de uma pessoa é fundamental por razões legais, administrativas, éticas e humanitárias, o que inclui dar respostas às famílias e à comunidade em geral, contribuindo para o alívio da incerteza e do sofrimento associados. O processo forense de identificação humana é baseado num exercício comparativo entre toda a informação disponível e relevante sobre a pessoa desaparecida (frequentemente designada de informação *antemortem*) e toda a informação sobre os restos mortais não identificados (informação *postmortem*), de forma a determinar o seu nível de compatibilidade e discrepância.

O objetivo geral desta dissertação consistiu na realização de uma revisão narrativa das contribuições da antropologia forense e da medicina dentária forense para a identificação de pessoas desaparecidas ou corpos não identificados. Em particular, o foco desta investigação centrou-se na revisão de casos de estudo e estudos de investigação publicados que se debruçaram sobre a utilização de identificadores tanto antropológicos como dentários no método comparativo, visando a identificação.

Tanto a antropologia forense como a medicina dentária forense têm sofrido desenvolvimentos significativos e, desta forma, contribuído para a resolução do número cada vez maior de pessoas desaparecidas ou não identificadas. No entanto, a aplicação bem-sucedida de métodos e técnicas de qualquer uma das disciplinas tem limitações. O papel da medicina dentária forense está bem estabelecido enquanto método primário de identificação. Contudo, fatores como as condições em que os restos humanos são frequentemente encontrados, assim como a ausência de informação antemortem comparativa ou um exame postmortem incompleto têm instigado a procura por alternativas fiáveis e cientificamente testadas. Assim, os designados métodos secundários, particularmente a antropologia forense, têm provado ser um contributo valioso para a identificação. Os identificadores antropológicos e dentários, utilizados de forma complementar, adequadamente identificados, documentados e interpretados, fornecem duas fortes linhas de evidência, aumentando significativamente a probabilidade de sucesso do processo de identificação humana forense.

Palavras-chave: identificadores antropológicos; identificadores dentários; antemortem; postmortem; reconciliação; ação humanitária forense

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List of Abbreviations/Acronyms

AAAS	American Association for the Advancement of Science
ABFO	American Board of Forensic Odontology
AFIS	Automated Fingerprint Identification System
AM	Antemortem
AMD	Antemortem Data
CDDIs	Clinically Detectable Dental Identifiers
CMP	Committee on Missing Persons in Cyprus
CONADEP	*Comisión Nacional sobre la Desapareción de Personas*
CT	Computed Tomography
COVID-19	Coronavirus Disease 2019
DNA	Deoxyribonucleic acid
*mt*DNA	Mitochondrial Deoxyribonucleic Acid
*nu*DNA	Nuclear Deoxyribonucleic Acid
DVI	Disaster Victim Identification
EAAF	*Equipo Argentino de Antropología Forense*
FASE	Forensic Anthropology and Society of Europe
HFA	Humanitarian Forensic Action
ICMP	International Commission on Missing Persons
ICRC	International Committee of the Red Cross
ICTY	International Criminal Tribunal for the Former Yugoslavia
ICTR	International Criminal Tribunal for Rwanda
IFRC	International Federation of Red Cross and Red Crescent Societies
IHL	International Humanitarian Law
IHRL	International Human Rights Law
INTERPOL	International Criminal Police Organization
MP	Missing Person
MPD	Missing Person Data
MRI	Magnetic Resonance Imaging
MSCT	Multislice Computed tomography
NGO	Non-governmental Organization

OMPF	Office on Missing Persons and Forensics
PAHO	Pan American Health Organization
PASWG	Pathology and Anthropology Sub-working Group
PM	Postmortem
PMD	Postmortem Data
PMCT	Postmortem Computed Tomography
RFID	Radio-frequency identification
SNPs	Single Nucleotide Polymorphisms
STRs	Short Tandem Repeats
SWGANTH	Scientific Working Group for Forensic Anthropology
UN	United Nations
UNMIK	United Nations Missions in Kosovo
UP	Unidentified Person
UPD	Unidentified Person Data
WHO	World Health Organization

Chapter I – Introduction

1.1. Who are the missing?

The issue of missing persons is probably one of the greatest crises the world faces today. A true tragedy which, in the United States, the National Institute of Justice has called "*the nation´s silent mass disaster*" due to the ongoing and ever-growing numbers of missing persons (Ritter 2007). However, this is not a single nation problem, but a worldwide problem that demands for a global response. Although the issue of missing persons has not always been a priority, over the last two decades it was brought to the spotlight, notably thanks to the work carried out by some international organizations, such as the International Committee of the Red Cross (ICRC), the International Commission on Missing Persons (ICMP) and the Committee on Missing Persons in Cyprus (CMP), which dedicate their efforts to resolving the missing.

According to Morewitz (2016), missing persons are individuals who have gone missing and their location and fate are unknown (Morewitz 2016). However, there are several contexts in and reasons for which people disappear, which might require a differentiated approach according to circumstances. Anyone, regardless of gender, age, ethnicity, social or educational background may become a missing person. And from this point of view, Warrington (2012) stated that "*(o)ne of the tragedies of missing persons is that it does not discriminate; it is universal. It crosses race, age, gender and class*" (Blau 2016; Warrington 2012). Indeed, this tragedy affects all people from all geographical areas, making it a phenomenon of global proportion.

According to the ICRC, a missing person is someone "*whose whereabouts are unknown to his/her relatives and/or who, on the basis of reliable information, has been reported missing in accordance with national legislation in connection with an international or non-international armed conflict, a situation of internal violence or disturbances, natural catastrophes or any other situation that may require the intervention of a competent State authority*" (ICRC 2007). This definition is an important one as it is broader in scope than the notion of disappeared persons, by including other situations such as mass disasters and the context of mass migration, and thereby ensuring that the rights of the missing person and the needs of their families are protected (Londoño and Signoret 2017). This is only made possible by framing the issue of missing persons under important international laws (Gaggioli 2018; ICRC 2003a).

Natural and man-made disasters are responsible for the mass disappearance of people (Beauthier et al. 2009; Cipolloni et al. 2019; Ranson 2015), as well as are contexts where interpersonal violence is involved, such as past wars, current armed conflict, interethnic conflicts, and state and political motivated violence (Crettol et al. 2017; Puerto and Tuller 2017). Some particular contexts where people have gone missing is that of forced disappearances, deaths in custody, or that of victims of summary or extrajudicial executions (Crettol et al. 2017). Enforced disappearances are particularly common in internal conflicts, through political repression by governments or by armed opposition groups. For instance, around 30,000 people were abducted victims by the military regime during the last dictatorship Argentina between 1976 – 1983. Since 2011, the Syrian conflict claimed around 82,000 victims of enforced disappearance, and the numbers are even higher in Sri Lanka with about 60,000 to 100,000 people being victims of disappearance, since the 1980s (Amnesty International 2021). Implemented in 2006, the International Convention for the protection of all Persons from Enforced Disappearance (CED 2021), was adopted to promote universal respect for, and observance of, human rights and fundamental freedoms, based on the Universal Declaration of Human Rights. Under the latter, enforced disappearance was defined as "*the arrest, detention, abduction or any other form of deprivation of liberty by agents of the State or by persons or groups of persons acting with the authorization, support or acquiescence of the State, followed by a refusal to acknowledge the deprivation of liberty or by concealment of the fate or whereabouts of the disappeared person, which place such a person outside the protection of the law"* (CED 2021).

The rising number of persons who go missing around the world is worrisome, and it is an issue hard to tackle mainly due to the wide range of causes behind it. This increase has been associated with the consequences of global warming, increased levels of migration, internal displacement, conflict, and many other causes. Over the past year and a half, the coronavirus disease (COVID-19) has become a global and serious threat, particularly with regard to management and disposition of bodies (Kumar and Nayar 2020). The systems' responsiveness to this mass fatality incident was clearly stretched and overwhelmed the mortuaries (Entress et al. 2020), increasing the probability of new disappearances. In fact, this topic has not received enough attention. Additionally, the investigation process related to the missing is experiencing serious difficulties due to the suspension of searches due to the mobilization and economic constraints caused by COVID-19 pandemic, which results in additional uncertainty for the families (ICRC 2021b; ICRC 2021c).

Consequently, there are a number of answers to the question why people go missing. Firstly, people may disappear voluntarily. Usually, this group of people create a new life or social identity to escape a crime committed, financial difficulties, and such. Moreover, children and young people may run away from their home or a care institution to avoid unfavorable and conflicting contexts (Morewitz 2016). In addition to children and young people, there are other at-risk groups of going missing which include people with mental illnesses, such as depression, suicidal ideations, elderly with dementia and those living with an intellectual or physical disability or without lifesaving medication (Morewitz 2016). A distinct group refer to those missing involuntarily. These can represent victims of foul play/crime such as kidnapping, homicide, domestic violence, and consummated death threats. Additionally, people can also disappear involuntarily due to an accident or misadventure. Ethnic, religious and/or political violence, human rights violations (including historical deaths), and human trafficking are also known important drivers of people going missing. Large-scale disasters, including natural (e.g., hurricanes, tsunami) and man-made mass disasters (e.g., terrorism, armed conflict, genocide) are known to lead to high numbers of missing people in affected areas (Blau 2016). Lastly, the complex and global phenomenon of migration has been responsible for mass fatalities and disappearances. Indeed, people can go missing at any point on their journey, and the causes can range from natural calamities or catastrophes, to shipwrecks, but can also be the result of crimes that may include human smuggling and human trafficking, arbitrary executions and massacres, as well as enforced disappearances (Hinkes 2008; Puerto and Tuller 2017).

1.2. The impact of the missing

The phenomenon of missing persons has a wide impact on their families and the community at large. Indeed, no matter why a person goes missing, in every case the missing person's family suffers immensely, not just emotionally but physically, financially, and socially until they learn the status of their loved one. The absence of information about the fate and whereabouts of their loved ones puts their lives on hold, and with increasing anguish and uncertainty, as time passes the struggles are only amplified. Consequently, the right to know and the right to justice are the most pressing needs of the missing and their families (Crettol and La Rosa 2006).

According to Boss (2000), the families of the missing often face a stressful type of loss called "ambiguous loss", which is described as an unclear loss with no official verification of life or death and thus, no closure (Boss 2017). The lack of facts to clarify whether their loved one is alive or death, or if dead, where the remains are located causes great suffering to the families. An ambiguous loss means the absence of a proof of death (physical proof) and, so, there are many doubts about the fate of the lost person, causing endless and long term-pain. Even society itself (i.e., the law, religious institutions, and the larger community) sometimes leaves families alone in this grief because "*the family's loss is often not* *considered "real" as it would be with a verifiable death"* (Boss 2017). Briefly, ambiguous loss may cause psychological damage (e.g., preventing the processes of coping and adaptation) and sociological damage (e.g., disrupting the family's structure and function). Individuals, families and their communities are all affected by this stressor (Boss 2017). Recent studies identified this traumatic experience (ambiguous loss) in families of Mexican missing migrants who have died or disappeared along the US-Mexico border (Crocker et al. 2021), as well as in transnational Mexican immigrant families (Solheim et al. 2016). It is in this way clear that, to face this traumatic process, the families of the missing and the community should receive psychological support based on therapeutic approaches (Boss 2017).

Additionally, the establishment of a close relationship between families and the authorities ensures, not only a needed emotional support, but also the exchange of information for the benefit of the investigation. Families can provide important information on the circumstances of the missing person's disappearance, as well as samples of the biological family members closely related to the missing person for potential identification. The forensic identification of human remains brings psychological and social benefits (e.g., reparations, compensation, life insurance, or state support after confirmation of death) to the families. In some cases, there is also a further need to meet certain cultural requirements, for instance, related to the need to pay proper respects in death after families receive the remains of their missing loved one. The family's wishes and the overall process of finding, recovering and identifying a missing person can be more easily fulfilled when there is a collaborative relationship and an open dialogue between the families and the authorities (Kim et al. 2016).

1.3. The missing in Humanitarian Forensic Action

The concept of Humanitarian Forensic Action (HFA) was first introduced by Morris Tidball-Binz, at the time the head of the Forensic Unit of the ICRC, in a speech in 2012 (Tidball-Binz 2012). There, he appealed to the humanitarian need to care for the dead, protect their dignity and prevent them from disappearing, as well as relieving the suffering of families (Moon 2020; Tidball-Binz 2012). Put simply, HFA can be defined as the application of forensic science to humanitarian endeavors, especially following natural disasters and man-made crises (Cordner 2018; Cordner and Tidball-Binz 2017). The latter may embrace various scenarios, such as: armed conflicts, war crimes, human migration, and terroristic attacks, which can be characterized as mass fatality events.

Forensic work has primarily played a role with legal objectives, i.e., the science at service of the law, mainly with a prosecutorial aim. However, with HFA there is a departure from the classic forensic intervention to include a humanitarian aspect, particularly associated to a dignified management of the dead and their return to families (Moon 2020). The aim of humanitarian action has always been one to support people affected by natural and man-made disasters, specially to save lives, alleviate suffering and maintain human dignity during crises. HFA, on the other hand, extends these notions to the dead and their families. Currently, HFA is seen as specific field of application of forensic sciences, where the forensic community can play a key humanitarian role regarding the care for the dead and their families, including protecting their human dignity and identifying them, as well as taking care of the survivors and allow the return to normality, which also implies the replacement of basic services (Cordner and Tidball-Binz 2017; Vieira 2018).

Additionally, Moon (2020) refers to HFA as "*a new and particular form of the death management*", applying the concept of "*extra-ordinary deathwork*" inspired by Walter (2005) who had previously developed the concepts of "*deathwork*" and "*mediator deathwork*". Despite the distinct and extraordinary character of HFA, Moon (2020) notes that there are characteristics and a social significance in common with more common forms of deathwork.

According to Vieira (2018), HFA must be guided by a set of core principles: humanity, impartiality, neutrality, and independence, overriding any political, economic, and military objectives. HFA should also be free of charge and framed under International Humanitarian Law (IHL) (also known as '*the law of war'* or '*the law of armed conflict'*), which provides the legal framework in armed conflict situations (Pantuliano 2014; Vieira 2018). Another important source of legal obligations is the International human rights Law (IHRL), which applies as much in times of peace as during war, as well as in natural disasters or internal disturbances where IHL does not apply*.* Indeed, both IHL and IHRL are complementary sources of law with the aim to protect lives, health, and human dignity (Gaggioli 2018; ICRC 2003a). Concerning the management of dead bodies, Gaggioli (2018) summarized the various legal obligations in six key duties: (1) the obligation to search for and collect the dead; (2) the humane treatment of the dead, which implies treating them with due respect, including the prohibition of mutilating dead bodies and the obligation to prevent the dead from being despoiled; (3) the return of human remains and personal effects of the dead; (4) a respectful disposal of the dead, which implies to respect the dignity and religion of the dead as well as the possibility of returning dead bodies to their families, at a later stage; (5) the accounting for the dead, including identifying them; and, finally, (6) the obligation of accounting for missing persons, including collecting and identifying them in order to provide answers, specially, to their families (Gaggioli 2018). Put simply, both legal frameworks come to place to ensure that the dead are treated with dignity and to prevent the phenomenon of missing persons, as well as to clarify the fate and whereabouts of those who do disappear (Romanowsky and Chau 2020).

Another term which has also been applied to the relationship between the forensic and humanitarian domains is 'forensic humanitarianism' (Moon 2013; Moon 2014; Moon 2020). Moon (2020) suggests that HFA and forensic humanitarianism tell different stories about the field, however complimentary. As such, forensic humanitarianism is presented as "a distinctive variant of humanitarianism" and the result of the convergence of four different and historical pathways: humanitarian, legal-humanitarian, political and scientific (Moon 2014). According to Moon (2014), the main purpose of forensic humanitarianism is to provide answers about the identity and cause of death of victims associated with state crimes and violent conflicts, as well as allowing the return of the dead to their families and provide evidence to legal trials for crimes committed. The similarities between these two terms are undeniable and one wonders about the need to distinguish them.

Historically, the investigation of the Katyn forest massacre in Poland, in the early 1940s, corresponds to the pioneering event in the use of forensic skills, namely forensic pathology, during an humanitarian crisis, and in the course of an investigation of a mass execution (Moon 2014; Raszeja and Chróścielewski 1994). Later, the Nuremberg (1945-1946) and Tokyo (1946-1948) trials were important milestones in the investigation of crimes against humanity and genocide, opening doors to forensic science in the investigation of human rights abuses, though not exclusively based on humanitarian purposes. However, it took until the 1980s to see the emergence of the foundations of HFA and forensic humanitarianism, according to Tidball-Binz (2020) and Moon (2014), respectively. In the aftermath of the military regime which ruled Argentina from 1976 to 1893, thousands of people were victims of forced disappearance. The action of families, especially the non-governmental organization *The Grandmothers of Plaza de Mayo*[1] (also known *The Grandmothers*), and, later, of the *Comisión Nacional sobre la Desapareción de Personas* (CONADEP) was responsible for the arrival of a delegation of forensic scientists to the country. The first step in the formation of the Argentine Forensic Anthropology Team (*Equipo Argentino de Antropología Forense* – EAAF) was made in 1984 (EAAF 2021). With support from the American Association for the Advancement of Science (AAAS), including training and professional advice from Dr. Clyde Snow, a notable American forensic anthropologist, the EAAF was a pioneer in the investigation of human rights violations using

[1] *Abuelas de Plaza de Mayo* – a non-governmental human rights organization dedicated to the search for children who were disappeared or who were born in captivity.

forensic anthropological methods and techniques. The work carried out by the EAAF served as a model for other countries in South America and beyond, and up to this date continues to provide reference work in the field. Interestingly, *The Grandmothers* were also pioneers in the use of forensic genetics to help identify their missing relatives and instigated the creation of the world's first national genetic databank (Berra et al. 1988; Penchaszadeh 1997). The humanitarian character of the work of *The Grandmothers*, and later from EAAF, was different from what had happened so far. More than providing reliable evidence for establishing criminal responsibility, there were well-defined humanitarian purposes such as solving the cases of missing persons, treating the dead with dignity, helping to identify them, and informing the families about the fate and whereabouts of their missing relatives (Tidball-Binz 2020). This paradigm shift is at the core of HFA, which privileges human identification.

The political changes that took place in the 1980s and 1990s in various regions (e.g., Latin America, Eastern Europe, and South Africa) also contributed to the proliferation of forensic sciences in the humanitarian field supported by several legal and institutional developments, including the following:

- The first United Nations (UN) Resolution on Human Rights and Forensic Sciences by the UN Commission on Human Rights (1992).
- The *Minnesota Protocol* (or Manual on the Effective Prevention and Investigation of Extra-legal, Arbitrary and Summary Executions (1989) by the UN. In 2017, a new edition was published titled "The Minnesota Protocol on the Investigation of Potentially Unlawful Death (2016)".
- The *Istanbul Protocol* (or UN Manual for the investigation and documentation of torture) (1999).
- The Interpol's General Assembly recognized the universal right to be identified after death (1996).
- The establishment of the International Criminal Tribunal for the Former Yugoslavia (ICTY) by the UN Security Council (1993) followed by the International Criminal Tribunal for Rwanda (1994).
- The creation of ICMP at the initiative of US President Bill Clinton at the G-7 Summit in Lyon, France (1996), which only formally achieved intergovernmental organization status in 2014. The ICMP was a pioneer in the use of high-through-put DNA-analysis and advanced database informatics for large-scale investigations of missing persons in the Former Yugoslavia (Cordner and Tidball-Binz 2017; ICMP).

- The United Nations Missions in Kosovo (UNMIK) created the Office on Missing Persons and Forensics (OMPF) in 2002 to resolve the problem of missing persons and deal with the needs of their families (Baraybar et al. 2007).

Further, the ICRC was responsible for the paradigm shift regarding humanitarian intervention, greatly influenced by the humanitarian consequences of the breakup of the Former Yugoslavia regarding missing persons. The 2003 Conference on The Missing and their families (ICRC 2003b) was a step forward in the attempt to resolve the problem of people unaccounted for as result of armed conflict or internal violence and to assist their families. It was clear then that every effort needed to be made to identify the remains, which includes observing and recording all information potentially relevant, attending to the rights and needs of families as well as acting in compliance with the legal provisions (Cordner and Tidball-Binz 2017; Thomsen 2017). The 2003 conference provided a set of recommendations about the recovery, management, and identification of the dead in armed conflicts and other contexts (Cordner and Tidball-Binz 2017; ICRC 2003b). The abovementioned developments led to the creation of the ICRC's first forensic unit in 2003, which has contributed to the development of HFA.

The manual titled "*Management of Dead Bodies after Disasters: A Field Manual for First Responders*" (ICRC et al. 2006) is a good example of work done by the ICRC in collaboration with the Pan American Organization (PAHO), the World Health Organization (WHO) and the International Federation of Red Cross and Red Crescent Societies (IFRC). This guidance, which complements the INTERPOL Disaster Victim Identification (DVI) (INTERPOL 2018) generally applied to small and medium sized disasters, filled a significant gap related to the management of a high number of deaths (also taking into account the identification process), as happened in the 2004 Indian Ocean Tsunami (Cordner and Tidball-Binz 2017).

In conclusion, HFA has a broad field of intervention, including but not limited to the management and identification of dead bodies in a post-conflict situation or mass disaster. Other phenomena such as gender and sexual violence, child and elder abuse, human trafficking (Buś et al. 2019; Obertová and Cattaneo 2018), torture (Pollanen 2018), ill treatment in cases of detention, mass graves, as well as the estimation of the age of living individuals, all require the action of forensic experts, in particular forensic anthropology, forensic odontology, forensic genetics, forensic pathology, and clinical legal medicine (Cordner and Tidball-Binz 2017; Vieira 2018).

1.4. Forensic investigation into the missing

Regardless of the causing event, the large-scale loss of life and disappearances of people are frequent outcomes, affecting the whole community and society. In addition to the social and cultural breakdown, the response from the medical-legal system is often overwhelmed, exceeding local capacity, which in some cases leads to the need for external, international forensic help. Thus, the management of forensic investigations into missing persons is particularly complex and challenging, including in most cases the process of search and recovery of bodies, the identification of unidentified bodies and sometimes the collection and analysis of evidences for legal purposes (Puerto and Tuller 2017; Tidball-Binz 2006).

Indeed, forensic sciences became one of the main drivers of social reconstruction in areas affected by mass violence or disaster. Its contribution is much more than a discipline integrated in a stable domestic medical-legal system, which responds to the needs of the law, particularly on the collection of criminal evidence and human identification. In this type of more complex scenarios, the forensic investigation may take two legal forms: humanitarian (based on the clarification of the fate and whereabouts of a missing or unidentified person) and/or criminal (based on the search for criminal accountability or a truth and reconciliation-based process). Nevertheless, an incorrect procedure can have negative consequences in terms of right to truth and access to justice for families and communities. The legal framework for the investigation must be clear and explicit, allowing families and the community to cooperate with the process without fear of reprisals or criminal prosecution, as happens in cases of search for criminal accountability or truth (Citroni 2019; Puerto and Tuller 2017).

To avoid socio-political problems and the application of incorrect procedures, any investigation must be legally framed, and its aims defined from the start. It is necessary to define whether the investigation has a humanitarian framework (locate and identify the victims), or a criminal prosecution framework (ascertain criminal responsibilities), or just an adjustment of historical records (reconstruction of recovery of the historical memory). In either of these contexts, at national or local levels, it is important to establish the proper legal framework specifically regarding the applicable law on information-gathering, data management and protection, the process of recovery and identification of the remains, the rights of the victims/families, and finally the sources of financing and budget. In fact, one of the major challenges can be the prescribed economic, political, and time constraints, which can seriously affect and limit the investigation and its purposes. Because there is no single and ideal model for all scenarios involving missing persons, as each context and event presents different challenges, an adaptative approach is necessary (Puerto et al. 2021;

Puerto and Tuller 2017). Further, the ICRC states that the search for missing persons must be participatory which means involving the families of the missing persons and/or their representatives, ensuring answers to the needs of families/relatives and community (i.e., to know the fate and whereabouts of their loved ones) and an exchange of information (Crettol et al. 2017; Tidball-Binz 2006). To assure the efficient management of the issue at hands, it is utterly necessary that competent humanitarian, political, judicial, and non-judicial mechanisms at the universal, regional, national, and local levels exist, with constant communication, prioritizing the needs of the families and communities involved (Crettol et al. 2017).

Regarding the forensic approach to the search, recovery and identification of the missing, Puerto and Tuller (2017) highlights several complex factors to take into account, which include the number of people assumed to be missing compared to the number of people actually missing; the demographic and personal characteristics of the missing people; the number of victims recovered; the circumstances and time when events took place; whether it is a closed, open or mixed incident; the condition/state of preservation of remains recovered; the degree to which remains are disarticulated and scattered or commingled; the timing at which forensic experts take over the investigation; the availability and type of antemortem (AM) information and reference samples; the financial resources; and the local forensic capacity to implement the identification process (Puerto et al. 2021; Puerto and Tuller 2017).

Briefly on the context of the event (i.e., type of case), its scale (number of missing people or deaths) and complexity will determine the methodological approach in the search for missing persons and identification of unidentified bodies. Particularly in armed conflicts or human rights violations, political and social factors exert a lot of influence on the complexity of the case. The assessment of the number of missing persons is also a challenging task, particularly in situations of enforced disappearance or migration contexts (Blau 2016). Frequently, families do not report the absence of family members because they are afraid of causing troubles to the missing. The common procedure is based on the construction of a compiled or unified list of victims, in which a unique file number is assigned to each person for quantification and case traceability purposes. This list eases the intra- and inter-institutional communication, reduces the possibility of duplication, as well as the recording, traceability, and comparison of information (Puerto et al. 2021; Puerto and Tuller 2017)

As for the scale of the event, a comprehensive approach is needed, which includes a well-defined strategy covering operational plans, intra- and inter institutional coordination (governmental and non-governmental entities), draft and implementation of standard operating procedures, the creation of multidisciplinary forensic teams, the availability of temporary morgues to process a great number of bodies, the centralization of information (centralized databases), specialized equipment and software (for genetic analyses) and support centers for relatives (Crettol et al. 2017; Puerto et al. 2021; Puerto and Tuller 2017).

Regarding the investigation of complex cases of unidentified bodies and human remains, which often involve commingled and highly fragmented remains (e.g., mass burials, tsunamis, plane crashes), a set of important steps are required, namely a strategy of coding and analysis of commingled remains, the adjustment of protocols and procedures, the creation or improvement of databases (involving enhanced traceability controls), the structural organization of the facilities for the analysis of remains in terms of space, the sampling strategy for genetic testing, the genetic matching strategy for both identification and reassociation of commingled remains, statistical genetic match thresholds for identification and reassociation purposes, and prior probability values (Puerto and Tuller 2017; Tidball-Binz 2006).

The cultural and religious beliefs and practices that involve the treatment of the dead can be an additional challenge for forensic practitioners. Undoubtedly, the cultural needs of the affected people must be respected, and all experts involved in the investigation must be aware of their customs and traditions. In this sense, multiple solutions within an adaptative approach must be found and put in place to embrace the diversity of cultural, religious, spiritual, and societal practices around the death. This may involve contact with governments, cultural leaders, and family groups (Kinsella and Blau 2013).

Another important challenge to consider in the investigation process, has to do with the fact that large-scale events generate massive amounts of information, which requires a multidisciplinary and integrated approach to the processing and systematization of such information. The management of “relevant information” (i.e., information that is reliable and pertinent) is paramount and includes AM information on the missing persons, information about the circumstances of the disappearance or of the event, potential location of the graves, and postmortem (PM) information of the unidentified bodies (Crettol et al. 2017). Currently, the use of missing persons databases (including but not limited to forensic DNA databases) provides an important support to the investigation, regarding the process of integration and centralization of information, and its role in the cross-referencing. Over the past few years, some important databases have been established, namely the Phoenix Program (Lorente et al. 2001), the National Missing and Unidentified Persons System (NamUS) (Murray et al. 2017), the Texas Missing Persons DNA database, the Victorian Missing Persons DNA Database (Hartman et al. 2015), the Banco Nacional de Datos

Genéticos (BNDG) Argentina (Estado argentino 2021), the Missing Person Database-gen (Da Silva et al. 2009), and the ICMP iDMS – Identification Data Management System (ICMP 2021b).

Depending on the context, the chosen approach to the forensic investigation process, including the choice on most appropriate identification methods and techniques, are decided by the head of the forensic team. The responsibility to ensure that families and the community at large are well and fully informed about the limitations and any issues associated with the forensic investigation is an important one, to minimize unrealistic or false expectations. The interaction with the families and communities can be complex, which requires a holistic communication strategy. This relationship is essential to the process, including a meaningful and thorough AM data collection, after a well-defined framework for the search, recovery and identification process is put into work.

Chapter II – Research Aim and Objectives

2.1. Overall objective

Forensic Anthropology and Forensic Dentistry are two disciplines within forensic sciences that are often applied, together or independently, in the process of forensic human identification. Both have witnessed important developments and made important contributions to resolve the ever-higher number of missing persons cases worldwide. Nonetheless, the successful application of methods and techniques of either of them is not without limitations. The overall aim of the present dissertation was to develop a narrative review of the roles of forensic anthropology and forensic dentistry when applied to the identification of missing persons/unidentified bodies. In particular, the focus of this research was to review published case reports and research studies on the use of identifiers by both disciplines in the comparative method towards identification.

2.2. Specific objectives

To achieve the above research goal, the following specific objectives were proposed:

- To understand the phenomenon of missing persons and unidentified bodies and to identify the need for urgent reliable, scientifically sound strategies regarding their personal identification.
- To recognize the various challenges to the forensic human identification process, including in disaster victim identification.
- To review the application and contribution of anthropological and dental identifiers to forensic human identification, by reviewing recent, published and peer-reviewed literature, including case reports and research studies.
- To evaluate and identify the main challenges and limitations regarding the successful application of anthropological and dental identifiers in achieving identification, namely by identifying the difficulties in the reconciliation of AM and PM data.
- To identify the main obstacles and present recommendations for the practice as well as for future research efforts in relation to the use of alternative identifiers.

Chapter III – Methodology

This literature research was based on the review of the current state of the art on the process of human identification, as well as published case reports and research studies on the use of identifiers by both disciplines in the comparative method towards identification of missing persons/unidentified bodies.

A narrative review was undertaken. Published articles were initially located by searching the WEB OF SCIENCE, SCOPUS, and PUBMED electronic databases. A Boolean search strategy was used with the following keywords, or combination of keywords: '*missing persons*, *forensic anthropology*, *forensic dentistry*, *human identification*, *antemortem data*, *postmortem data*, *reconciliation*, *humanitarian forensic action*, *disaster victim identification*, *database*'. After the initial search, reference lists of relevant articles or other published studies were scanned for any additional articles that were not discovered during the initial search.

The inclusion criteria were the access to the full version and articles written in English, Portuguese, or Spanish and published in a peer-reviewed journal. The exclusion criteria were studies performed in non-human animals, and identification by techniques other than forensic anthropology and dentistry. Altogether 74 publications were considered relevant, which includes case identifications (73), and research studies (20).

Chapter IV – Forensic Human Identification

4.1. The process of Human Identification

Human identification (or personal identification) has proven to be one of the most challenging and relevant tasks in the field of forensic sciences (Nikam et al. 2015). The definitive and early identification of corpses and human remains is of utmost importance in a properly structured medico-legal death investigation, regardless of the context (Holobinko 2012). Thus, personal identification is crucial regarding legal issues (criminal and civil concerns), as well as social, ethical, and humanitarian ones. Legally, issues such as inheritance or succession of property, payment of insurance obligations, remarriage, issuance of a death certificate, and the investigation and resolution of a crime are dependent on the identification process. Ethically, personal identification is crucial to assist those who survive, that is the families and the community at large who want to mourn and close a chapter. It is also required to fulfill the obligations of the international humanitarian law and to uphold human rights, as it is the families right to know the fate of missing relatives (Cattaneo et al. 2010). Furthermore, all human beings have the right to their personal identity, not only in life which begins with the right to life, as promoted by the international law through a range of declarations and conventions (e.g., Universal Declaration of Human Rights, UN Convention on the Rights of the Child), but also after death (Marshall 2014).

Although the term “human identification” is used consistently to refer to the identification of dead bodies, it is also applied to the identification of the living (e.g., missing persons cases, vulnerable minores without the presence of an adult or legal guardian, among others). Regarding specifically to medico-legal investigations of death, there are three wide categories where establishing the identity of the deceased is a requirement, namely: criminal investigations resulting from a homicide, suicide, or unexplained natural death; accidents and mass disaster incidents, which can be a result of forces of nature or human origin, either accidental or intentional; and war crimes and genocide, where international law plays a key role in protecting those involved (Black 2006). Usually, the medico-legal authority or law enforcement officer is responsible for the confirmation of personal identification, as well as the issue of a death certificate. However, there are situations in which forensic experts (e.g., forensic anthropologist, fingerprint examiner) take over the identification process (Christensen and Anderson 2017).

From the point view of disaster victim identification, biometrics, and forensic science, the term identity refers to biological aspects of human identity (of the living or the deceased) (Black 2006). More precisely, the term identity refers to the set of physical (e.g. sex, age, stature, tattoos, scars, malformations, biotype), functional (e.g. locomotion, writing, sensory functions), or psychic (e.g. personality traits, intelligence) characteristics, either normal or pathological, that defines an individual (Nikam et al. 2015). All the characteristics listed above and their particularities – individualizing traits – make the individual unique and allow to differentiate them from others. Thus, biological criteria must be unique, unchanged, and perennial. Basically, in the realm of forensic sciences, individualizing traits provide a sustainable basis for identification, based on the assertion that the probability of having another individual with the same set of characteristics is practically null. On the other hand, the term identification refers to the act of establishing that identity (Black 2006). The process of identification involves several proceedings using techniques and methods to obtain a personal identity. Its main purpose is to achieve individuality (Black 2006; Gowland and Thompson 2013). Wrongly, the term identification is also often used as a synonym for visual recognition, which consists of an empirical and subjective "identification" without any scientific thoroughness, as opposed to the human identification process.

Furthermore, identification methods are based on the comparison of AM (of a missing person) and PM (of an unidentified individual) data (i.e., all available information related to the case) in a process known as reconciliation. According to Páez (2020), AM information corresponds to all the data collected from sources in a technical way that identifies and characterizes a person, before disappearance or when alive; in turn, PM information refers to all the data collected from the corpse or human remains subjected to a medico-legal autopsy, including other complementary exams (Páez 2020). The choice and success of the identification methods depend on the PM condition of the body, as well as on the availability, quantity, quality of AM information about the missing or the deceased (Christensen and Anderson 2017). According to Interpol identification guidelines, the identification must consider circumstantial findings (clothes, personal belongings, and so on), as well as findings from external examination (physiognomic traits, fingerprints, and so forth), and the means of PM examination (clinical, dental, DNA data). However, each local jurisdiction determines how each deceased is identified and what means are applied (De Boer et al. 2020a). In fact, currently, there is no consensus amongst the forensic community regarding the categorization of personal identification, i.e., the degree of confidence and reliability of a specific identification method or rationale (Cattaneo and Gibelli 2013; Christensen and Anderson 2017). Since there are different identification methods, there are also different identification categories characterized by particular attributes that correspond with a level of certainty (Holobinko 2012). Usually, the identification hierarchy encompasses the following levels (Christensen and Anderson 2017; Holobinko 2012):

- Tentative identification: there is a suspicion of identity based on circumstantial materials and associated items.
- Presumptive identification: there are strong consistencies between the deceased and the missing person, but which require the inclusion of additional identification features.
- Positive identification: there is a confirmation of the uniqueness of the individual's features (i.e., individualization). For such, DNA, fingerprints, and medical/dental records are key elements in conjunction with other features such as the biological profile, skeletal anomalies, tattoos, scars, personal effects, among others.
- Identification by exclusion: most used in mass fatality situations with a 'closed' population when all other persons have been identified and there are no factors inconsistent with identification.

A recent hierarchy proposed by Puerto et al. (2021) includes only three categories: identification, exclusion and inconclusive. The authors reject the use of subcategories for identification (presumptive, circumstantial, possible, probable, positive, etc.) because they introduce doubts from the point of view of decision theory.

Unfortunately, it is not always possible to achieve the purpose of the identification process. Over the last years, the phenomenon of migration, particularly in the Mediterranean region (Hammond 2015) and at the United States-Mexico border (Hinkes 2008; Spradley 2021) has resulted in thousands of dead migrants, of which many of the recovered bodies remain unidentified. A significant and dramatic tragedy was the Lampedusa shipwreck, on October 3rd, 2013, off the Italian coast, which caused 366 victims (number of bodies recovered), of which only 31 victims were identified according to non-genetic biological methods (facial/anthropological/odontological methods) and DNA (Olivieri et al. 2018). The difficulties in the identification process in these contexts are related to the lack of the appropriate strategies for data collection (at times, there is no possible PM and/or AM data), as well as the lack of national and international investment in dealing with these situations (Olivieri et al. 2018). Already in 2010, Cattaneo and colleagues drew attention to the growing problem of unidentified bodies and human remains across Europe, which has serious implications from the social to the medico-legal field, as well as to the need to find immediate but lasting solutions (Cattaneo et al. 2010). Even more worrying is the lack of knowledge and records concerning the frequency of unknown decedents in several European countries (Cattaneo and Gibelli 2013; Cattaneo et al. 2010). There is, of course, a need for an international approach to address the problem of unidentified human bodies across borders, whose numbers have increased with the increase in migration flows (Duijst et al. 2016). As put by Duijst et al. (2016), *“(t)here is significant amount of scientific literature about identification methods, but very little articles are written about the process identification”*, which reflects what the focus should be from now on and what strategies should be pointed out to face the challenges of the identification process. Because more than knowing and applying the methods, identification is only possible when there are AM and PM data that can be compared.

Unequivocally, the process of human identification involves a multi- and transdisciplinary approach, which requires a rigorous coordination of different information from several scientific disciplines including forensic pathology, anthropology, dentistry, radiology, genetics, among other disciplines. Therefore, the choice of the identification method to be employed depends on each specific context. Only a holistic and multifaceted approach will meet the needs of the identification process, for which the experts should choose and apply the most reliable, cheapest, and fastest method for each specific case. Regarding deceased individuals, the state of preservation of the human body and the consequent greater or lesser availability of individualizing features, as well as the quality and quantity of AM information determines the success of the identification or the exclusion of identity (Blau et al. 2021).

PM changes, including immediate alterations (e.g., loss of voluntary power, cessation of respiration and circulation), early changes (e.g., eye changes (*tache noir*), primary flaccidity, rigor mortis, hypostasis, cooling of the body) and late changes (e.g., putrefaction, mummification, saponification, skeletization), as well as alterations caused by predators or other external factors (e.g., dismemberment, dispersal, erosion), result in an unidentified body which can range from a well-preserved corpse, to skeletal or badly burnt remains. Each will present different challenges to the forensic experts. When death is recent and the human body is still fresh with enough evidence available, the personal identification is usually a straightforward process; however, the PM changes due to decomposition or injury, or both, can hinder the identification. In these cases, the individualizing information is mostly provided by the soft tissues (Christensen and Anderson 2017), which requires a general description of the body (external examination) regarding sex, age, stature, hair color and length, eye color and other distinguishing features such as congenital formations (e.g., cleft lip), sequelae of traumatic injuries, congenital or acquired dermal traces (e.g., warts, scars, nevi) and personal adornments (e.g., piercing, tattoos).

Frequently, in most countries, recent and well-preserved bodies are readily visually “identified”, although visual recognition is a controversial issue. The recognition process is usually performed by a relative or an acquainted person in routine situations (Caplova et al.

2018). As a mean of identification, however, it presents low reliability and high risk of misidentification due to the influence of biological and emotional factors (Caplova et al. 2018; Goodwin et al. 2009), given that the basis of recognition is the human memory (Hautzinger 2005). A member of a crew was visually misidentified by another crew member not aboard based on comparisons of AM and PM photographs after a ferry accident in Estonia (1994) (Soomer et al. 2001). Similarly, after Bali bombings in 2002, nine victims were visually misidentified by relatives (Griffiths et al. 2003). Clothes and personal belongings (e.g., jewelry, footwear, identification documents), on the other hand, can also be recognized (Cattaneo and Gibelli 2013; Christensen and Anderson 2017). Nonetheless, this method of identification has been applied in mass disasters, as happened in Thailand after the Boxing Day tsunami, where 560 of the 5395 recovered bodies were visually identified by their families (Wright et al. 2015). Currently, comparison and superimposition of facial features is used in some contexts, although there are important limitations in its application (e.g., the lack of a standardized manner of comparison between two images, the lack of criteria of admissibility and the lack of knowledge about error rates) (Mallett and Evison 2013). The comparison of two profiles based on morphological features can lead to an exclusion or an identification, but this too is a controversial method. Current methods based on physical appearance (human face and body) concerning deceased persons were recently reviewed by Caplova et al. (2018). All features were classified into four categories: simple visual recognition, identification based on specific facial/body areas (lip prints, facial creases, ears), soft biometrics (tattoos, moles, scars, and iris and face matching) and, finally, AM/PM dental superimposition. While there is no doubt about the individualizing character of these features, the authors stressed the need to establish applicable techniques and protocols based on tested, reliable, and accurate methods (Caplova et al. 2018).

In addition to the personal descriptors presented above, the identification by fingerprint analysis (i.e., comparison of friction ridges or fingerprints, or dactyloscopy) is a more reliable and scientific method of identification. Due to its individualizing capacity, the probability of two individuals that have identical fingerprints is extremely remote, even in homozygous twins (Daluz 2018). However, AM records are needed for comparison, which can be available through criminal records or a civil database. In Portugal, there is a civil database that can be used for criminal purposes, in a regulated manner, and there is a AFIS (automated fingerprint identification system) system. Databases such as AFIS have played an important role regarding the automatic recognition and checking of fingerprints in order to achieve an identification (Moses 2010).

When it comes to the identification of a skeletonized, decomposed, dismembered, or badly burned body, the expert faces a much more complex and challenging task. In these cases, fingerprint analysis is often hampered by the decomposition processes (putrefaction, mummification, corification, saponification) or by PM factors (e.g., fire). Usually, putrefaction and saponification are characterized by conditions of humidity, while in carbonization and mummification there is dehydration of the tissues. Both conditions induce changes in the epidermis and/or dermis, which require the application of specific procedures and treatments (chemical and physical techniques) to attempt to recover the papillary design (Chen et al. 2017; Kahana et al. 2001; Morgan et al. 2019). Nevertheless, with PM changes some features can become more easily visible such as scars and tattoos. In relation to tattoos, after the loss of stratum corneum (the horny outer layer of the epidermis) and its sliding, the chromatic components become more prominent and help the visualization of tattoos (Simpson and Byard 2009). The information contained in certain tattoos may provide valuable information about the decedent's history, such as military tattoos in service personnel, rudimentary line tattoos with antisocial and anti-police messages in ex-prisoners, among others (Byard 2013).

In such cases, for example where fingerprint identification is not possible, anthropological and odontological methods can play a key role in personal identification. Due to greater resistance and durability to taphonomical agents compared to other tissues of the human body, bones and teeth are valuable sources of information.

Generally, the available techniques and methods used for human identification can be categorized as reconstructive or comparative, which can be used in isolation or concomitantly (Pinchi et al. 2012; Silva et al. 2013). In the reconstructive method, without AM records, biological data is extracted from human remains to generate a biological profile, guiding the collection of AM data and narrowing the search for potential victims. On the other hand, the comparative method is based on the comparison of AM and PM records in order to achieve an identification (Silva et al. 2013). Especially in the cases of extensively decomposed and/or skeletonized human remains, forensic anthropology and dentistry can directly contribute to human identification, by assessing a variety of anatomical features and by radiographic comparison (or related imagery) with AM data; or by providing additional information that contributes, together with other lines of evidence, to achieve an identification (Ubelaker et al. 2019a). Both reconstructive and comparative phases can be applied in the same case. Firstly, the reconstructive phase is characterized by the establishment of biological profile (i.e., sex, stature, age at death, and other relevant anatomical landmarks); then, during a comparative phase, this information is used for comparison with the AM data from reported missing persons, all after a proper recovery and detailed documentation of all evidence. According to the context, other significant tasks are performed by the forensic anthropologist such as the determination of whether the remains are in fact human, the assessment of skeletal trauma (ante-, peri- and post-mortem trauma), the identification of the spatial-temporal relationships between the bodies and associated evidence, if the remains are commingled and the number of individuals present (Blau 2017; Stanojevich 2012). Simultaneously, a careful dental examination can also provide valuable information about person's age, sex, and stature, as well as anatomical references for personal identification (or exclusion) (Cattaneo et al. 2006).

Undeniably, DNA molecular analysis is the most popular method of identification. In the last 30 years, the fast technological developments in DNA research have revolutionized the field of forensic human identification. The individuality is provided by differences found in the human genome, so the probability of having two people with the same DNA profile that are not identical twins is very small. DNA techniques for forensic purposes are based on the analysis of mitochondrial (mtDNA) and nuclear DNA (nDNA). Maternally inherited (no recombination), mtDNA has a lower power discrimination and is less polymorphic than nDNA (nDNA undergoes homologous recombination (i.e., maternal and paternal DNA are mixed)). However, mtDNA has an excellent sensitivity and success with limited or badly damaged samples due to large number of mtDNA molecules per cell and the fact that the small mtDNA molecule is more robust than nuclear DNA. Regarding nuclear DNA analysis, short tandem repeats (STRs) loci are the most studied polymorphisms in forensic identification. Nevertheless, there are other sources of variation in the genome that can be applied in a forensic context, such as MiniSTRs and single nucleotide polymorphisms (SNPs) (Pinheiro 2010).

Genetic analysis is based on the comparison of a suitable PM sample with a reference sample from the individual (if available, or from first-degree relatives) or from personal items containing DNA (e.g., toothbrush, hairbrush, shaver, clothes, and other personal belongings). Currently. it is possible to obtain a DNA profile from all types of biological traces, even when they are found in very small quantities or very degraded. DNA sampling and extraction is more difficult in a body in an advanced state of decomposition or skeletonized, due to less availability of biological sources and greater vulnerability to contamination. In this sense, some studies have shown which bone elements ensure greater availability and quality of DNA, such as the lower limb bones (Mundorff et al. 2009) and smaller cancellous bones of the hand and foot (Mundorff and Davoren 2014). DNA testing can be performed even on cases involving partial or severely decomposed remains. It is the best way to identity body parts, and its analysis can be automated ensuring maximum quality and rapidity of high-volume testing (INTERPOL 2018).

The process of DNA analysis to identify human remains includes the following steps (ICRC 2009): (1) the collection, storage and extraction of DNA from the human remains, (2) DNA sampling from either relatives of the missing person or from sources belonging to missing person (e.g., hair, saliva stains, or other biological material) for comparison, (3) getting a DNA profile from both the human remains and reference samples, (4) comparison of both DNA profiles, and (5) presentation of the degree of matching (ICRC 2009). The quantification of the degree of matching of two biological samples, which includes a statistical analysis of the frequency of discrete characters, allows to show the numerical probability of both samples belonging to the same person. This is a clearly advantage over the other identification methods (Cattaneo and Gibelli 2013). Nevertheless, DNA is not the answer for all problems. It is still quite expensive and time consuming, although the use of forensic DNA databases is speeding up the identification process. At the same time, if a previous narrowing of the potential missing persons, for example, through other investigative methods is not achieved there will be no samples to run the genetic profile comparisons. In fact, a current challenge is related to the absence of AM biological samples for comparison in particular contexts. In the case of illegal immigrants, there may be no suitable relatives for DNA comparison or personal items may not be available. In addition, the comparison process becomes more complex, and the results may not be enough if reference samples are provided by cousins or half-siblings rather than close relatives (De Boer et al. 2020a).

4.3. Disaster Victim Identification

A particular context where forensic human identification plays a crucial role is largely referred to as Disaster Victim Identification (DVI), which refers to a set of procedures used to identify victims after a mass fatality incident. According to the INTERPOL DVI guide (INTERPOL 2018), a widely recognized and accepted reference, "*a disaster is an unexpected event causing the death of many people",* which can be classified as open disaster, if the number and identity of victims involved is mainly unknown (e.g., Asian tsunami in 2004, world trade center tragedy) or a closed disaster, if the number and identity of victims are more readily known through a fixed and identifiable group (e.g., aircraft crash with passenger list), or even a combination of both (e.g., aircraft crash in a public area). Regardless, there is no consensus on the minimum number of fatalities that constitutes a mass disaster, and there are several and challenging contexts in which the DVI process is applied, such as natural disasters (e.g., earthquakes, tsunamis, hurricanes), traffic or any transport related accidents (e.g., aircraft, train, ship), technical accidents (e.g., fires, explosions), terrorist attacks (e.g., chemical, biological, radiological, nuclear or high yield explosive attacks), or events occurring within the context of wars or humans rights violations (Brough et al. 2015). A correct classification and characterization of a disaster is crucially for the DVI approach that follows, as each mass disaster is a distinct and challenging event. Large scale disasters, which affect thousands of people and, sometimes, more than one country, are increasingly prevalent but other mass fatality events such as illegal migration (e.g., in Mediterranean region, Sub-Sahara Africa, at the US-Mexican border and in Australasia) and terrorist attacks present new challenges for DVI. In relation to the countless deaths caused by mass migration, the mains challenges are related to the lack of AM data (or even a missing persons list), as well as the need to integrate PM data from different countries. To overcome these difficulties, a collaboration between all forensic and humanitarian entities and governments is needed, as well as the search for alternative identification methods due to the impossibility of using traditional methods. In the case of terrorist attacks, the DVI process is secondary due to the criminal nature of the event. Therefore, criminal investigators should work together with DVI teams in order to ensure that the crime scene is approached correctly (De Boer et al. 2019).

Based on the importance to treat disaster victims with respect and dignity, identifying them and supporting the grieving process of the families and the community at large, INTERPOL developed a set of specific guidelines (INTERPOL 2018), recommendations, protocols, and international standards for a DVI operation, which are globally recognized but are not mandatory. From its first publication in 1984, INTERPOL DVI has promoted uniformity and effectiveness as well as international cooperation in the victim identification process. The DVI guide also recommends to all member countries the setup of one or more DVI teams in order to achieve, maintain and improve standards, and facilitate international cooperation (which enables the exchange of information between the intervening organizations). These teams are also responsible for pre-planning and training (INTERPOL 2018). The INTERPOL guide encourages interdisciplinary work based on a collaborative approach between different scientific disciplines (e.g., pathology, forensic anthropology, forensic dentistry), as well as open communication, respect, and honesty (INTERPOL 2018). Additionally, DVI guide is regularly reviewed and updated based on the lessons learned from many disasters throughout the world as well as the advancements in victim identification techniques (Sweet 2010b).

The process of identification in the aftermath of a mass disaster can be a slow and very complex process, depending on the context, number of deaths, degree of body destruction and fragmentation, rate of human decomposition, and the availability of AM data related to missing persons (Brough et al. 2015). Especially in the case of large-scale disasters, the

Interpol DVI guide is complemented by the manual "*Management of Dead bodies after disasters: A Field Manual for First Responders" (ICRC, et al. 2006)*, which offers practical guidelines for non-specialists/non-experts on how to handle human remains after a mass fatality. This guidance for first responders promotes a proper and dignified handling of the dead, ensuring that they are later identified by forensic specialists. The manual covers the essential aspects of managing the death in aftermath of a mass fatality as well as contains data collection forms, checklists, practical recommendations, useful additional information and links (Ellingham et al. 2016).

The DVI process as proposed by INTERPOL includes four main phases, each with its own area of responsibility and coordination. These phases are described as follows:

Phase 1 - Scene: should be treated as a crime scene following jurisdictional policies and procedures. It is characterized by the processing (photograph, record, and label) of human remains and property at the disaster site, after the definition of a management plan, which depends on the nature of disaster. INTERPOL DVI recovery forms should be used to record the post-mortem information.

Phase 2 - Post-mortem: after the recovery, storage (and preservation) and transportation of human remains and property to the mortuary, there is a detailed and thorough examination of all material collected in the scene, as well as the record of all relevant PM information on the pink INTERPOL DVI Post-Mortem forms. Photography, radiology, DNA sampling, autopsy procedures are some of the examination processes and methods applied in this phase.

Phase 3 - Ante-mortem: includes a challenging collection of missing person data from various sources (e.g., interview with families, relatives or friends, clinical records), after the definition of a missing person list. Detailed descriptions of each missing person or potential victim, including specific details (e.g., jewelry, clothing, dental and medical records, photographs, DNA, fingerprint) should be collected and recorded on a yellow INTERPOL DVI ante-mortem form. At this phase, there should be concerns about AM data protection from distant locations.

Phase 4 - Reconciliation: this phase takes place at the Reconciliation Centre and it is characterized by the comparison of PM data with AM data in order to identify the deceased. The identification depends on the existence of reliable identifiers and whether the requisite standards are met. After the identification, a death certificate confirming the cause of death and the identity of the deceased is issued by the Identification Board.

Although the Interpol DVI guide presents only four main stages, some authors argue that the final stage is a debrief, referred to as phase 5, with the purpose of developing new strategies and protocols in order to improve the capacity of all agencies to respond and resolve future incidents (Bassed and Leditschke 2011; Blau and Briggs 2011; De Boer et al. 2019).

Regarding to identification methods, the INTERPOL DVI protocol distinguishes between primary methods of identification, which includes dental comparison, fingerprints analysis, DNA analysis, and medical/surgical implants with numerical information (serial numbers), and secondary methods of identification such as personal descriptors, medical information, clothing, jewelry, tattoos, and other circumstantial evidence. Primary identifiers provide a reliable identification of the deceased, either individually or in combination, based on the most reliable scientific methods. On the other hand, secondary identifiers are, according to INTERPOL, "not sufficient to be used as sole means of identification and cannot be standalone to prove identity of disaster victims" (INTERPOL 2018). Often, they are used to complement the primary methods; nevertheless, when primary sources are limited or absent, the combination of secondary methods may provide information to achieve identification (Khoo et al. 2016). Indeed, both primary and secondary identifiers can be equally relevant depending on each context (De Boer et al. 2020a).

Identification of the living who survive a mass fatality is also an important element in any DVI response. For instance, in the case of an open disaster, the identification of survivors allows to promptly narrow the missing persons list. The collection of medical information of survivors can help on identification purposes. The identification of the survivors together with the identification of the deceased can ensure that the identification process does not stall due to lack of information.

4.3.1. The role of forensic anthropology and forensic dentistry in DVI

The role of forensic anthropology (Blau and Briggs 2011; De Boer et al. 2019; De Boer et al. 2020b; Hackman and Black 2017; Mundorff 2012; Park et al. 2009; Wiersema and Woody 2016) and forensic dentistry (Forrest 2019; Hill et al. 2011; Toupenay et al. 2020; Wood and Kogon 2010) in DVI process has been a topic of research and discussion in the literature over the last years. Usually, the variability of extreme forces (e.g., heat, impact, crushing, explosion, freefall and/or environmental influences) involved in a disaster results in serious damage and profound changes in the condition of the human body. As a result, practitioners involved in the location, recovery and analysis of victims are faced with several states of preservation, including intact, fairly intact, decomposed, fragmentary, commingled, burned, or cremated bodies, as well as partially burnt, distorted, buried or a combination of these states of preservation. Consequently, this range of differentially preserved skeletal remains justifies the intervention of the forensic anthropologist and the forensic dentist in the DVI process (Blau and Briggs 2011; De Boer et al. 2019). After the 2004 Boxing Day Tsunami, arguably the largest and most complex international DVI response, the role of the forensic anthropologist in DVI has become even more relevant. Currently, the inclusion of forensic anthropologists in the INTERPOL Pathology and Anthropology Sub-Working Group (PASWG) is a clear recognition of the roles and responsibilities of the forensic anthropologist for DVI. Table 1 summarizes the most common functions of the forensic anthropologist according to each phase of DVI process.

Dental identifiers are one of the most reliable identifiers appointed by INTERPOL (INTERPOL 2018). The role of forensic dentist is based on the comparison of AM and PM dental profiles in order to support identification. However, the success of the identification process depends on the availability and quality of AM dental records (e.g., written dental records, dental radiographs, computerized tomography (CT) data, 3D surface scan date, dental study models, dental appliances, clinical photographs, or photographs showing smiling faces), which is not always the case. The lack of dental records or their poor quality, particularly in countries with low socioeconomic status, limits the intervention of forensic dentistry in DVI operations (Forrest 2019). A systematic review of the role of forensic odontology in the identification of victims of major mass disasters across the world was presented by Prajapati et al. (2018), emphasizing the role of forensic dentistry in disaster victim identification, namely, when AM records from general dental practitioners are available.

Table 1. The role of the forensic anthropologist according to each phase of DVI process.

DVI Process	Forensic Anthropologist
Phase 1 Disaster Scene	Distinction between non-human remains or non-osseous items
	Ensure that all the boy parts/fragments are collected
	Helps the forensic archaeologist in mapping the disaster scene
Phase 2 Postmortem	Separating osseous from non-osseous material
	Confirming that the remains are human
	Separating recognizable vs non-recognizable fragments that require DNA analysis
	Identifying and managing commingled remains
	Siding to left and right of skeletal elements (minimum number of individuals present)
	Analysis of cross-sections of bone in soft tissue masses
	Analysis of incinerated remains with no soft tissue
	Providing a biological profile and other identifying information (e.g., anatomical variants, previous fractures, personal artefacts)
	Assisting in reconstructing the manner of death (e.g., in case of bullet trajectories or locating shrapnel)
	Providing an opinion on ante-, peri- and postmortem trauma
	Selection of the most appropriate samples for DNA analysis according to the scale of fragmentation and commingling
Phase 3 Antemortem	Usually, AM data collection in human rights and post-conflict forensic investigations
Phase 4 Reconciliation	Providing information at the pathology reviews to assist in confirming or denying the possibility of reassociating body parts for release for families

Chapter V – The contribution of anthropology and dentistry to forensic human identification

The world is facing a truly unprecedented humanitarian crisis in terms of the number of missing people and unidentified bodies, as a result mostly of armed conflicts, large-scale natural disasters, and recent migration flows. In this kind of challenging scenarios, the application of the primary methods of identification (DNA, dental information, fingerprints) is limited to non-existent. There are a number of reasons that explain the inapplicability of some of the most scientifically reliable methods of identification, including the lack of primary AM comparative data, an insufficient PM collection that may be hampered by the state of preservation of the remains or even the lack of appropriate strategies for data collection, the lack of official databases, as well as the lack of a complete and updated list of missing persons. Moreover, sometimes the place where AM records are available can be destroyed by a catastrophic event (De Boer et al. 2020a).

A peculiar humanitarian context is the case of dead migrants, for which at an international level there are still no fully defined strategies in place to deal with data collection, with the exception of the Italian case where unmatched efforts have been made to identify migrants (Olivieri et al. 2018). At times, there are no official data on people migrating from countries with poor living conditions (e.g., limited access to healthcare) and access to AM data is a very complex process. Moreover, there are no evident services where to ask for information or to look for the missing, and due to political instability of some countries of origin, it is practically impossible to get in touch with the victim’s relatives. Often, families do not search for their loved ones because they are not aware of their fate and need to be identified. Consequently, there is also no access to the missing person's personal belongings for DNA extraction and analysis (Olivieri et al. 2018; Olivieri et al. 2017). For all these reasons and despite its highly individualizing potential, the application of primary identifiers is not always possible. In this sense, there is an urgent need for alternative identifiers and for improving the chance of personal identification.

There are several contexts where the use of secondary means has proven to be crucial for identification of missing persons, including war victims (Djurić 2004; Slaus et al. 2007), victims of natural disasters (Wright et al. 2015), death migrants (Anderson 2008; Olivieri et al. 2018) and domestic/single case investigations (Vaz and Benfica 2008). Regarding dental identifiers, their use is well-established in the scientific community as a primary method of identification. Therefore, its applicability and effectiveness are more readily recognized given its well-established role in forensic identification. However, they are not without limitations. The main factor limiting the applicability of dental identifiers is the poor quality or inexistence of AM data, particularly in the developing countries where there is limited access to health care. Sometimes the data may not be sufficiently discriminative, but typically also due in large part to the poor quality of the records, or the poor quality of preservation of the remains (Sweet 2010a).

Primarily, forensic anthropologists and dentists play a key role in developing the biological profile. This entails assessing the remains and provide information concerning the biological characteristics (e.g., age at death, sex, ancestry, stature, and idiosyncrasies) of the deceased. AM pathological conditions, anomalies/abnormalities, analysis of trauma and dental configurations also assist in obtaining a profile. Consequently, this reconstructed profile assists law enforcement in narrowing the range of possible victims (missing persons), puts forward presumptive identifications and provides search paths for the collection of AM evidence (Austin and King 2016; Blau and Briggs 2011).

Afterwards, the use of anthropological and dental identifiers is based on a comparison analysis (Cattaneo and Gibelli 2013). This differs from reconstructive identification since they rely on AM records available for comparison and the existence of a presumptive identification (Sweet 2010a). Therefore, the comparison of AM and PM characteristics should be based on the search for individualization factors (i.e., unique characteristics that contribute to personal identification, since no two skeletons are alike) and should match in sufficient detail (Simões et al. 2014). On the other hand, the presence of unexplained discrepancies can lead to the exclusion of an identity. Indeed, examination and comparison of AM medical records with PM data obtained from the remains has long been an established and accepted basis of identification for forensic odontologists and, increasingly, forensic anthropologists (Scott et al. 2010).

Recently, the use of forensic anthropology methods and anthropological identifiers in personal identification was duly recognized by the Board of the Forensic Anthropology Society of Europe (FASE) (De Boer et al. 2020a). This recognition and position statement is in line with the position of the WHO/ICRC (ICRC et al. 2006) and the U.S. National Institute of Justice (National Institute of Justice (US) 2005), which recognize morphological comparison as a principal means of identification. The former considers that unique physical or medical traits, including skeletal radiographs and numbered surgical implants, are highly discriminating means of identification, i.e., “conclusive to a degree that would be considered beyond a reasonable doubt in most legal contexts”. Concerning the position of U.S. National Institute of Justice, the confirmatory identification of the deceased in mass fatality incidents can be established using the following methods: fingerprints, odontology, radiology, DNA analysis and forensic anthropology. These are considered to provide sufficient proof of identity. On the other hand, presumptive methods includes direct visual or photographic identification of the deceased if visually recognizable, as well as personal effects, circumstances, physical characteristics, tattoos, and anthropological data (National Institute of Justice (US) 2005).

Radiographic comparison is an important source of data for human identification, by supporting the PM anthropological and odontological analysis. Thanks to its huge application in several medical fields and, consequently, the availability of AM radiographic images, radiographic comparison became a regular procedure in the identification of unknown remains. It can be applied both in the reconstructive method (for instance, on age estimation procedures narrowing the search for potential victims) and in the comparative method (comparison of unique traits such as morphological features) (Cattaneo and Gibelli 2013; Christensen and Anderson 2017).

5.1. Anthropological identifiers

Secondary identifiers, particularly anthropological identifiers, have proven to be viable alternatives providing useful information about a person or even contributing to an identification, either based on traumatic and surgical features, or on anatomical variants (De Angelis et al. 2016; De Boer et al. 2020a). Recently, Cappella et al. (2019) stated the importance of using skeletal features in the identification process, providing interesting numbers of individualizing features (e.g., AM fractures, pathological changes, the presence of surgical interventions and dental work) present in a skeletal sample from the CAL (Collezione Antropologica LABANOF) Milano Cemetery Skeletal Collection (Cappella et al. 2019). In a sample of 276 well documented individuals, clinically and demographically, 124 (45%) individuals showed one or more skeletal features with an individualizing potential. Of these, 79% showed two or more features, which occurred in many different combinations. In this review, the analyzed identifiers were related to morphological features. According to Komar and Lathrop (2006), a morphological feature is defined as a physical characteristic resulting from a permanent AM modification to morphology that endures the decomposition process and is recognizable PM (e.g., AM fractures, evidence of surgical intervention or pathological conditions) (Komar and Lathrop 2006). These morphological identifiers should be unique to the individual and stable over time and they are rare enough to be seen as individualizing characteristics. However, due to the ubiquity of some features, single conditions may not be useful in personal identification (Komar and Lathrop 2006). Indeed, personal identification should be established through a set of characteristics or multiple corresponding factors, rather than the frequent presence of any single morphological feature (Komar and Lathrop 2006). Therefore, due to its power of discrimination, anthropological identifiers may provide key information for the identification of an unknown body or may even have sufficient evidentiary value for a conclusive identification.

5.1.1. Categories of anthropological identifiers

According to De Boer et al. (2020a), forensic anthropological identifiers can be classified as (1) external morphological features, which includes morphological features of the face, teeth, and other body parts, and skin alterations (e.g., moles, scars, tattoos) and (2) skeletal features, which includes the morphology of individual skeletal elements and structures (e.g., frontal sinuses patterns, trabecular bone pattern, anatomical variants, developmental anomalies, pathological changes, and medical interventions) (De Boer et al. 2020a). Additionally, Cappella et al. (2019) categorized skeletal features into two groups: (1) features that are common and can be used for personal identification only when comparative imaging is available, and (2) features that are rare and can therefore be used as potentially individualizing traits, particularly when occurring in combination. Naturally, the prevalence of various skeletal characteristics varies across different population groups and samples, which changes the classification to be attributed to a given characteristic (Cappella, et al. 2019).

The study of morphological features on the living subject has become increasingly relevant to forensic anthropologists. Currently, they contribute to the age estimation in living individuals, gait and stature assessment from closed-circuit television images and identification of individuals from their facial images. The study of external morphological features can be done using facial image comparison, following the guidelines relating to the living (ENFSI 2018). Although it has low reliability, craniofacial superimposition has been used in personal identification, particularly in the exclusion of an identity due to observed gross incompatibilities (Fenton et al. 2008; Lorkiewicz-Muszynska et al. 2013; Ubelaker et al. 2019b). Both methods use AM photographs of a missing person who might be represented by the remains. Concerning personal identification, an external examination can also reveal the presence of significant depressions or protuberances on the anatomical structure (e.g., osteoma on the forehead) that could be visible on the living subject, and would be retained on the remains PM, thus having individualizing power. However, most contexts in which forensic experts are involved include incomplete, fragmented, burned, decomposed, commingled remains or any combination of the above, particularly in mass fatality incidents. In these conditions, the assessment of external morphological features is very limited or unpractical, unlike what happens in the fresh and well-preserved corpse, or the living subject. For this reason, our focus will be on the anthropological identifiers related to skeletal features.

Morphological identifiers

Due to individual skeletal variation observed in several anatomical regions, the general shape and contours of bones (bone profiles) exhibit individual variability and therefore provide potential sources of individualization. Examples of such features are paranasal sinuses shapes, cranial suture patterns, trabecular bone patterns, and external bone contours. Although the study of many of the anatomical structures mentioned do not present an adequate standardization or robusticity from the statistical point of view, nor specific algorithms to identify them, the uniqueness of their morphology is very useful for individualization (Cattaneo and Gibelli 2013). This has been demonstrated by the use of thoracic vertebral margin contour (Watamaniuk and Rogers 2010), clavicle and cervical spine shape (Stephan et al. 2011), among others, in personal identification.

The use of frontal sinuses in the identification process is one of the most studied and well-established methods, and one of the most reliable methods of identification (Christensen 2005). Located in the anterior part of the frontal bone, its outline shape, along with its development, symmetry, size, and area, are unique to each person. This anatomical variability, even in homozygous twins, can be attributed to several factors including genetics, biomechanical and hormonal factors, craniofacial configuration, and ambient air pressure. Frontal sinuses become radiographically evident at age 5-6 and are fully developed by age 10-12 (Christensen et al. 2014). According to Besana & Rogers (2010), frontal sinuses can be radiographically compared using metric, morphological and superimposition methods. The authors suggested that superimposition methods provide the best results with highest levels of accuracy and precision and the lowest level of error, however, this is not entirely consensual (Besana and Rogers 2010). Some authors claim that there are problems with superimposition due to the orientation and angle of the x-rays (Cameriere et al. 2005; Hashim et al. 2015). Recently, Pereira et al. (2021) systematically reviewed the different methodological approaches using imaging techniques applied to the visualization and comparison of the frontal sinuses. Their results show both skull radiographs and CT as the imaging techniques used to perform metric analysis, direct image superimposition analysis or morphological analysis. Direct image superimpositions and 3D visualization revealed more advantages over other techniques (Pereira et al. 2021).

Thanks to its stability and high interpersonal variability, trabecular bone patterns, which are visible radiographically, can be used as a forensic marker for personal identification (Brogdon et al. 2010; De Angelis et al. 2016; Kahana and Hiss 1994; Quatrehomme et al. 2014). According to Mann (1998), there were no identical patterns (or distribution) after looking at the radiographs of internal bone structure of 42 femora and 38 tibiae. The study of internal bone structure, particularly radiodensities, of many individual bones, including hand bones (Brogdon, et al. 2010; Kahana and Hiss 1994), femora and tibiae (Mann 1998), has revealed distinct features necessary for personal identification, even though age-related changes could be seen. Kahana and Hiss (1994) and Kahana et al. (1998) proposed a method to assess bone trabecular pattern based on the quantification of bone morphological similarity, whose results were critically reviewed by Ciaffi et al. (2010). Indeed, Ciaffi et al. (2010) argue that it is not possible to safely quantify identification by means of bone density patterns of the proximal humerus through thoracic radiographs, after the analysis of trabeculae of the humerus in two sets of thorax radiographs. The authors justify that there can be possible slight differences in the positioning of the arms, which affects trabecular density patterns. Nevertheless, morphological analysis of trabecular bone patterns remains a viable option when other means of identification are not available, or the available radiographs do not show any particularities for morphological correspondence (Ciaffi et al. 2010). De Angelis et al. (2016) reported a case of personal identification through CT-scan based on the presence of areas of idiopathic osteosclerosis or dense bone islands (i.e., asymptomatic, and radiopaque areas characterized by dense, trabeculated, non-inflamed vital bone) within the trabecular bone of the proximal portion of the right femur. These features are stable in time and therefore useful in personal identification.

Cranial suture patterns have also been suggested as potential individualizing elements, thanks to their personal variability and numerous distinct patterns (Sekharan 1985). However, its use in forensic personal identification remains problematic. As stated by Jayaprakash and Srinivasan (2013), sutural morphology undergoes several changes characterized by a significant remodeling during growth into adulthood (Jayaprakash and Srinivasan 2013). Contrary to what was indicated by Sekharan (1985), who suggested 7 years of age as the lower limit for stabilization of cranial suture patterns, Jayaprakash and Srinivasan (2013) suggest the onset of adulthood as the age for stabilization of cranial suture patterns, highlighting its use in forensic personal identification. Tables I and II present a review of research studies and a review of forensic cases, respectively, of personal identification based on anthropological morphological identifiers.

Developmental anomalies (or nonmetric traits or discrete traits)

In addition to continuous skeletal variation referred to above, personal identification can be achieved using morphological features denominated as discrete traits (or anomalies or nonmetric traits), due to their high individualization potential, in particular when dealing with very rare ones (i.e., a frequency lower than 10%). They are most often recorded as ranked or scored based upon a visual inspection (Cunha 2006; Verna et al. 2013). Nonmetric traits can also provide an interesting source of information to complete the biological profile (e.g., discrete traits associated with age or population groups). Usually, these asymptomatic anatomical variations have an epigenetic or congenital origin with a specific location and may or may not have clinical relevance (Verna et al. 2015; Verna et al. 2013). Some examples of these morphological variants that can be useful in individualization include accessory bones (e.g., wormian bones); bipartite bones (e.g., bipartite patella); sternal, septal, and other apertures; bifid and/or supernumerary ribs; vertebral shifts and other axial anomalies; prominent features (e.g., everted gonia, bilobed chin); cranial asymmetry not attributed to cultural modifications (e.g., scaphocephaly), and polydactyly. Moreover, the genetic heritage of specific traits (e.g., the persistence of metopic suture) can be an important aid in personal identification, particularly if identified in the deceased or in close relatives (Cunha 2006). With regard to forensic analysis of human remains, these conditions should be carefully evaluated in order to distinguish a non-metric trait from a pathological or traumatic condition, especially as it deals with AM and perimortem trauma, and PM damage (Mann and Hunt 2019). For instance, congenital sternal perforation could be misinterpreted as bullet injuries. Thus, the experience and training of forensic anthropologist is of utmost importance (Cunha 2006).

The prevalence of certain discrete traits are population dependent (Verna et al. 2015), meaning the distribution of these conditions differs between populations. The scarce data related to frequencies of these features in modern populations is a clear disadvantage in forensic terms, particularly with regard to personal identification. In this sense, several studies have explored the distribution and frequency of certain traits in samples of a modern French population, including the discrete traits of the sternum and ribs (suprasternal bones, sternal cleft, sternal foramen, type of xiphoid end, lumbar ribs, absence of 12th rib, fusion between two ribs, and bifid ribs) (Verna et al. 2013), and the postcranial traits from the first vertebra to the pelvic girdle (spina bifida occulta, butterfly vertebra, supraclavicular nerve foramen, coracolavicular joint, *os acromiale*, suprascapular foramen, manubrium foramen and pubic spine) (Verna et al. 2015). A similar study was performed in a sample of the modern population of Spain in order to assess the prevalence of each morphological variant in the anterior thoracic skeleton, and their association with sex and age (Macaluso Jr and

Lucena 2014). The authors evaluated the occurrence of sternal cleft, sternal foramen, bifurcated sternal rib ends, manubriosternal fusion, and type of xiphoid process end (Macaluso Jr and Lucena 2014). In the studied sample, there were two traits related to the xiphoid process associated with age, which may help establish a minimum age estimate of unknown human remains (it was absent more often in younger individuals, particularly specimens below the age of 30 years, whereas complete fusion of the sternoxiphoidal junction was more often observed in individuals above 50 years of age). Moreover, the low percentage of occurrence of other anomalies can provide valuable information for forensic identification such as sternal foramina (3.3%), bifid ribs (3.3%), absent xiphoid process (6.6%), and triple-ended xiphoid process (1.6%). Table III presents a review of research studies and one forensic case of personal identification based on anthropological anomalies/discrete traits.

Pathological and traumatic identifiers

The potential of bone pathology as an identification factor has been noted by several authors. According to Martrille et al. (2020), although bone pathological conditions are not unique to the individual and show a lack of stability over the time (e.g., signs of healing or medical intervention), their morphological variability (i.e., shape, contour, details) in bone involvement can allow their individualization (Martrille et al. 2020). The abnormal anatomy as result of a pathological condition can be grossly recognized by radiographic methods, or histologically. Additionally, the identification of a pathological condition can provide valuable information about the victim's occupation (occupational markers) and suggest a geographic origin, sex, and age (biological profile),

Concerning traumatic lesions (AM events), healed or healing fractures, namely the osseous callus formation, may be useful for personal identification. Naturally, rigorous and detailed AM medical records of the observed morphology are crucial for comparison with rigorous and detailed PM documentation (Cunha 2006; Komar and Lathrop 2006). As stated by Rhode et al. (2012), bone remodeling can be a problematic issue regarding radiographic comparison thanks to its capacity to change bone structure (e.g., shape and morphology, the remotion or "preinjury" bony anatomy) over the period between AM and PM radiographic records. In addition, the rate and degree of fracture healing depends on multiple factors (e.g., fracture type, body region, medical treatment, sex, age, general health, among others).

To improve forensic personal identification process based on traumatic and pathological skeletal features, further studies are needed to demonstrate its frequency and distribution within a population or a specific subgroup and to allow calculation of identity probability (Steadman et al. 2006). The occurrence of fractures is remarkably common based on data collected from two modern North American skeletal collections as showed by Komar and Lathrop (2006). On the other hand they can be seen as rare in a sample of an Italian collection of 276 skeletons and potentially individualizing features, particularly when occurring in combination (Cappella et al. 2019). However, Cappella et al. (2019) also caution that the samples studied may only be representative of the general population and not the population of "victims" due to differences in the demographic and socio-economic composition of the samples (Cappella et al. 2019). Table IV presents a review of forensic cases of personal identification based on anthropological pathological/traumatic identifiers.

Therapeutical identifiers

The identification process can benefit from the presence of orthopedic hardware (e.g., joint replacements, fixation devices, wire, plates) and surgically implanted devices (e.g., surgical implements, artifacts, appliances, marks of surgical interventions), as they are highly individualizing markers due to its unique configuration and offer multiple points of comparison. For instance, in cases of extensive thermal alteration, the presence of prosthetic implants may be the only possible way to achieve personal identification (Matoso et al. 2013). Usually, the device or implant present additional data (i.e., manufacturer's symbol along with unique serial number) that can be traced to obtain manufacturer and product information. Subsequently, this information can ideally be linked to a specific individual or at least narrow the search (when serial number do not provide adequate information) (Simpson et al. 2007). The unique morphology of some devices (e.g., joint replacements) and its anatomical location can be compared radiographically with AM records (Wilson et al. 2011). However, radiographic identification is particularly applied to a closed population, when there is a presupposition of the victim's identity, as opposed to an open population (e.g., mass disaster context) (Wilson et al. 2011). The search for this type of identifiers should be based on a thorough analysis, including the conventional anatomical sites (e.g., dentomaxillofacial region) and the most vulnerable anatomical sites (e.g., knees) (Silva et al. 2014a).

Additionally, the presence of a surgical device is indicative of an illness or injury which required medical intervention, a fact that may be known to friends and family. It can also reveal the socio-economic (and geographic) status of the individual (e.g., living conditions and access to health care) given the necessary means for a major surgery, as well as potentially being suggestive of an individual of middle or advanced age, depending on the type of implant. This type of information can once again be very useful in narrowing the search for an individual's identity (Matoso et al. 2013). Tables V and VI present a review of forensic cases and a review of research studies, respectively, of personal identification based on anthropological therapeutical identifiers.

5.1.2. AM sources of anthropological identifiers data

Anthropological features can be collected through background research, which includes various sources, such as interviews (family members, witnesses, friends, activists, doctors, perpetrators, others) or written records (medical or legal reports, police and military reports/archives, others).

In some cases, relevant AM information is available through radiographs or other medical imaging types, namely computed tomography (CT). The technological progress in clinical radiology and its widespread use in medical institutions as part of diagnostic procedures increase the probability of the existence of AM records, because at one time or another in their life, most people are imaged for some medical reason, recording skeletal features that can be particularly useful for identification (Ciaffi et al. 2011; Silva et al. 2013). Indeed, there are several human identification cases that highlight the importance of forensic radiology, including cases based on conventional radiographs (Rhode et al. 2012; Silva et al. 2014a), cone-beam computed tomography (Franco et al. 2019; Silva et al. 2011a), and multi-slice computed tomography (Silva et al. 2017b).

Even when there are no AM radiographic images, written or charted medical records may contain documented features or patterns useful for searching for consistencies and inconsistencies. Moreover, a family member can report medical histories from the individual's life that impact the identification process (e.g., the left arm fractured as a teenager). For instance, this is particularly common in situations of war victims (Djurić 2004). However, the main problem is related to the accuracy and rigor of this information, which can lead to misinterpretations. Thus, medical records of injuries, pathological conditions, and anatomical variants are especially useful for identification.

AM photographs are also a useful source of information. They can be used in a direct comparison with the skeletal portion, or a photograph of that skeletal portion (e.g., photographs of disfigured limbs) or applied in a skull-photo superimposition, if there is a photographic record of adequate quality (SWGANTH 2010; Wilkinson and Lofthouse 2015). However, there are some issues regarding the visual comparison between AM and PM images, as visual comparison and identification can lead to high error rates (or misidentification). For photographic superimposition, the skull has to be adjusted in such way that the inclination and orientation are the same as that of the head in the photograph. The study of anatomical landmarks (e.g., orbits, angles of the mandible, zygomatic processes) will provide conclusions, although this method can only help in exclusion rather than conclusion. However, a slight change on the enlargement of the AM photograph or a slight change in the angulation of the skull can lead to mismatch.

Of interest too are databases (e.g., NamUS) that can provide the necessary AM information for comparison with unidentified skeletal remains, including all information on missing persons, such as personal, physical, medical, and dental information, as well as information on the circumstance of their disappearance (Craig 2016).

5.1.3. PM collection of anthropological identifiers data

The establishment of an identification requires a proper recovery, documentation, and assessment of the remains. PM anthropological data may include a reconstruction of the biological profile, and the collection of general information about the remains, such as medical facts including unique characteristics of the remains (e.g., signs of old bone fractures of the remains), trauma and PM damage to the remains (both intentional and accidental), and circumstantial information about the remains (e.g., where they were found).

All anthropological data collected (dataset), including the unique/individualizing features found after an accurate and thorough PM physical examination, will be the basis for personal identification. Concomitantly, radiological skeletal assessment can provide useful and often conclusive elements to assist identification (De Angelis et al. 2016). In this sense, radiographic examination should simulate the available AM radiographs in scope and projection, in order to enable a point-by-point comparison and the search for consistencies and inconsistencies (SWGANTH 2010). Indeed, this is the best practice, however PM data collection does not always occur with prior knowledge of AM data, and in such cases the PM radiographic examination should be as thorough as possible, preferably including multiple views of the same anatomical region/element. Even if in the absence of AM records, PM radiographic examination may provide an efficient guide to supplement conventional autopsy, and record data that may be of use later in the process.

Regarding orthopedic and surgical devices, several publications have demonstrated the usefulness of the variety and uniqueness of orthopedic devices to achieve a personal identification. A case reported by Scott et al. (2010) showed the “serendipitous nature” of a surgical artifact discovery after the recovery of eight staples from the soil matrix highlighting the need to use alternative screening methods to recover cultural artifacts in soil surrounding the skeleton (Scott et al. 2010). These case report highlights the importance of effective forensic recovery of human remains and its artifacts based on a pre-planned, methodical approach. A correct archaeological approach includes: 1) the location and setting up of grid, delimiting the place where the operations will be carried out for the application of basic or specialized search techniques, 2) searching for and excavating the remains, including collecting and carrying the excavated soil to be screened, 3) documentation, including written and photographic documentation, and possibly mold making, 4) handling and packaging of remains and evidence, and personal protective equipment. The surrounding soil matrix should be researched systematically and carefully without stepping on any evidence. Moreover, the action of scavengers (e.g., dogs or foxes) should be taken into account, as they may be responsible for the dispersal of human remains and artifacts (Iscan and Steyn 2013). It must also be bared in mind that it is not always possible to recover certain surgical devices (e.g., dental prosthesis, pacemakers) in the PM examination, which does not mean they were not present at the time of death (Cappella et al. 2019).

Concerning pathological identifiers, a simple record of the existence of an injury or a pathological condition may not be enough for individualization (Cappella et al. 2019). SWGANTH guidelines (SWGANTH 2012) highlight the mains aspects to take in account when diagnosing a pathological skeletal condition including a careful differential diagnosis that may require a macroscopic or microscopic or histological analysis, according to the condition. Especially important for the comparison analysis in the identification process is the existence of a detailed and clear description of the morphology of the abnormal bone together with the identification of its location (patterning) and distribution, as well as the use of a clear and unambiguous terminology to describe the pathological changes (SWGANTH 2012). On the other hand, a thorough differential diagnosis will allow distinguishing a pathological condition from PM damage, for example, since taphonomic factors can produce similar bone changes to those caused by a pathology.

5.1.4. Reconciliation of AM and PM anthropological data

In forensic anthropology, the identification results are categorized into tentative, circumstantial, presumptive, and positive. When there is suspicion of an identity and the actual identification cannot be excluded, the identification can be classified in the first three types listed (Christensen and Anderson 2017; Ubelaker et al. 2019a). On the other hand, positive identification is characterized by a consistency between AM and PM anatomical features and the guarantee that they are unique enough to enable the identification. Currently though, there is no consensus concerning how many descriptors/features (i.e., the minimum number of concordant points) are needed to establish a definitive identification, only that they should be unique, and no unexplainable discrepancies can be found after a meticulous comparison of details (Cattaneo and Gibelli 2013; Hinchliffe 2011a; Mundorff et al. 2006). The identification process, however, is not error-free with regard to the interpretation of anthropological evidence, and misidentification can lead to tragic consequences with a severe impact on the families and the community (Ubelaker et al. 2019a).

The comparison of anthropological identifiers obviously requires attention to details. Concerning human identification based on the comparison of radiographic records, there are still limitations. Firstly, due to the changing nature of pathological bone lesions, AM images must have been taken close to the time of death to be relevant for forensic identification (Cunha 2006; Martrille et al. 2020). In this sense, a significant time gap between the AM and the PM image records limits their comparison, which can also be of particular concern in the case of degenerative diseases (e.g., spondylosis) (Cappella et al. 2019). Although the authors do not propose a specific time frame, the possibility of a significant AM evolution of the pathological condition since the last radiographic record should be taken into account. Furthermore, in cases of bone remodeling, Rhode et al. (2012) advise the simultaneous use of both abnormal, when present, and normal anatomic features in radiographic comparison to maximize the number of coincident features (Rhode, et al. 2012). Secondly, not all forensic institutions have their own X-ray and CT equipment to perform the necessary analyses. Also, the reliability of X-ray technologies particularly with regard to the analysis and description of lesions is still under debate. Some authors claim that only a limited percentage of skeletal traits or lesions is detected by CT and X-ray examinations, if compared with the evidence collected from autopsy or after maceration of bones (Ciaffi et al. 2011). Additionally, further studies are still needed with statistical data concerning the mean error, in order to distinguish correct from incorrect matches. The standardization and statistical analysis applied to morphological methods will facilitate the admission in court of evidence from anthropological and radiological analysis (Ciaffi et al. 2011). Further, the reliability of radiographic comparison is dependent on several factors, including discrepancies between body orientation in AM radiographs and the position of the skeletal elements at the time of PM radiographic record. The practitioner must recreate exactly the original position as noted in the AM record (if there are AM records) (Mundorff et al. 2006; Scott et al. 2010). However, identification might still be possible even without the exact recreation of the original position, particularly when unique morphological features of single bones that are not dependent on articulation between elements are involved (Mundorff et al. 2006).

Concerning AM data – PM data match, electronic databases with automated matching and other application tools, (e.g., NamUS) can provide hypotheses of identity, particularly in large-scale investigations of missing persons and unidentified remains. This process includes the matching of anthropological identifiers, such as unique physical or medical traits, including X-rays and numbered surgical implants or prostheses (ICRC 2021a).

5.2. Dental identifiers

Dental identification is one of the most common means of identification as well as one of the most reliable and cost-effective methods used in forensic human identification. Due to the strength and durability of dental tissues, as well as to the uniqueness of each person's dentition, it is possible to extract significant information leading to the identification based on the comparison of AM and PM dental profiles (Forrest 2019; Hill et al. 2011). Sex, age, ethnicity, occupation, and habits can be also estimated from teeth analysis (Franco et al. 2015).

The use of dental identifiers is well established and documented, having contributed to personal identification in many contexts. For instance, AM - PM reconciliation of dental elements including dental restorations, root canal treatments, fixed or removable prostheses, implants, surgical plates and orthodontic appliances, were crucial in the aftermath of terrorist attacks in Paris, in November 2015 (Toupenay et al. 2020). Moreover, dental identification has played a significant role in identification of victims of major mass disasters around the world, including accidental, natural and criminal disasters (Prajapati et al. 2018).

Indeed, dental human dentification should combine all the available identifiers (Pereira and Santos 2013), although the type of dental identifiers used in the identification is changing. In the last decades, the increased awareness of oral health has reduced the need for dental treatment and decreased the need for restorative interventions (Petersson and Bratthall 1996), which led to a decrease in dental identifiers related to dental treatments. Since then, dental morphological identifiers have become even more relevant in personal identification.

5.2.1. Categories of dental identifiers

According to Angelakopoulos et al. (2017), dental identifiers are categorized into morphological, pathological, and therapeutical (Angelakopoulos et al. 2017; Franco, et al. 2015). Thus, the combination of different types of identifiers leads to a specific and unique dental profile that may be very distinctive and useful for personal identification (Cattaneo and Gibelli 2013). A review of forensic cases of personal identification based on dental identifiers is presented in Table VII.

Morphological identifiers

The importance of morphological identifiers was underlined by Angelakopoulos et al. (2017) after a study of clinically detectable dental identifiers (CDDIs) related to teeth morphology, position, and number. The authors analyzed a set of features including rotation magnitude and pattern, displacement and pattern of displaced teeth, presence of diastema, missing tooth, type of occlusion, and type of dentition. Overall conclusions demonstrated that dental-related morphology features are more specific than treatment attributes, as well as the patterns of identifiers are more unique compared to single identifiers (Angelakopoulos et al. 2017). Thus, morphological identifiers provide a high potential of uniqueness enabling individualization (Angelakopoulos et al. 2017; Du et al. 2021). Morphological aspects can also include changes in position (e.g., dental crowding, transpositions, and ectopic eruptions) and changes in the occlusion affecting several teeth, which can have functional, aesthetic, and therapeutic repercussions. Usually, occlusion patterns can be characterized according to the anatomical plane in Angle's class, I, II or III (sagittal plane), crossbites and midline deviations (transverse plane), and open bites and deep overbites (vertical plane) (Guimarães 2018).

Moreover, changes in teeth structure and color can be equally interesting for individualization. For instance, the use of drugs (e.g., tetracyclines) and the presence of certain anomalies (e.g., amelogenesis imperfecta and dentinogenesis imperfecta) can cause teeth discoloration. In the case of tetracyclines ingested during pregnancy or nursing, tooth discoloration occurs when tetracycline binds with the calcium needed for tooth development and since they are prescribed for adults, the only people with stained teeth will be those whose mother took the antibiotic while pregnant (Sánchez et al. 2004). Moreover, specific changes in tooth structure can be produced by certain habits including the use of wind musical instruments, a tongue, labial or dental piercing, smoking pipes, or bruxism (Guimarães 2018).

Incisors, canines, premolars, and molars may vary in shape and size, and their arrangement in oral cavity can be different. The developing unerupted and impacted third molars or even the remaining teeth and sound teeth are dental elements with forensic implications in personal identification (Silva et al. 2021).

Developmental anomalies (nonmetric traits)

Morphological elements also include dental anatomical traits (or nonmetric traits or developmental dental anomalies), which can assist the identification process due to their individualizing capacity or by providing key features for the biological profile (e.g., those related to ancestry) (Fernandes et al. 2018). They are characterized by changes in normal color, shape, size, and number of teeth, and they are the result of the influence of genetic, epigenetic and environmental factors, which reflects their uniqueness and stability (Puri et al. 2019). Dental anomalies and variations include conditions such as macrodontia, microdontia, hypodontia/oligodontia/anodontia, hyperdontia/supernumerary tooth, impacted teeth, ectopic eruption, dilaceration and flexion, taurodontism, supernumerary cups (e.g., talon cusp, Carabelli's cusp), enamel pearls, Hutchinson's incisors, winged incisors, enamel hypoplasia and enamel imperfecta, among others. However, the importance of each dental anatomic feature depends on its frequency in any given population. The lower the frequency of the trait, the greater the possibility that it will not be shared by many individuals, which will be useful for the identification process (Simões et al. 2014). Nevertheless, it is necessary to know the frequencies of different populations from modern samples to assess its forensic relevance. There are already some studies carried out in samples from different populations, such as Brazilian (Tinoco et al. 2016), European (Hsu et al. 1997; Simões, et al. 2014) and sub-Saharan (Irish 1998) populations. For instance, Fernandes et al. (2018) presented a clinical case of taurodontism in a mandibular second molar, highlighting the forensic importance of this condition and other dental anomalies in human identification, either because of their morphology or because of their low frequency in the population (Fernandes et al. 2018).

Pathological and traumatic identifiers

Dental pathological identifiers can also play an important role in human identification, particularly specific identifiers such as periapical lesions. However, due to its low stability and changes resulting from the disease progression, they should be preferably applied in conjunction with other identifiers (Du et al. 2021). Dental abnormalities or pathologies such as dental caries (tooth decay) and periodontal (gum) conditions, attrition, hypercementosis, cementomas, apical periodontitis, periapical condensing osteitis, enamel hypoplasia, dentinogenesis imperfecta, as well as periapical lesions and teeth fractures can provide valuable information (Du et al. 2021; Forrest 2019). In addition, pathological conditions of the jaw such as osteomyelitis, jaw fractures, cleft palate, idiopathic oasteosclerosis can also assist personal identification, when properly documented (Du et al. 2021). Concerning pathological features, ABFO guidelines (ABFO 2019) highlight the presence of crown pathology (including caries, attrition/abrasion/erosion, atypical variations (e.g., peg laterals, enamel pearl, dens in dente and dentigerous cyst); root pathology (root fracture, hypercimentosis, external resorption, root hemisections); pulp chamber and root canal pathology (pulp stones, dystrophic calcification, root canal therapy, internal resorption, apicoectomy, periapical pathology, periapical abscess/granuloma/cyst, cementomas, condensing osteitis); periodontal ligament pathology (thickness, widening, lateral periodontal cyst, alveolar process and lamina dura, height/contour/density of crestal bone, thickness of interradicular alveolar bone exostoses, tori, pattern of lamina dura, periodontal bone lyses); and other pathologic processes/jaw bones (developmental/fissural cysts, hemorrhagic (traumatic) bone cyst, salivary gland depression, reactive/neoplastic lesions, metabolic bone disease) (ABFO 2019).

Therapeutic identifiers

The third group of identifiers concerns features related to medical interventions or treatments. Dental interventions including restorations, root treatments, tooth extraction, implants, prostheses (e.g., full, or partial dentures), and other surgical treatments introduce changes to the dental profile that can be of utmost importance to human identification. Regarding to dental restorations, besides promoting changes in tooth size and shape, they are fabricated form different dental filling materials with different levels of radiopacity (e.g., dental amalgam or metal crowns, and some tooth colored materials) (Forrest 2019). Currently, endodontics and orthodontics provide important distinctive elements for personal identification (Silva et al. 2021). Endodontically-treated teeth, particularly the morphology of an obturated single root canal, can be easily identified and compared radiographically (Khalid et al. 2016). The presence of an orthodontic appliance is already an important identifier. Nevertheless, the information related to bonding position and shape of the brackets can be highly distinctive (Picoli et al. 2019). A recent forensic case reported by Picoli et al. (2019) is a prime example of a dental human dentification process by matching morphological and therapeutic identifiers. In this case, the combination of orthodontic and endodontic features (root canal filling, metallic post and core, and aesthetic crown) with unerupted, impacted and not completely developed third molars allowed to establish a personal identification (Picoli et al. 2019).

Another equally interesting feature is the presence of dental prosthesis. Today, at best, dentures can be marked or labeled for ownership identification (identifying name or number). In addition, certain features such as old or recent repairs, areas of soft tissue relief, soft linings, material used, or a particular tooth type and arrangement may assist with identification (Queiroz et al. 2017; Richmond and Pretty 2006). More specifically, in cases of fully edentulous patients, the presence of a dental prosthesis is crucial to aid identification (Richmond and Pretty 2006). However, there are still some doubts about its ability to resist high thermal insults, particularly fire. In the case of removable acrylic prostheses, the action of fire can completely eliminate the prosthesis, except for the hooks. On the other hand, new techniques with a higher level of security such as microdots, RFID chips, and memory card has been applied in order to survive a extremely hostile conditions and are cost-effective (Queiroz et al. 2017; Richmond and Pretty 2009).

All over the world, dental implants have become a common practice for replacing missing teeth, in particular, endosseous implants (i.e., typically screw-shaped, inserted into either maxilla or mandible) (Berketa et al. 2011). In a forensic context, particularly in cases of severe incineration, implant bodies and abutments, which are usually made of highly resistant material to mechanical and thermal aggression such as titanium, may be the only dental remains to assist with valuable information to the identification of victims (Berketa et al. 2010a). Most importantly, many of these dental interventions are properly documented and radiographically recorded (AM records).

Aesthetic dentistry (e.g., botulinum toxin injection, lip fillers), tooth modifications due to cultural reasons or aesthetic reasons (e.g., filling, notching, drilling, etc.), oral soft tissue modification (e.g., perforation of the lower lip for insertion of a decorative plug or other ornament; gum tattooing), and oral jewelry (e.g., tooth rings and tattooed crowns, tongue or lip piercings and other anatomical locations) can help on forensic dental identifications, namely if there are records of them (Farrukh and Mânica 2019). For instance, Interpol DVI forms recognized the forensic value of tooth jewelry and tooth modifications along with other personal effects (INTERPOL 2018). Recently, Farrukh and Mânica (2019) provide an interesting review about the role of oral jewelry in forensic odontology and suggested an elaborated oral charting system to document oral jewelry and tooth modifications and respective abbreviations in order to help on forensic identification (Farrukh and Mânica 2019).

5.2.2. AM sources of dental identifiers data

The availability of good quality records is a first step towards identification, as stated by Forrest (2019): “when good-quality AM data are available, forensic odontology classically identifies approximately 60% of victims, and contributes to approximately 30% of further identifications in collaboration with other identifying methods” (Forrest 2019). However, currently, the absence of dental records is still frequent, mostly in developing countries, either due to lack of access to healthcare system or cultural reasons. Additionally, there are no rigorous standards regarding documentation and description of dental intervention and storage of dental records (Hinchliffe 2011b). Even in Europe, there are differences between countries concerning the obligation of storing dental clinical records.

According to ABFO guidelines, the collection of AM records is usually performed by the investigative agency that has access to missing person’s reports (local, state, or national level). However, the intervention of the forensic dentist can improve the process, recognizing additional features that may be useful to establish an identification. Concerning sources for AM data, ABFO presented a list of potential sources of information including local agencies (e.g., hospitals, other health care facilities, dental schools, health care providers); state agencies (e.g., dental insurance companies, federal agencies); other sources (including family/friends/co-workers, public aid insurance administrator, employer dental insurance carrier, prior military service, prior judicial detention in country, prior hospitalizations, oral surgeons, or orthodontists in the area, veterans administration hospitals, any previous areas of residence and chiropractic X-rays) and/or even national or international websites (ABFO 2019).

Today, dental AM data are not limited to traditional dental radiographs. There are other valuable resources that can assist the identification process, including written dental records, a detailed dental care sheet (tooth number, treatment nature, location, type of material and dental equipment), CT scan, 3D surface scan data, dental study models (e.g., plaster models, casts), dental appliances (e.g., orthodontic appliances, occlusal splints), clinical photographs (extra-oral and intra-oral), photographs showing smiling faces, serial numbers etched into dental implants, and other additional elements (e.g., removable dentures) (Forrest 2019; Toupenay et al. 2020). Concerning written dental records including hand-written dental charts or dental formulas, they are among the least useful records because of its subjectivity and/or low quality. Indeed, recording information may contain errors that lead to false interpretations (Lorkiewicz-Muszyńska et al. 2013).

It is important to note, that both endodontic and orthodontic processes are usually documented and recorded radiographically, which allows to access to viable AM records and their identifiers. More specifically, periapical radiographs are common in endodontics in order to guide dentist's performance, while in orthodontics, there is a high probability of having panoramic radiographs (used in the visualization of dentomaxillary structures prior treatment) and lateral cephalometric radiographs (primarily used for orthodontic diagnosis and treatment planning) (Picoli et al. 2019).

Increasingly, the use of smile photographs has also proven to be an alternative source of AM information regarding forensic human identification and biological profile reconstruction, although the method has limitations, such as the lack of technical standard found in personal photographs (Silva et al. 2015b). Usually, specific features such as the anterior dentition recording the shape, position, angulation, size, color, incisal alignment and occlusal relation of maxillary and mandibular incisor and canines can be easily observed and recorded. Equally observable can be dental restorations and prosthetic appliances, if it is a smile photograph with open mouth (Tinoco et al. 2010). In the presence of a skull with anterior dentition and a AM smile photograph, the evaluation of the shapes of individual teeth and their relative positions can provide the distinctive features necessary for an identification (Silva et al. 2008a; Tinoco et al. 2010). Superimposition of dental elements observed in the smile photographs (or a photograph of cadaver or of a dental cast of the remains) has been tested in several studies, showing promising results (Santoro et al. 2019). However, there are two important requirements: both dental structures analyzed must have the same orientation and the absence of major alterations in the teeth after the picture in life (Cattaneo and Gibelli 2013).

5.2.3. PM collection of dental identifiers data

The PM dental examination, particularly physical examination can be very challenging due to the conditions of the human remains, which determines the procedure to be followed in a dental identification. However, a previous radiographic can guide physical examination of the forensic dentist. INTERPOL recommendations include bitewing radiographs, periapical images of upper and lower molars, premolars and incisors on both sides, separate images of teeth with distinctive features (e.g., root canal fillings, prosthetic dental crowns), orthopantomography radiographs, and a photographic documentation (images of the occlusal surfaces) (Forrest 2019; INTERPOL 2018). In cases of decomposed/incinerated body and/or skeletonized remains jaw specimens may be kept and preserved for further analysis, removed through facial dissection and/or jaw removal in order to have full access to dental structures (ABFO 2019). Accordingly, all information collected in PM examination should be present in a report, which includes the PM dental record (basic data, body description (general), and jaw fragment(s) description), dental examination (anatomical dental chart), a narrative description and nomenclature, dental impression and dental radiographic examinations (ABFO 2019).

Concerning dental implants, PM radiographic identification may not be enough for comparison/identification, apart from that some individual features of the implants will no longer be recognizable radiographically after a major thermal or mechanical insult. Thus, a intraoral examination and the physical removal of the implants for measurement and visual analysis as well as the use of other imaging modalities (e.g., intraoral radiography, 3D imaging, panoramic radiography) allows access to interesting details such as name of the manufacturing company, type (through the shape and thread pattern), width, or length of dental implant(s) (Berketa et al. 2010a; Berketa et al. 2011). Currently, it is possible to find a serial number (or batch number) within the chamber of some implants and track a set of additional information (Berketa et al. 2010b) as well as apply digital analysis for the recognition of implant components (Nuzzolese et al. 2008). Over time, advanced systems of human identification based on dental characteristics (including several computerized matching systems) have been proposed. Many researchers have focused on morphologic variation of a single tooth including contours, relative positions of tooth, dental restoration shape (Jain and Chen 2004; Nomir and Abdel-Mottaleb 2007) as well as in dental patterns (Lee et al. 2004). Today, the use of coding systems and data matching software allow accurate identification performance with simpler identifiers (Angelakopoulos et al. 2017). These computer-guided tools which improve and assist reconciliation process, became widely common, particularly in complex cases. Plass Data (Plass Data Software A/S, Holbaek, Denmark) and WinID3 (American Board of Forensic Odontology Inc., USA) are two examples of dental computer software that can be used in human identification, especially in mass disasters (Franco et al. 2019). In short, clinically, or radiographically detected dental identifiers are converted into understandable codes by the software, which establish matches between available AM (from dental patient files) and PM data (observed in the unknown body). For this purpose, Interpol developed a standardized dental identifier list (Figure 1), which contains oral identifiers categorized according to related features (Jensen et al. 2020). Furthermore, the use of encoded dental identifiers has been explored in different imaging modalities, namely in cone beam computed tomography (CBCT) scans and panoramic radiographs (Franco et al. 2019) and PM computed tomography (Franco et al. 2012; Jensen et al. 2020). All methods have proven to be useful in detecting dental identifiers.

Group	Code	Meaning	Group	Code	Meaning
Bridges	abu	abutment tooth	Root	ipx	implant
	pon	pontic		ppx	parapulpal pin
Crown pathology	mtl	marked tooth loss		rfx	root filling
Crowns	uic	unidentified crown		apx	apicectomy
	mcc	metal ceramic crown		pox	post
	mtc	metal colored crown	Status	mam	missing antemortem
	amc	amalgam crown		mja	missing jaw fragment
	goc	gold crown		mpm	missing postmortem
	tcc	tooth colored crown		une	unerupted
Dentures and orthodontic appliances	den	denture tooth		non	no information
	ort	orthodontic appliance		pre	tooth present
	foa	fixed orthodontic appliance		eru	partially erupted
	roa	removable orthodontic appliance		imv	impacted tooth (visible)
Fillings	fis	fissure seal		nad	no abnormality detected
	jew	jewelry		rov	retained root
	uif	unidentified filling	Surfaces*	M	Mesial
	mcf	metal colored filling		O	Occlusal
	amf	amalgam filling		D	Distal
	gof	gold filling		V	Vestibular
	tcf	tooth colored filling		L	Lingual
Periodontium	per	periodontal pathology			

Figure 1. INTERPOL's dental codes used for the Disaster Victim Identification (DVI) System International (DVI5) (adapted from Dental Codes).

5.2.4. Reconciliation of AM and PM dental data

The analysis of comparative data is by far the most difficult part of a dental identification (Carneiro et al. 2015). Oftentimes, in forensic cases PM dental evidence is not always complete due to the presence of fragmented, mutilated, burnt, and decomposed human remains. There is still a clear need for validation studies for these situations regarding dental identification.

It is also necessary to keep in mind that the dental profile of each individual is changeable over time. As such, the differences found between AM and PM records should be identified and explained by the forensic dentist, which are usually explained by the time between AM and PM radiographs or due to a new treatment (Sweet 2010a). Particularly in subadults, the progressive modification of the dental profile due to frequent dental treatments and alterations related to growth may hinder personal identification (Cattaneo and Gibelli 2013). As showed by Gorza and Mânica (2018), the accuracy of dental identification is positively correlated with the age of the AM radiograph, when the AM and PM radiographs show different development stages (Gorza and Mânica 2018).

Similarly to the use of anthropological identifiers, in forensic dentistry there is no minimum number of concordant points between AM and PM evidences to establish an identification, however they must be unique and with high discriminative capability and no unexplainable discrepancies should be present (Pretty and Sweet 2001). Each case must be assessed individually, so establishing a definitive number of concordant points is actually not necessary (Adams 2003b; Silva et al. 2011b). In fact, it is possible to achieve an identification from a single distinctive identifier (Acharya and Taylor 2003; Silva et al. 2009b), but the higher the number of matching identifiers AM and PM, the stronger and more reliable the identification process (Silva et al. 2021). Still, Keiser-Nielsen (1980) claimed that 12 or more ordinary concordant details would be enough to establish dental identity. In this sense, identification should be graded as to the weight of dental evidence: identity established (12 or more uncharacteristic concordant details), identity probable (between 6 and 12 uncharacteristic concordant details) and identity possible (6 or less concordant details) (Keiser-Nielsen 1980; Pereira and Santos 2013).

As stated before, the combination of several identifiers produces a specific and unique dental pattern. Its use for the purpose of personal identification has been proposed by several authors (Adams 2003a; Adams 2003b; Lee et al. 2004). There are a vast and progressively number of combinations in human dentition, including unrestored, filled and missing teeth, whose diversity increases with time. However, its low stability due to the close relationship with dental health status is one of the main limitations (Martin-de-Las-Heras et al. 2010) (Adams 2003b). Due to the current “restorative era”, the number of remaining teeth throughout a person’s life has increased, which increases the usefulness of dental patterns. In this way, radiographs such as the orthopantomography (or panoramic radiography) has proven to be an excellent tool for analyzing the diversity of dental patterns (Adams 2003b; Bhateja et al. 2015; Lee et al. 2004). However, orthopantomography does not show fine anatomic details and cause magnification, distortion, and overlapped image of teeth. Its use is advantageous in the study of anatomy, number of tooth roots, detection of dental fillings and other treatments. Several authors have studied the usefulness of dental patterns in forensic identification, including a quantitative statistical approach (Martin-de-Las-Heras, et al. 2010). Recently, Lee et al. (2019) showed that advanced dental pattern analysis considering the chronology order of each tooth in panoramic radiographs is a useful tool for a human identification and reducing sample population in potential forensic cases (Lee et al. 2019). Furthermore, the oral cavity contains other equally individualizing structures. Both lip grooves (cheiloscopy) and palatal rugae (palatoscopy) can be used successfully in personal identification, thanks to their special features (Caldas et al. 2007; De Angelis et al. 2012). Although its stability remains controversial, the high variability in rugae patterns (form, classification, location, and size of the palatal rugae) can help with personal identification, particularly in cases of edentulous cadavers (Castro-Espicalsky et al. 2020;

Chong et al. 2020). Interestingly, recent studies also show its potential for sex discrimination among different populations (Bharath et al. 2011; Muhasilovic et al. 2016).

Accordingly, the results of dental identification are usually categorized into positive (the comparison of AM and PM data allow to establish an identity based on concordant features and the absence of known discrepancies); potential (there are consistent features between AM and PM data with no unexplained discrepancy, but it is not enough due to the poor quality of remains or AM evidence); insufficient (the available data does not allow reaching a conclusion); and exclusion (there are clearly inconsistencies between AM and PM data, however, in some cases, the identification by exclusion is a valid technique) (ABFO 2019; Hill et al. 2011).

Chapter VI – General Discussion

The main goal with this review project was to assess the current state of the art on the roles of forensic anthropology and forensic dentistry when applied to the identification of missing persons and/or unidentified bodies. Specifically, a critical review of the evidentiary value of anthropological or dental identifiers in the forensic identification process was carried, by analyzing reported cases and research studies where either or both types of identifiers were used to achieve or exclude identification.

Fundamentally, establishing an identity requires finding traits or a set of qualities with enough weight or individualizing power that allow to distinguish one individual from others. In this sense, anthropological and dental elements, supported most of the time by medical records, offer the uniqueness and power of discrimination necessary for forensic human identification. Regarding dental identifiers, the analyzed reported data demonstrated the existing wide variety of differentiating characteristics (number of dental pieces, their anatomy, specific particularities, pathologies, the different types of restoration, missing teeth, prostheses, implants, among others), highlighting its potential for individualization by providing many points of comparison for dental identification. However, due to often poor quality of records (AM records) from the dental office or due to absolute inability to retrieve such records, the possibility to use dental information for AM/PM comparison is challenging if not impractical. Compared to dental identifiers, the use of anthropological identifiers still lacks wide scientific consensus and recognition as a reliable and conclusive marker of identification. A proof of that is the fact that Interpol guidelines ranks anthropological findings among the secondary means for human identification. However, the forensic anthropologist can directly contribute to human identification, through assessment of a variety of anatomical features, particularly distinctive features of the skeleton, and by comparing them to AM records (Ubelaker et al. 2019a). In fact, the present review of the use and discriminatory value of anthropological identifiers demonstrated their wide and varied application towards identification. Anthropological features are no longer limited to unique cranial evidence, for example. Although features of the human skull such as frontal sinuses display extensive variation and are widely studied, findings from the post-cranial skeleton provide abundant anatomical features with identification potential, namely general trabecular bone patterns, general bone contours, anomalies. Moreover, the diversity of pathological conditions and medical interventions, including orthopedic hardware and surgically implanted devices, provide remarkable anatomical details valuable for identification.

The study of anthropological and dental identifiers is based on a qualitative and quantitative (i.e., the number of similarities and discrepancies) analysis which, relatively speaking, provides a reliable, quick, low-cost, and accurate identification. Obviously, however, only trained and qualified professionals can guarantee the optimal outcomes. Among the scientific community of both forensic disciplines, there has been an important continuous debate on the minimum number of concordant points to establish an identification. Regarding dental identifiers, initially, a minimum number of 12 concordant points was proposed by Keiser-Nielsen (1977). However, it became clear that it was possible to achieve an identification with less than 12 concordant points, due to the quality of certain morphological features present in radiographic records, reducing the probability of error (Taroni et al. 2000). For instance, there was a case of a partially skeletonized body which was identified based on features observed in a plaster cast, resulting in 9 concordant points (similarities) and 7 explainable discrepancies (Silva et al. 2015c). On the other hand, 28 concordant points (and 4 explainable discrepancies) allowed to the identification of an unknown, highly decomposed body (Picoli et al. 2019). In fact, even a small number of common dental characteristics may produce a very rare dental pattern (Adams 2003b). In this sense, more than a considerable number of similarities, the expert must look at the quality of the evidence and ensure a correct interpretation.

Likewise, there is no agreement on the minimum criteria for identification regarding the use of anthropological identifiers, although some authors have argued that one to four unique characters, without evident discrepancies, are enough for identification (Cattaneo 2007; Mann 1998; Mundorff et al. 2006). For instance, Mundorff et al. (2006) reported an identification of a deceased individual based only on two points of concordance after a qualitative comparison of morphology of two vertebral spinous processes (Mundorff, et al. 2006). Interestingly, Ross et al. (2016) developed a standardized system and minimum number of concordant features for making positive identifications through radiographic comparison of craniofacial (n = 41), chest (n = 100), and proximal femur (n = 49) radiographs. The mechanism involved several steps, including a side-by-side examination of AM and PM radiographs, the assessment of the quality of radiographs, the identification and comparison of traits of various anatomical regions, particularly the cranium (glabella, frontal sinuses, orbital plates, cribriform plates, and sella turcica), the chest (cervical region, thoracic region and lumbar region), and the femur (femoral head, neck, greater trochanter, and lesser trochanter). Additionally, the assessment of points of concordance was based on a robust data mining partition technique called classification decision trees, and the main conclusions were that two or more points of concordance are required in lateral cranial radiographs or radiographs of the proximal femur for a 97% probability of a positive identification, while for chest radiographs, cervical vertebrae showed the most predictive value. In this case, if there is more than one concordant point there is a 99% probability of correct identification, decreasing to 79% when less than 4 concordant lumbar features are present (Ross et al. 2016).

Evidently, the number, type or even the combination of traits or concordant points will vary with each case and the reality is that the use and evaluation of a combination of traits is more efficient than the analysis of a single condition. Attempts to define a minimum number of requirements (or matching characteristics) for identifications, is arguably an unfruitful and superfluous endeavor, and the diversity of cases and contexts of the reviewed literature points to the need for each case to be assessed individually in this regard. As suggested by Steadman et al (2006), the use of a database where certain combinations of traits could be assessed, could serve as a reference to how many other individuals would match certain criteria in a large population. However, the combinations may also not be particularly useful if there are individuals with the same biological profile (for example, combination of pathological traits in older individuals). In this way, contextual information is of utmost importance for individualization.

Furthermore, a challenging and controversial issue in forensic human identification is precisely related to the use of the term uniqueness and what constitutes a unique trait or even a combination of unique traits (Jayaprakash 2013; Page et al. 2011). To prove that a particular trait is unique it would be necessary to evaluate all individuals in the world which is naturally unfeasible. The existence of few scientific studies that allow establishing human dental or skeletal diversity, i.e., the knowledge of the frequencies of several conditions (pathologies, treatments, developmental anomalies) in the general population on which identification is based is a limitation to the process. This knowledge on diversity would allow to conclude the degree of certainty (potential error) or probability of identification, a key aspect in the process of identification of missing persons (Guimarães 2018; Puerto, et al. 2021). A particular trait could be found to be more or less common in specific populations, after collection of reference data for analysis of variability and frequencies (Maijanen 2014; Steadman et al. 2006). Moreover, establishing an identification based on any number of concordant points says little about the accuracy of a match and it would be arguably more relevant to know how common or rare the shared traits are in a given population (Christensen and Hatch 2016). Indeed, the use of population frequencies is the basis for the validity of any identification approach, including radiologic identification. Frequency studies describe how often a feature is found in the relevant population. In this sense, the more unusual a shared feature is, the greater the probability that the identification is correct (Christensen and Hatch 2016). Christensen and Hatch (2016), refer to an important repository with population frequencies for commonly assessed radiologic traits, where it is possible to access resources to obtain data from different studies with documented population frequencies. Practitioners can access to this online database (https://cfi.unm.edu/rad-id-index.html) for forensic comparison of casework (Christensen and Hatch 2016). Nonetheless, in general, population frequency data is still limited, and additional studies related to population frequencies for many traits, not only related to their presence or absence and its general localization, but also data about size, morphology, or particular location. While quantitative approaches are more informative, they are also more complex (Christensen and Hatch 2016). Therefore, the scarce data related to frequencies of these features, particularly in modern populations, is a disadvantage in forensic field. Conversely, possibly the most difficult aspect of this approach is the selection of samples used to represent the population at large (Steadman et al. 2006), and deriving questions arise, for instance, on how to define a population group for anthropological and odontological studies. A population can be large or small, representative, or not, depending on what you are interested in studying, among other issues. Linked to this, it could also be questioned what percentage or frequency would in practice assure rareness or uniqueness. Studies related to discrete traits in forensic anthropology have used a frequency lower than 10% to characterize bone discrete traits with relevance to forensic identification. However, one questions how widely applicable such a reference of rareness/uniqueness can be if, for example, the provenience of the unidentified body is unknown.

Further to the lack of knowledge on frequency of traits, the comparative method, in particular radiologic comparison, involving a morphological, qualitative evaluation of similarities or dissimilarities between AM and PM records, is often if not always a subjective assessment. It is unavoidably dependent on the skill and experience of the practitioner/expert, as well as on the quality and quantity of available data. As noted by Christensen and Hatch (2016), subjective comparisons are not enough to express quantitatively the evidentiary value of an association, as they cannot be used to determine the probability of a correct or incorrect identification. The ideal would be to express quantitatively as with DNA profile comparisons. In this sense, likelihood ratios applied to radiologic identification would describe "*the probability of the AM and PM image sharing radiologic features given that identification is correct, divided by the probability of sharing the features if the identification is incorrect"* (Christensen and Hatch 2016). Recently developed forensic methods try to validate their results based on a solid statistical framework. The quantification and probability assessment of features used in identification are increasingly a legal requirement due to the pressure from legal system. However, this is not a simple matter since morphological assessment of bone structures are not easily quantifiable (Cattaneo and Gibelli 2013). To increase the likelihood of admissibility in court, it is necessary for these methods to follow the Daubert criteria (Daubert v. Merrell Dow Pharmaceuticals 1993). Daubert guidelines determine that the judge is the "gatekeeper" and must evaluate the expert's scientific knowledge based on the following criteria: theory or technique can be/has been tested; subject to peer-review and publication; known or potential error rates; technique standardization; and widespread acceptance within the field. In this sense, forensic experts have been forced to test their methods and their error rates, and to create methods for which the errors rates can be calculated (Christensen, 2005). This led to new questions: what kind of features can be empirically tested? And quantified? Steadman et al. (2006), for example, used frequency data on pathological conditions (healed fractures) or skeletal features to calculate probabilities. The idea was to use the likelihood ratios traced for the identification based on known population frequency data, to evaluate the certainty of the identification and provide justification in the court room. However, the reference sample for forensic cases was not the most suitable, due to the lack of fracture data for modern Americans, as they used data from soldiers listed missing in Korean war (Maijanen 2014; Steadman et al. 2006)

Additionally, standardization also emerges as part of Daubert criteria for courtroom admissibility. The SWGANTH guidelines are a clear example of standardization, and the professional in forensic anthropology, i.e., someone who possesses specialized knowledge, practices within an ethical framework (following a code of ethics without conflicts of interest) and fulfills a societal need, should follow the best guidelines and standards, which are synonymous with quality systems, policies, procedures, and autonomy. Quality, reliability, efficiency, and consistency is only possible with the existence and implementation of standards. In this sense, accreditation is the recognition that organizations or institutions follow a set of standards and are competent for the execution of specific tasks, while on the other end, certification ensures that the professional in forensic anthropology or forensic dentistry has the necessary knowledge and expertise in their field (Passalacqua and Pilloud 2021). Moreover, the adoption of an ethical behavior ensures that members of an organization avoid unprofessional behaviors and thus maintain the credibility of the profession and professional organization. All these issues of professionalism and ethics are particularly essential in the field of missing persons due to the incredibly important and recognized risk of misidentifications, and their consequences. Although misidentifications are rare, they are possible and they do happen (Christensen and Hatch 2016). Ciaffi et al. (2010) argued that expert knowledge, training, and experience are sufficiently reliable for a correct identification (Ciaffi et al. 2010). For this and other reasons, it could be of interest to raise and foment an honest debate among the wider academic, scientific and practitioners' communities on the value of a widespread and adequately implemented certification process of forensic professionals, in particular forensic anthropologists and forensic odontologist. Another important consideration ought to be seriously evaluated would be the widespread practice of case report peer-reviewing, as a measure of quality control/assurance that would most likely enhance the process of forensic identification at large.

Regardless, the investigation and identification of missing persons is always a complex and challenging process. Unfortunately, misidentifications can occur even when and where forensic resources are widely available, and forensic experts should be aware of this painful reality. According to Puerto et al. (2021), the causes to bodies are misidentified or returned to the incorrect family may be related to all phases of the investigative process and can include any of the following: lack of a comprehensive, integrated and systematic approach to the identification based on rigorous procedures; over reliance on one criteria/technique of identification only; a process based only on visual recognition or acceptance of circumstantial personal information alone; the use of unreliable methodologies for identification or unreliable information on the missing person; an inadequate recovery of human remains; an inadequate forensic examination of the unidentified person/body; the lack of, or inadequate, comprehensive interpretation and reconciliation of the information; problems with the chain of custody (e.g., incorrect labelling); the lack of qualified practitioners in each step of the process; the lack of quality control and quality assurance mechanisms; and, the external pressure to complete an identification without following the procedures and/or reach the necessary certainty degree. Particularly in mass fatality incidents, due to political and public pressure and the urgent need for responses in a situation where local resources are under stress, the risk of potential errors is typically greater. Additionally, the lack of local expertise and experience working with multiple lines of evidence, the poor planning and preparedness, including the lack of training in DVI, also increase the probability of error (Puerto et al. 2021). Still, one misidentification can lead to tragic consequences. For families, it means more pain, suffering and again uncertainty. There is a huge impact on a psychological, religious, cultural, psychosocial, financial, and legal level. There is also a loss of confidence in the investigative process and the responsible authorities/institutions, putting into question other identifications. When a misidentification happens, the entire process must be rigorously investigated, the accurate identification established, and the correct body returned to the family. Furthermore, families should be unequivocally and in expedite manner informed of the reasons for misidentification, and what measures/actions were taken to resolve and prevent future situations. For example, in Kosovo, hundreds of people killed during the 1998-99 war were wrongly identified before they were buried. At the time, identifications were based on visual recognition and/or their clothes or other belongings, because the more sophisticated and reliable process of DNA matching was not yet available. The pressure to solve the cases based on traditional methods of identification with a significant risk of error led to a catastrophic situation. The solution consists of reopening the graves and collecting genetic reference samples from the remains and from family members whose loved ones were identified without the use of DNA. However, this whole process is traumatic for families, who sometimes refuse to cooperate (Haxhiaj 2019). This is, however, not unique to Kosovo and according to ICMP, after the Croatian conflict and for the same reasons, misidentifications had a strong impact (ICMP 2021). In response to these problems, in addition to the use of DNA, anthropological and dental methods can provide relevant contributions, clarifications and reassurances.

Evidently, families, relatives and the communities are also victims in cases of missing persons, and they are the major stakeholders to the whole search process. Once they are at the center of the operation, they should be informed regularly on developments and any decisions taken, whether technical or scientific issues arise, as well as their right to take informed decisions should be respected. The expectations and wishes of families should be carefully and thoughtfully approached. Moreover, the will of the families and their religions and cultural beliefs should be strictly respected, making the necessary viable adaptations to procedures. Relatives and acquaintances can be active participants by providing relevant information and/or biological reference samples (Gaggioli 2018). In this sense, the interaction and communication with the families and the communities is particularly crucial. Indeed, there are several figures that can provide and collect information to and from the families (e.g., accompanier, specialists, key religious figures within the community, national NGOs, international organizations, representatives of the local authorities, or even other family members) (ICRC 2013). Regarding technical or scientific concerns, the reality is that not always is the forensic expert who is called upon to communicate directly with the families. Sometimes (if not often), the necessary explanation of the limitations and management of expectations is carried by the authorities, whoever those might be within the specific context. However, in many cases the authorities do not have the appropriate knowledge to be able to convey particular information to the families, contributing to misunderstandings and lack of trust. On the other hand, other cases are that the forensic expert is also not capable of leaving the scientific jargon out and put in lay terms for the families (as well as authorities and community at large) to understand all associated issues. Family participation is a key concept that still needs further discussions, including coordination strategies that involve clear and concise communication by the right entities and the right time.

Lastly, looking forward and envisioning important discussions and hopefully improvements in the field of forensic human identification, particularly in what concerns to the work on missing persons worldwide, a recent and very comprehensive publication by Puerto et al. (2021) laid out a renewed concept for the search for and identification of missing persons, as well as suggested the adoption of new terminologies. All of these with a clear objective to standardize and make the entire process more uniform and comprehensible. The "*Search Process"*, as defined by the authors, is a broad concept that includes several phases with the goal to clarify the whereabouts and fate of a missing or unidentified person, either alive or dead (Puerto et al. 2021). Thus, the identification phase is of particular importance regarding the fulfilling of the purpose of establishing the fate and circumstances of the disappearance. On the whole, the process should be understood as multidisciplinary, objective, integrated, holistic, exhaustive, multi-agency coordinated, and able to withstand peer review (Puerto et al. 2021; Puerto and Tuller 2017). The recommendations made by the authors included the following reviewed concepts and terminologies:

- The concept Missing Persons (MP) concerns all identities without bodies. On the other hand, Unidentified Persons (UP) refers to all bodies without identity, which include living persons (e.g., in cases of undocumented persons, migrants) or human remains.
- The concepts Missing Person Data (MPD) and Unidentified Person Data (UPD) replace the traditional *antemortem* data (AMD) and *postmortem* data (PMD), respectively. The authors argue that both terms are restrictive and not suitable for all scenarios. Actually, the use of both terms implies that the person is dead, which is not always true (not all missing persons are dead just as all unidentified persons are not dead). After confirmation of death, PMD is a part of a comprehensive concept of UPD.
- The comparison of available information can lead to different classifications, including compatibility, relative or explainable inconsistencies/discrepancies or absolute or excluding inconsistencies/discrepancies.
- Identification outcomes should be categorized into Identification (consistency, no excluding discrepancies), Exclusion (inconsistencies - absolute or unexplainable discrepancies), and Inconclusive (available information is not enough to conclude with certainty in favor of identification or exclusion). In this sense, the use of subcategories such as positive, presumptive, circumstantial, possible, among others, should be avoided since they contribute to an ambiguous and unfair decision for the individuals and their families.

Regardless of the context, the identification process should always include several lines of evidence rather than exclusively rely on a single technique, method or source of information (i.e., fingerprint, dental, DNA, circumstances). Indeed, each case must be assessed individually. It is clearly distinct to approach a crime scene with only one unidentified body compared to a mass incident with multiple fatalities (multiple unidentified bodies) and missing persons. In both, the identification process should be supported by multiple lines of evidence through reliable comparative data related to the missing person and the unidentified person, considering the probative value of each of them. The comparison will allow to establish their compatibility (consistency) or discrepancy (inconsistency). Both scientific and not scientific information (e.g., background information, personal belongings) have potential to individualize a specific person. However, the specific nature of some contexts (e.g., large scale events) requires the application of identification methods that are "scientifically reliable, applicable under field conditions and capable of being implemented within a reasonable period of time", as well as are cost-effective (Puerto et al. 2021).

From this point of view, and in agreement with the requirement for a process informed by multiple lines of evidence, the hierarchy of primary and secondary identifiers put forward by Interpol guidelines (INTERPOL 2018) can arguably be determined no longer relevant. In fact, this was previously a topic of discussion by members of the FASE (De Boer et al. 2020a). These authors recognized the importance of using alternative techniques (i.e., anthropological findings) in the identification process, particularly in cases where traditional and well-established scientific means (i.e., fingerprints, dental identification, genetic identification, or medical information) are not applicable or available, for instance, in catastrophic scenarios that involve a large number of bodies or human remains. Moreover, there was also consensus around the need for research and development in relation to secondary identifiers to be stimulated. Particularly, if there is an increase in the use of secondary identifiers, effective reference datasets and databases will be required, and they will need to withstand legal, investigative, and scientific challenges (De Boer et al. 2020a).

Related to is the development and use of electronic investigative tools such as the ICRC's AMPM database (ICRC 2021a), NamUs and others, which provide an automatic searching of missing persons cases against unidentified decedent cases, besides resources and information. These electronic databases facilitate the reconciliation process when huge amounts of different types of data are accumulated. ICRC's AMPM database is highly configurable for use in a large variety of contexts (disasters, war, internal violence, migration) and contributes to a thorough and efficient data management and analysis process. In the case of the NamUs platform, it is a centralized, nationwide database with streamlined use registration. Professional users can access a comparisons tab which gives them access to a powerful matching tool. Anthropological and odontological data can be obviously registered on the platform and thus assist in the identification process. For instance, the introduction of skeletal features is an excellent resource to help search through thousands of files where the missing persons' reports can contain ambiguities or even subtle hints of skeletal anomalies that can lead to an identification (Craig 2016). One of the main advantages in this particular case is the participation of the public, by allowing the visualization of missing persons and unidentified dead cold cases from around the country, and who can contribute details to the resolution of the cases. Moreover, due to its nature as a centralized and nationwide repository, the information can be shared by authorities and match the unknown with the missing. The main disadvantages are related with slowness of the process and the fact that law enforcement is sometimes leery of releasing too much case information to the public, especially in situations where it is known or believed that a crime was committed (Rothaar 2015). Overall, the potential of such databases as a tool for collecting, organizing, sorting, accessing, and matching of immense and diverse datasets is a promising and encouraging accessory to global efforts to search for, identify and resolve missing persons cases.

Chapter VII – Conclusions

Finding and identifying a missing person or an unidentified body is never a straightforward path. The investigation and identification of the missing (with or without bodies) should always be based on a multidisciplinary, objective, integrated, holistic, exhaustive, multi-agency coordinated approach.

Forensic Dentistry has been, for a long time, a reliable reality in the process of human identification. The combination of all available dental identifiers, which leads to a unique dental pattern, offers an individualizing and differentiating potential with regard to the personal identification process. In this sense, human identification through comparative dental evidence does not necessarily have to meet a minimum number of similarities (i.e., concordant points or matching evidence), but rather the greater the number or quality of points of concordance between AM and PM records (with no unexplainable differences), the greater the reliability of the identification. For that reason, dentists should be aware that properly filed, detailed and up-to-date dental records can make a difference in the reconciliation process. Also, Forensic Anthropology, in its direct role in human identification, including individual cases and mass fatalities, has proven to be a reliable tool, due to the abundance and diversity of unique and individualizing bone features observable in the human skeleton, both in the skull and in postcranial skeleton. In addition to the essential contribution to the reconstruction of a biological profile, anthropological identifiers can be applicable under field conditions, are time-effective, and may produce accurate results, similarly to the methods of identification traditionally regarded as primary. Likewise, there are no consensual criteria regarding the minimum number of unique features without discrepancies needed to establish an identification. Future studies should be carried out to support the development of standards/guidelines for personal identification based on skeletal features. There is a need for quantitative and properly validated approaches in order to overcome the subjective assessment of mostly morphological, qualitative assessments between AM and PM data.

The identification phase of the process, just like any of the other phases of the overall process to resolve missing persons' cases, should consider several lines of evidence, which includes comparable data from different sources. In open scenarios with multiple fatalities, a large amount of information is generated. In this way, further actions should target specific procedures and the use of an appropriate data management tool (unknown bodies/missing persons), allowing a better assessment of AM and PM information and the integration of more information, which is not exclusively scientific forensic data.

Further, the process of missing persons identification should provide conclusions about the degree of certainty or probability of identification. At this current point, new forensic identification approaches, which are based on the quantification of evidentiary value for forensic radiologic comparisons are dependent on further studies and documentation of population frequencies for skeletal and dental traits/characteristics. Therefore, additional research on this area will contribute significantly to Forensic Dentistry, Forensic Anthropology and Forensic Radiology by facilitating the use of anatomical diversity both for identification and for excluding identities in the forensic procedure.

Overall, in order to address the global humanitarian crisis that is the ever-growing number of missing persons and unidentified bodies, all countries must recognize the need to do more and better, implementing a systematic and coordinated response, particularly for the victims of migratory movements. Firstly, we have to recognize the real, devastating nature of such a humanitarian and social emergency, which include hundreds of men, women and children, migrants and others, who die in search for better living conditions, and whose bodies are never found or are buried without being identified (Cattaneo et al. 2015). Secondly, an honest answer to the question whether everything possible is being done and in the best possible way to provide an identity to these people and to respect their rights, and the rights of their families. The issue of missing persons and unidentified bodies remains a serious and underestimated problem, and a unmeasurable drama for all involved (Cattaneo, et al. 2010). The active and timely involvement of the families is of utmost importance to achieve investigation and identification goals.

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Appendices

Table I. Review of research studies on personal identification based on anthropological morphological identifiers.

Anthropological Morphological Identifiers	**Context**	**Methodology**	**Results**	**References**
Frontal sinuses	Research study 30 subjects (15 males and 15 females) who underwent 2 maxillofacial CT scans in a time ranging from 1 month up to 5 years from a hospital database + 200 patients randomly selected from the same database and undergo the same procedure (group of mismatches)	Segmentation of frontal sinuses + superimposition Statistical analysis	In the group of matches, root mean square (RMS) ranged between 0.07 and 0.96 mm (mean RMS 0.35 ± 0.23 mm), while in the group of mismatches, it ranged between 0.96 and 10.29 mm (mean RMS 2.59 ± 1.79 mm), with a statistically significant difference ($p < 0.0001$). Neither the matches nor the mismatches group showed statistically significant differences according to sex. A novel 3D approach for the assessment of anatomical uniqueness of frontal sinuses, providing both morphological and quantitative analysis, was proposed.	(Gibelli et al. 2019)
Frontal sinuses	Research study Dataset composed of 310 CT images obtained from 31 people	Proposed method: frontal sinus segmentation + frontal sinus feature extraction + frontal sinus recognition	Novel frontal sinus recognition method: 77,25% of identification accuracy Automatic frontal sinus segmentation in CT images: Cohen Kappa coefficient = 0.8852 when compared to the ground truth (manual segmentation) The automatic frontal sinus recognition based on characteristics extracted from computed tomography images is viable and effective	(Souza et al. 2018)
Frontal sinuses	Research study 116 individuals selected with at least one antero-posterior skull X-ray in their file (100 used in the first stage; the remaining 16 were set aside as test cases as the individuals had duplicate antero-posterior cranial X-rays)	1st stage: measurements of all variables of the frontal sinuses to determine the interdependence of the traits 2nd stage: Analysis of combination of traits that were found to be independent of each other in the 1st stage 3rd stage: conversion of all possible metric traits into discrete traits 4th stage: superimposition test	The most sinus traits are dependent upon one another and thus cannot be used in probability combinations. When looking at traits that are independent, metric methods are too fraught with potential errors to be useful. Discrete trait combinations do not have a high enough discriminating power to be useful. Only superimposition pattern matching is an effective method of identifying an individual using the frontal sinuses.	(Besana and Rogers 2010)
Thoracic vertebral margin variation	Research study Radiographs of healthy male individuals, aged 18-35		21 of 24 (87.5%) unknown radiographs positively identified	(Watamaniuk and Rogers 2010)
Lateral patella outline shape	Research study (validation study) Right lateral knee radiographs of 22 cadavers 35 analysts surveyed	Two analyses: quantitative method (patellar outline) and survey method (35 analysts surveyed)	Osseous patellar morphology is individuating High capacity for correctly matching radiographs by human analysts	(Niespodziewanski et al. 2016)

			Significant narrowing down of the candidate pool to just a few potential matches by quantitative method (successful computerized matching)	
Clavicles, C3-C7	Research study (Validation study) AM chest radiographs of 1460 individuals and PM radiographs from 12 male skeletons were used in this study	8 examiners undertook various combinations of the 12 trials (image comparison, simultaneous arrays, and sequential arrays)	Comparison all images within a single test: only true-positive identifications. AM radiographs presented one-at-a-time, in sequential order, and without examiners that have knowledge of array size: erroneous identifications resulted but they were exclusively made by untrained examiners (accuracy = 35% vs. 90% for trained examiners). Chest radiographs are valuable for the identification of disarticulated and even eroded skeletons	(Stephan et al. 2011)
Hand bones (trabecular bone pattern, bone morphology)	Research study (Validation study) 40 AM radiographs of fleshed cadaver hands and 10 PM radiographs of skeletonized hands	12 examiners from the forensic science community working independently, to attempt match	Overall accuracy rate was 95% Collective sensitivity and specificity were 95% and 92%, respectively The accuracy of each examiner was related to the amount of radiological training and experiences Participants noted bone morphology, trabecular patterns of the proximal and middle phalanges, and distinctive radiopaque and radiolucent features Comparative analysis of hand radiographs is a valid method for identification (it contains 27 bones that are available for comparison	(Koot et al. 2005)
Bone Density Patterns of the Humerus	Research study 2 sets of thorax radiographs of living subjects: the first set (1960 – 1990) included 190 X-rays from 88 subjects (only 25 were used); the second set (2005-2006) included 108 X-rays from 59 subjects (only 46 belonging to 25 subjects were used)	AM/PM simulated comparisons	It is not possible to safely quantify identification through bone density patterns of the proximal humerus taken from thoracic X-rays	(Ciaffi et al. 2010)
Bone trabeculae	Research study Radiographs: 42 adult distal left femora and 38 left tibiae of adults of both sexes, older than 18 years and all bones were complete	Visual examination (2 examiners) Analysis of radiodensities and radiolucencies Features: small, localized areas of dense or thin bone and single or multiple “bars” of bone oriented transversely, vertically, or diagonally	No two bones were identical in the pattern or distribution of trabeculae Radiolucencies and radiodensities in the distal femur and proximal tibia provide individualizing features	(Mann 1998)

Chest (anatomical structures)	Research study (Validation study) 30 sets of matching AM and PM chest films for comparison and 12 additional unmatched AM chest films	4 examiners independently compared the radiographs	Only 80% accuracy Quality of the AM and PM radiographs was the major limitation Chest radiograph comparisons proved to be reliable, if basic decedent information was provided, and AM and PM radiographs were adequately positioned and exposed Morphological approach to comparison should be prioritize the number of normal anatomical landmarks and skeletal structures rather than relying upon diagnostic abnormalities	(Kuehn et al. 2002)
Skull sutures (sutures of occipital zone) Ectocranial, endocranial and radiographic suture patterns	Research study 22 juvenile skulls ranging from 1 to 10 years of age 100 adult skulls aged between 17 and 70 years	Radiographic comparison	Morphological transition in the patterns of the sutures during growth from juvenile to adulthood state The onset of adulthood is suggested as the age for stabilization of suture patterns	(Jayaprakash and Srinivasan 2013)

AM: antemortem; PM: postmortem; CT: Computed Tomography; RMS: Root Mean Square

Table II. Review of forensic cases of personal identification based on anthropological morphological identifiers.

Anthropological Morphological Identifiers	Context	Methodology	Results	References
1. Frontal sinus pattern 2. Morphology of dental restorations	2 case reports (Italy): 1. a burnt body found in a partially burned-out car 2. charred remains found in a burned-out car	1. Visual comparison and superimposition AM anteroposterior and lateral radiographs of the skull / PM radiographs 2. AM radiographs / PM radiographs	1. Identification based on outlines and edges of the frontal sinuses, as well as the nasal septum deviation + morphology of the dental restorations 2. Identification based on a dental restoration with an exact match in term of structure, details, shape, and size + impacted tooth	(Campobasso et al. 2007)
Frontal sinus morphology	Single case report: parts of human skeleton found in a patch of woodlands (Brazil)	Frontal sinus morphological analysis AM clinical records (2 skull posteroanterior x-ray images) / PM radiographs	Identification based on morphology of frontal sinus	(Silva et al. 2008b)
Frontal sinuses	Single case report: an unidentified adult male killed in a traffic accident (Brazil)	Direct comparison, computerized superimposition, and metric analysis AM: dental records including periapical radiographs, seven radiographs of the torso, one CT scan and two skull X-rays – a lateral and a PA radiograph) / PM photograph	Identification based on the ration of AM/PM measurements of points of reference related to frontal sinuses and convergent superimposition area + traumatic and pathological conditions of frontal sinus	(Silva et al. 2009a)
Frontal sinuses	Single case report: heavily decomposed human remains found in a forest region (Brazil)	Direct comparison AM: 20 axial images of the paranasal sinuses obtained by MSCT PM: posteroanterior radiograph + CBCT scan	Identification based in morphological findings of the frontal sinuses (compatibility on the lateral expansion of the left lobe, the anteroposterior dimension, and the position of median and accessory septa)	(Silva et al. 2017b)
External configuration and internal trabecular pattern	Single case report Several hundred burned bone fragments and other artifacts (commingled with bone fragments of non-human species)	AM radiographs: dental arches, facial bones and lower half of the skull, the right shoulder, the lumbosacral spine, and the left hand and wrist PM radiographic examination	Identification Positive matches in unique trabecular patterns in the terminal phalanges of the index and ring fingers and a partial fragment of the middle phalanx of the index finger from the left hand	(Brogdon et al. 2010)
Bone trabeculae	Single case report: a decomposed body found in a technical locale (France)	AM X-rays of the ankle and foot PM X-rays of the same structures	Identification based on trabecular comparison of the ankle and the foot, which provide more than 50 points, particularly in first metatarsal	(Quatrehomme et al. 2014)
Trabecular bone pattern	Single case report Extensively charred body (Israel)	Visual comparison Densitometric analysis of the trabecular bone pattern PM radiographs of the right thumb of the body	Identification Visual comparison of the trabecular pattern of the first metacarpal and distal phalanx of the right hand indicated that both PM and AM radiographs belonged the same individual	(Kahana and Hiss 1994)

		AM radiographs of the right and left thumbs	Correlation between the densitographs Later on, two other methods confirmed the original positive identification (fingerprint and DNA comparisons)	
Shape of the spinous processes in two vertebrae (7th cervical and the 1st thoracic vertebrae)	Single case report: partially skeletonized human remains of an unidentified male demonstrate adipocere and disarticulation at the extremities and upper cervical vertebrae, with absence of the head (USA)	Visual comparison Radiographs of the neck and chest	Identification based on variability in vertebral morphology + biological profile	(Mundorff et al. 2006)
Idiopathic osteosclerosis (anatomical variant)	Single case report: a body in advanced state of decomposition found in apartment (Italy)	AM: Clinical records (CT-scan of the abdomen and pelvis) PM: radiological examination of the right femur of the corpse (CT-scan) Juxtaposition and superimposition	Identification based on three dense bone islands (correspondence of the number, position, and shape)	(De Angelis et al. 2016)
Configuration of wormian bone	Single case report: a highly decomposed unidentified male body	AM: radiograph of the anteroposterior view of the head PM: radiological examination	Identification based on the sutural contour of lambdoid wormian bone (epigenetic marker)	(Jayaprakash 1997)

AM: antemortem; PM: postmortem; CT: Computed Tomography; PA: Periapical; MSCT: Multislice Computed Tomography; CBCT: Cone-beam Computed Tomography

Table III. Review of research studies and a forensic case of personal identification based on anthropological anomalies/discrete traits.

Anthropological anomalies/discrete traits	Context	Methodology	Results	References
Unilateral lumbosacral transitional vertebra	Single case report: incomplete skeletal remains	AM dental records and radiographs Clinical antemortem records	Identification based on a transitional vertebra (a congenital abnormality)	(Kanchan et al. 2009)
Morphological variations of the anterior thoracic skeleton: sternal cleft, sternal foramen, bifurcated sternal rib ends, manubriosternal fusion, sternoxiphoidal fusion and type of xiphoid process end.	Research study (122 chest radiographs from Spanish individuals who showed no evidence of chest trauma, pathology or prior surgery collected over 15-month period)	Analysis of posterior-anterior digital radiographs Statistical analysis	None of the morphological variations were associated with sex or age, with the exception of two traits related to the xiphoid process The xiphoid process was absent more often in younger individuals, particularly specimens below the age of 30 years, whereas complete fusion of the sternoxiphoidal junction was more often observed in individuals above 50 years of age	(Macaluso Jr and Lucena 2014)
Discrete traits of the sternum and ribs (Suprasternal bones, sternal cleft, sternal foramen, type of xiphoid end; lumbar ribs, absence of 12th rib, fusion between two ribs, and bifid ribs)	Research study (500 anonymous thoracic CT scans from a modern population in southern France, without bone trauma or tumoral bone disease, 15-60 years)	3D analysis after volume reconstruction Statistical analysis	The frequency of all discrete traits was lower than 5%. The xiphoide process was more frequently absent in females, and triple-ended xiphoid was more often present in males ($p<0.05$). Most individuals with no xiphoid process were aged below 30 years and those with a triple-ended xiphoid were aged more than 40 years.	(Verna et al. 2013)
Postcranial discrete traits (from the first vertebrae to the pelvic girdle) (Spina bifida occulta; butterfly vertebrae; supraclavicular nerve forâmen; coracoclavicular joint; os acromiale; suprascapular forâmen; manubrium forâmen; pubic spine)	Research study (502 anonymous CT scans from polytraumatized individuals, without bone disease, 15-65 years)	3D analysis after volume reconstruction Statistical analysis	The eight postcranial discrete traits present a frequency lower than 5% in the study population. Some traits were significantly associated with sex (supraclavicular nerve foramen and the coracoclavicular joint in males and the pubic spine in females) One trait significantly associated with age (older than 50 years): the suprascapular foramen	(Verna et al. 2015)
Features of sternal bone (nominal features (synostosis, suprasternal bones, foramen in the corpus, notch, cleft, sclerotic bands longitudinal and transversal, foramen in the xiphoid) + metric features)	Research study (44 in situ PM CT scans of sternal bone and their corresponding AM CT scans; fully anonymized data)	Evaluation of CT scans (visual examination + metric analysis); intrarrater assessments by two different examiners; automated identity evaluation	Sternal bone is a suitable structure for radiological identification The automated comparison was successful in 76.7% of the cases, whereby an unambiguous identification was possible in 65.1%.	(Weiss et al. 2018)

Asymptomatic osseous variants of the postcranial skeleton	Research study (Analysis of 58 anatomical variants from an identified Portuguese sample characterized by 282 contemporary adult skeletons (148 females and 134 males)	Frequency of asymptomatic osseous variants; binary (0 for absent and 1 for present) and bilateral classification	Rarest variants: frequencies lower than 1% (duplication of acromial extremity of the clavicle, misplaced manubriosternal joint and dorsal defect of the patella) Most frequent variants: frequencies greater than 50% (ulnar medial trochlear notch form, suprascapular notch and bipartite anterior facet of the calcaneus)	(Fagundes et al. 2017)

AM = antemortem; PM = postmortem; CT: Computed Tomography

Table IV. Review of forensic cases of personal identification based on anthropological pathological/traumatic identifiers.

Anthropological pathological/traumatic identifiers	Context	Methodology	Results	References
Tuberculous bone lesions	Single case report: bones of a single individual scattered over a surface of 100 m^2 in the woods; skeleton in very good state of preservation and mostly complete (France)	Comparative analysis AM images: scans (3D reconstruction) PM images: CT scans and 3D reconstruction of cranial vault and the available vertebrae Juxtaposition and superimposition	Identification based on several points of correspondence in the position of the skeletal lesions on the bones, the anatomical contour and details of the affected osseous elements, the character of the bone lesions, and their morphological characteristics	(Martrille et al. 2020)
Osteoarthritic changes, marked lumbar scoliosis and degenerative changes in all the lumbar vertebrae	Single case report: partially skeletonized human remains consisting of a femur and a complete foot + scattered remains (Spain)	AM: clinical notes and a series of radiographs (treatment of a degenerative arthritis in the right and left knee joints and scoliosis) PM: radiological examination	Identification based on concordant points (Large and unique osteophytes in the vertebrae; a deep concavity in a vertebral body; unique features of the spinous and transverse processes; identical trabecular patterns; identical angulation of the lumbar scoliosis; posterior osteophytic processes and loss of joint spaces between the lumbar vertebral bodies)	(Valenzuela 1997)
Type 1 Spinal diastematomyelia (a rare congenital spinal cord abnormality) + bilateral hip prostheses	Single case report: an extensively charred body in an abandoned burnt-out car (presence of several fractures) (Ireland)	AM imaging studies: MRI PM: neuropathological examination PM CT imaging	Identification based on a rare spinal congenital anomaly (diastematomyelia)	(Beggan et al. 2014)
Wormian bones (morphological abnormalities of the viscerocranium and the neurocranium)	Single case report: single well-preserved skeleton of a middle-aged man found during the exhumation of human skeletal war remains (Croatia)	Visual examination + cranial measurements + PM CT scan AM: missing person report	Identification based on the comparison of the findings of skull (cranial deformities) and left elbow deformity (old trauma) with the description in the missing case report	(Kuharić et al. 2011)
Ochronosis (alkapton)	Single case report: a set of bones of an unidentified body (2 femora, 2 hip bones, 2 lower thoracic vertebrae and the skull) (Mauritania)	PM: Observation and histopathological analysis AM: medical records and family information (confirmed arthropathy and blackish urine)	Identification based on unique features shown at the articular surfaces (unusual dark-brown blackish pigmentation) (rare disease)	(Sudesh 2006)
Thoracolumbar and hip joint dysmorphism (due to the effects of degenerative disease)	Single case report: visually unidentifiable deceased person after incineration (Australia)	Comparison of AM and PM radiographs of the vertebral column and hip joint	Identification based on anatomical variant due to the effects of degenerative disease Multiple points of dysmorphic concordance (degenerative changes to the lumbar vertebrae and right hip, with contour variants to the vertebral bodies and right femoral head and acetabulum)	(Hulewicz and Wilcher 2003)

Multiple exostoses (anatomic variants of the lower limb)	Single case report: an incinerated deceased 16-year-old male (Australia)	Comparison of AM radiographs of the knees with PM radiographs	Identification based on anatomic variants of the lower limb bones (tibia and fibula) associated with a neoplastic process Concordant dysmorphic anatomic variants: two exostotic lesions on the left tibia and three lesions on the fibula)	(Wilcher 2008)
Pathological findings 1. Outstanding deformity of the spine and ankylosis of the sacroiliac joints; diffuse idiopathic skeletal hyperostosis 2. Healed depressed skull fracture; healed depressed fracture of the right zygomatic bone; osteoarthritis (vertebrae); osteocartilaginous exostosis (femur); thickening and deformation of the right tibia; chronic osteomyelitis (tibia) 3. Healed fracture (deformity of the right 7^{th} rib)	A mass grave with human remains of 39 individuals in an advanced stage of decomposition (Kosovo) 3 case reports	1. Data obtained from an interview with family 2. AM data related to a traffic accident and information from family 3. Clinical AM data PM radiographic examination	Identification of 3 persons based on previous pathology	(Djurić 2004)
Clavicle fracture that developed into a pseudo-arthrosis	Single case report: an almost completely skeletonized body with skull, upper extremities, thorax, pelvis, and lower extremities clothed in a t-shirt and floral-patterned dress (Hawaii)	Radiographic comparison (size, shape, and orientation) 6 AM radiographs PM radiographs	Identification At least 10 concordant points reflecting similarities in size and orientation, fracture position, and eight additional morphological similarities No discrepancy other than the remodeling along the fracture margins was observed	(Rhode et al. 2012)
Suprapelvic and pelvic phleboliths (+ trabecular pattern of the proximal third of the femora + vertebral processes of the lower thoracic and lumbar spine + degenerative changes in the vertebral bodies)	Single case report: A decomposed body of an elderly male clothed only with sweatshirt and sweatpants (Israel)	AM data: recent abdominal radiographs PM radiographs of the lower abdomen	Identification The location, configuration, relationship to each other, size, and number of phleboliths matched almost completely, although some minor differences due to the decay of the soft tissues in which the phleboliths are embedded were allowed	(Kahana and Hiss 2002)

AM = antemortem; PM = postmortem; CT: Computed Tomography; MRI: Magnetic Resonance Imaging

Table V. Review of forensic cases of personal identification based on anthropological therapeutical identifiers.

Anthropological therapeutical identifiers	Context	Methodology	Results	References
Surgical sutures	Single case report: a set of skeletonized remains (a nearly complete skeleton) discovered in a dense, wooded area (EUA)	AM medical records (incomplete) PM radiographic examination + reconstruction of the cranium Metric analysis Macroscopic photography Investigative process used to pinpoint suture manufacturers (provide informations about suture's manufacturer, construction material and structure, size, and medical use)	Identification based on one green surgical suture within the right acromial process of the scapula as result of rotator cuff surgery	(Shepherd et al. 2010)
AM traumas + skeletal morphology + surgical artifacts (surgical clip and surgical staples)	Single case report: a cranium discovered submerged in a semi-urban recreational lake; postcranial remains were discovered 6 months later (Canada)	AM records (thoracic and cranial radiographs, cranial CT scans, and the associated medical written notes) PM radiographic examination	Identification based on presence of surgical artifacts, healed fractures and morphological consistency between AM and PM radiographs	(Scott et al. 2010)
Post-surgical apparatus in the patella	2 Case reports (Brazil) 1. Unknown body compatible with a male adult 2. unknown skeletal remains	1. AM post-surgical radiographs of the left knee / Dissection of the right and left patella 2. AM lateral radiograph of surgical approach on left patella / PM radiographic examination of patella	1. Identification based on two bone channels detected vertically crossing the fractured patella, which diameter and position were compatible with the post-surgical metallic pins radiographically detected AM 2. Identification based on transversally fractured patella, which presenting a metallic apparatus composed by stainless steel surgical wires and pins for internal fracture fixation	(Silva et al. 2014a)
EBI osteostimulator	Single case report: Incinerated human remains in a car consumed by fire (USA)	AM radiographic records taken at the time of insertion of the EBI osteostimulator PM radiographic examination	Identification based on surgically implanted device Compatibility between AM radiographic records and PM X-rays of the device recovered embedded in the vertebrae of the individual Although the intense heat distorted the device slightly, spacing of the plugs and the positioning of the wires within vertebral elements are consistent between AM and PM records	(Bennett and Benedix 1999)
Surgical fixation devices	Single case report: unknown mostly skeletonized individual presenting an extensive AM trauma with several fixation devices (USA)	Device-tracking process which allowed to access medical records (Multiagency cooperation)	Identification based on information provided by the combination of the fixation devices and the biological profile	(Haugen 2008)

Implanted orthopedic device (6 screws fixing a seven-holed-plate in an ulna bone)	Single case report: an unknown burned human body (Brazil)	AM radiograph of a left arm PM radiographic examination and dissection Device-tracking process	Identification based on information provided by an orthopedic device surgically fixed in ulna (radiographic comparison), tracking information from manufacturer and information regarding a tattoo	(Matoso et al. 2013)
Two parts of broken steel plates with along with 5 screws in each fixed on the lateral side of the right femur	Single case report: a skeleton found inside a well (India)	Skull-photograph superimposition AM radiograph of the medically treated femur PM radiographs	Identification based on superimposition of AM and PM radiographs of the femur	(Pushparani et al. 2012)
Metallic plates fixed with metallic screws on bones of the neurocranium and viscerocranium (frontal bone)	Single case report: A carbonized and partially calcined body found inside a vehicle (Brazil)	AM records: two spiral CT scans of the transverse sections of the skull; panoramic radiograph PM periapical radiograph + photographs	Identification based on coincidences found in the procedures as well as I the shapes, quantities, and positions of devices on the skull + dental comparison	(Andrade et al. 2017)
Implanted metallic plate and screws	Single case report: skeletonized remains	Serial number tracking	Identification	(Kinoshita et al. 2009)
Orthopedic implants, bone morphology, healing fractures	8 Case reports: 1. severely incinerated body of an adult female in burnt-out house 2. skeletal remains of an adult male found in a forest (post cranial remains were mostly complete, but much of cranium was missing) 3. A dismembered, partially skeletonized body of an adult female found in eight separate bags 4. skeletonized body of an adult male located in a padock 5. a decomposed body of an elderly female found in her home 6. a decomposed body of an elderly male located inside a house 7. A portion of human ulna (two pieces of bone shaft connected by a metal plate) with manufacturing information 8. Single fragment of human humerus with a metal plate affixed to the bone by a number of screws presenting inscribed information	1. PM and AM radiographs 2. PM radiographs / AM radiographs of the Harrington rods + skull radiographs (frontal sinuses) 3. AM and PM radiographs 4. AM and PM radiographs 5. AM and PM radiographs 6. AM radiographs (antero-posterior and lateral views of the skull, and a radiograph of the left elbow region) / PM radiographs 7. Information tracking 8. Information tracking	1. Identification based on a right hip prosthesis and a calcified uterine fibroid 2. Identification based on 2 metal Harrington rods connecting the T4 and L3 vertebrae, and anatomical features examined radiographically 3. Identification based on comparison of a healed fracture of the right humerus 4. Identification based on evidence provided by penetration of the most distal screw of the plate through the shaft of the ulna + healed fractures in right metacarpals 5. Identification based an unusual calcaneal spur on the left heel 6. Identification based on evidence of dental restorations to numerous teeth, and irregularities of the distal posterior humerus and proximal ulna, including olecranon process 7. Individual remains identified (no individual identifying features) 8. Individual remains identified (no individual identifying features	(Simpson et al. 2007)

AM = antemortem; PM = postmortem; CT: Computed Tomography

Table VI. Review of research studies on personal identification based on anthropological therapeutical identifiers.

Anthropological therapeutical identifiers	Context	Methodology	Results	References
Midline medical sternotomy wires (hand-tied wires)	Research study 5 AM and 20 PM anterior-posterior chest radiographs with sternotomy wires (no identifying information about these know individuals was included in the study)	Comparison of AM and PM medical radiographs with sternotomy wires by 46 examiners (23 forensic anthropologists and 23 graduate students) + anonymous survey	Sternotomy wires can be used as reliable method for radiographic identifications Participants were 99.5% accurate in matching the radiographs. Sensitivity was 98.7%, and specificity was 99.7%. No statistically significant differences in the participants' ability to make a correct match was found. As the high accuracy rates indicate, the shape, size, and various characteristics of the sternotomy wires are individualizing and can confidently be used when assisting with personal identification cases.	(Fleischman 2015)
Medical devices (prosthetic shoulder joint, prosthetic knee joint, intramedullary femoral rod, intrathecal medication pump, clavicle fixation plate, and malleolar fixation plate)	Research study Retrospective review of photographs and autopsy reports of forensic autopsies (608) performed at a regional medical examiner office (mixed urban and rural population). Study period: January 1, 2015 – August 1, 2016	Retrospective review and identification of cases that required an alternative, nonvisual method of identification (justification) and the percentage that utilized implanted medical devices for identification, and the type of device	56 cases required an alternative method of identification due to decomposition (n = 35), gunshot wound (n = 9), blunt trauma (n = 6), or charring (n = 6). Of these 56 cases, eight (14.3%) were known to have an implanted medical device. Of these eight cases, five (63%) could be positively identified by comparing serial numbers. Prosthetic orthopedic joint was the most frequently used for identification Comparing medical device serial numbers is a rapid and definitive method of identification	(Blessing and Lin 2018)
Pre- and post-surgical foot and ankle changes	Research study (Retrospective study) 34 sets of pre-surgical ("AM") and post-surgical ("PM") foot and ankle radiographs	Radiographs were retrospectively evaluated simulating a postmortem identification. In each radiographic set, the films were separated by a surgical event to reproduce the effects of an alteration in the anatomy. The radiographs included both matches and mismatches	10 sets were correctly assessed as not having come from the same individual (not a match, exclusion, or negative identification) and 23 sets as having come from the same person (match or positive identification) The overall shape of each bone and trabecular patterns were used with greater frequency than other skeletal features Surgical intervention with subsequent healing does not preclude positive identification in foot and ankle radiographic comparisons	(Rich et al. 2002)

Pathological features (osteoarthrosis, spondylosis and cancer), traumatic features (AM fractures), surgical interventions (amputations, orthopedic devices, and pacemakers) and dental work	Research study (a skeletal sample consisting of 276 individuals from **the contemporary documented CAL** Milano Cemetery Skeletal Collection)	The skeletons underwent anthropological analysis in order to identify pathological, therapeutic, and dental features	124 (45%) individuals showed one or more skeletal features that may be potentially individualizing. Of these, 79% showed two and more features, which occurred in a multitude of different combinations. Skeletal pathological features and surgical interventions may provide valuable clues for the identification process by having the potential to reduce the effective number of victims and provide indications for a targeted search for AM data	(Cappella et al. 2019)

AM = antemortem; PM = postmortem; CAL: Collezione antropológica Labanof

Table VII. Review of forensic cases of personal identification based on dental identifiers.

Dental identifiers	Context	Methodology	Results	References
Therapeutic (root canal filling, post, core and crown in maxillary central incisor) + morphological (unerupted, impacted and not completely developed third molars)	Single case report: severely charred body (Brazil)	Visual inspection; radiographs	Identification No unexplainable discrepancies	(Silva et al. 2021)
Orthodontic appliances + morphological traits of the canines, incisors, and dental roots	Single case report: Unknown body higly decomposed (Brazil)	Panoramic radiographs; occlusal photographs; superimposition of AM and PM outlines	Identification 28 concordant points 4 explainable discrepancies No unexplainable discrepancies	(Picoli et al. 2019)
Pigmentation, type and precision of the direct and indirect restorations, and periodontal conditions Endodontic treatments	Single case report: decomposing corpse, skeletonised and with no mandible (Italy) Human mandible found later	Radiographs; photographs; impressions of dental arches; sampling of dental enamel for geological analysis and sampling of dental material for SEM analysis	Confirmation that the mandible belongs to the skeletozined subject (anthropological examination and type of restorations) Subject from central Europe (based in geological analysis and analysis of dental material) General profile Not yet identified (no AM data)	(Nuzzolese 2018)
Endodontic treatment of the maxillary right 2nd pre-molar and the maxillary left lateral incisor + pneumatization of the maxillary sinuses in the molar region + absence of the maxillary right 1st molar	Single case report: Unkown body recovered from a traffic accident (Brazil)	Periapical radiographs	Identification	(Silva et al. 2014b)
Endodontic treatment (radiopaque substance) + similarities of the upper second and third molars	Single case report: Body remains after a intense fire (water-soaked charred coal-like ashes of skeletal bone fragments) (USA)	Endodontic Radiographs Analysis of a small delicate portion of the anterior part of the maxilla, a piece of posterior portion of the right maxilla with two roots (one root had an alloy clinging to the dentine), and blackened anterior root	Identification	(Weisman 1996)

Morphological features + treatment intervention (root canal treatments)	Three case report (Brazil): 1. A highly decomposed body found near a river 2. A body in highly decomposed rate (again near a river) 3. A body in the countryside	Periapical radiographs Clinical file containing details of endodontic interventions (case 3)	All three victims were identified 1. Root canal treatment + morphology of the 1st and 2nd premolars + missing molars + similarities in alveolar bone loss (region of the mandibular left molars) 2. Endodontic treatment + incomplete root development + alveolar bone crest extending obliquely 3. Endodontic treatment + impacted maxillary canine transversely positioned	(Silva et al. 2016)
Anatomical features surrounding the upper and lower anterior dental arches; occlusion; missing teeth; orthodontic appliance; amalgam	Three case report (Brazil): 1. A male subject in advanced stage of decomposition 2. Skeletal remains of a adult female of Russian origin 3. Carbonized body of a male indiividual found in a forest region	Superimposition of smiling photographs (cases 1, 2 e 3) Odontologic clinical dental records (case 2 e 3), periapical radiographs (case 3)	All three victims were identified No odontological AM records (case 1)	(Silva et al. 2008a)
Dental crowding between mandibular canines and lateral incisors + shape and position of the maxillary anterior teeth	Single case report: skeletal remains found near countryside (Brazil)	Smile photograph – direct comparison and digital superimposition	Identification High compatiblity of proportion, shape and position of teeth in the maxillary and mandibular dental arches)	(Silva et al. 2015b)
Present and absent teeth, dental crown morphology, position of the dental arches, presence of dental interventions, incisal contours	Single case report: a charred body after airplane crash (Brazil)	Smile photographs – analysis by direct comparison, image superimposition and analysis of upper and lower incisal edges	Identification after the application of the 3 techniques	(Silva et al. 2015a)
Small amounts of residual endodontic material (two radiopaque root filling material objects)	Single case report: a deceased adult male in advanced stage of decomposition with an edentulous maxillary arch (Australia)	Periapical radiographs (comparative analysis)	Identification based in dental evidences of edentuluous areas (use of extruded root canal material even though the tooth was extracted)	(Berketa et al. 2019)
Therapeutic material: dental implant and site of bone integration	Single case report: charred bone fragments found at the bottom of a sewer (victim of homicide)	AM Orthopantomography and PM radiographs of the implant	Identification based on peculiar deature correspondences regarding the implant and the portion of integrated bone connected to the screw No incompatibilities	(De Angelis and Cattaneo 2015)

Anatomical features of three permanent molars (specific occlusal anatomy: stellate-shaped mesial fossa and marginal ridge area of molar tooth)	Single case report: a burned body after a car crash (USA)	Digital superimposition of AM and PM features Upper and lower dental casts Digital metric and nonmetric shape analysis	Identification based on uncommon configuration of grooves and fissures of occlusal anatomy and metric profile No exclusionary data was noted.	(Johansen and Bowers 2013)
Dental particularities: old loss, PM loss, intact tooth, twisted tooth, filllings	Single case report: a partially skeletonized body found in advanced stage of decomposition, with mummified soft tissues	Comparison between AM records (plaster cast) and PM records (corpse maxillary dental arch) - Registers of clinical exam and an upper dental prosthesis within a dental cast	Identification based on features observed in a plaster cast 9 concordant points (similarities) 7 explainable discrepancies	(Silva et al. 2015c)
Lacking teeth, supernumerary tooth, PM loss, loss of tooth substance in the occlusal surface, intra-radicular post and a partially obtured root canal + rehabiliation treatment, rotated teeth	Single case report: a skeleton found in a reed bed (Brazil)	Panoramic and periapical radiographs Orthodontic documentation (extra-oral photographs, panoramic radiographs and dental casts of the maxilla and mandible)	Identification Several concordant points	(Terada et al. 2014)
Occlusal amalgam restorations + fixed orthodontics appliances with bands + teeth present + teeth rotation + diastema	Single case report: an unknown human body higly decomposed with several ody parts skeletonized found in a Forest region (Brazil)	Intraoral radiographs; orthodontic records (intraoral photographs + panoramic radiograph)	Identification based on the comparison of photographic dental data No discrepances (explainable or not).	(Silva et al. 2017a)
Restorative treatments and rehabilitation procedures + dental implant Presence or absence of teeth; artificial crown and endodontic filling; nometallic restoration; dental implant and prosthetic crown; temporaray restoration	Single case report: a decompsoed human body found in a forest region (Brazil)	Periapical and panoramic radiographs	Identification 30 concordant points (similarities) 2 explainable discrepancies	(Silva et al. 2017c)
Upper denture (completely edentulous maxilla) Teeth presence in mandible (central and lateral incisors, and the right 1st premolar) + amalgam restoration + dental atrition	Single case report: a skull, complete bones, and denture found in a crime scene (Brazil)	Dental records and periapical radiographs	Identification DNA exam confirmed the dental comparison of AM and PM records	(Queiroz et al. 2017)
Anomaly of tooth position (upper left canine buccaly displaced) + remaining visible teeth	Single case report: Human remains of caucasoid female found in an advanced stage of decomposition (Brazil)	Skull-photo superimposition Smile photographs	Identification based only on particular positional anomaly of the canine	(Tinoco et al. 2010)

Filled teeth (with fissure sealants) + 2 paramolar tubercles in the first deciduous upper molars (low-frequency trait) + presence of certain teeth + sound teeth	Single case report: corpse of a female child recovered on a beach, in a state of advanced decomposition (Portugal)	Dental records and a plaster cast from the upper jaw	Identification 15 concordant points No unexplainable discrepancies Presence of a very distinctive feature – the paramolar tubercle (a low-frequency trait)	(Carneiro et al. 2015)
Missing, sound and filled teeth + root canal filling + osteointegrated implants + anatomic position of implants + morphology of each bridge (mainly the morphology of each cantilever) + presence of fixed contention in the upper jaw	Single case report: unidentified skeletal (presumable homicide crime) (Portugal)	Panoramic radiograph; Dental records including X-rays	Identification 35 concordant points	(Pereira and Santos 2013)
Presence of othodontic appliance + presence of supernumerary teeth + shape and site of amalgam restorations in most of the posterior teeth	Single case report: incinerated remains of a man found inside a car (Brazil)	Orthodontic records (clinical chart, panoramic radiograph, lateral radiograph, intraoral photographs, extraoral photographs, a radiographic interpretation report and a pair of plast impressions)	Identification 20 concordant points	(Silva et al. 2011b)
Presence of root canal treatment (case 1) Features of the endodontic restauration, radicular and bony anatomy and the coronal restorations (case 2) Completed root canal treatment (case 3) Endodontic intervention (case 4)	4 case report (Australia) 1. No details 2. A body with severe fractures to both mandible and maxilla after a traumatic incident 3. Deceased person severely putrefied 4. No details	Visual comparison (radiographs) (cases 1 e 2) Image superimposition (periapical radiographs) (case 3) Subtraction imaging (radiographs) (case 4) Periapical radiographs; written dental records	All 4 cases were identified based on root canal treatments	(Forrest and Wu 2010)
1. Dental fillings (composite and amalgam types) + features of good hygiene habits 2. Presence of sealent in the first molars + dental caries + dental fillings (composite)	2 case report (Poland): 1. A charred body with extensive thermal injuries 2. a human skull and human body	Dental patient records; dental X-ray images; pantomographic image; dental diagram	Identification with no unexplained differences 1. Observed sight explainable differences (due to dental treatment) 2.Explainable differences (due to dental treatment and different classification of discoloured fissures)	(Wochna et al. 2016)

AM = antemortem; PM = postmortem; DNA = Deoxyribonucleic acid