Universitat Autònoma de Barcelona

Taphonomic and Anthropological Analysis of Unclaimed Human Remains from Cemetery Context in Barcelona

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PhD Dissertation, 2016

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ABSTRACT

INTRODUCTION: The purviews of Forensic Anthropology are the interpretation of the decomposition process of human remains, the elaboration of biological profiles, the interpretation of taphonomic effects in form of differential decomposition, disarticulation and/or lost of bone elements, and the estimation of the postmortem interval. The latter is one of the most complex tasks. In the case of remains in advanced decay, it is even more puzzling because a large range of variables affects the final cadaveric state. In Europe there is a lack of research on human decomposition, and animal models tend to be used. Using human remains from cemetery context is a way to overcome the issues related to the low availability of human corpses, the low number of remains and the antiquity of samples.

AIMS: To evaluate the influence of different taphonomical agents on the cadaveric state observed during exhumations in cemetery context.

MATERIAL AND METHODS: Unclaimed human remains from Cemetery of Terrassa, Cemetery of Montjuïc and Cemetery of Collserola were analysed, with a mean postmortem interval of 22.63 years. The sample contains 301 exhumed corpses of both sexes, predominantly adults. Description of observed cadaveric states was performed separately for each cemetery as well as for all three cemeteries together. Taphonomic, Anthropological and Depositional information was gathered in the exhumation record. Meteorological data were observed from three different automatized weather stations close to the cemeteries. Postmortem interval was calculated from the day of death until the date of exhumation.

RESULTS: Five cadaveric states were established: total skeletonization, skeletonization with wet putrid matter, skeletonization with dry putrid matter and partial desiccation, mummification, saponification with wet putrid matter. The dry cadaveric state was in general predominant. The anterior parts of the corpses were more complete that the posterior parts. Intrinsic factors (sex, age, cause of death) did not show any effect on the cadaveric state, but extrinsic factors did. Plastic body bags, funerary sheets, and an increase of the height of the niches facilitated the conservation in form of wet cadaveric state. Clothes and diapers delayed the destruction of soft tissue. Autopsied corpses did not present a clear prevalence of any cadaveric state. Regarding postmortem interval, totally skeletonized corpses presented the longest time since date of inhumation. No influence of the season when the individual died or

of the presence of insect activity was confirmed. However, the influence of meteorological variables was statistically demonstrated, for instance, on the saponified corpses with wet putrid matter. Artifacts linked to cemetery context were described and classified into two groups: those highly indicatives, and those suggestive of the cemetery origin of the remains. A new method of evaluation of joint disassociation pattern was elaborated. Joint structure was described as articulated, disarticulated or displaced based on minimum unidirectional movements to reconstruct environmental characteristics of decomposition, including human intervention. It is a useful tool to describe the funerary ritual in the case of ancient remains and the circumstances surrounding the death in forensic context.

CONCLUSIONS: The locality of each cemetery displayed unique environmental conditions that affect the observed cadaveric state. Differences among cemeteries were found, which highlights the importance of climatic differences even in similar contexts. Total skeletonization generally showed the longest postmortem interval when all cemeteries were analysed together. An effect of external factors related to funerary practice (burial place, type of wrapping, type of clothing), human manipulation (autopsy), and meteorological variables on the cadaveric state was confirmed, being those related with human intervention the most influent on advanced decomposition. Cemetery artifacts showed to be useful when the origin of human remains has to be identified. In the case of skeletons, and/or partially skeletonized remains, the pattern of joint disassociation was described to help reconstruct the mortuary practice of the remains and a new unbiased method based on minimum unidirectional movements was elaborated. The use of human remains from cemetery context stands out as an important model to analyse human decomposition and understand the evolution of corpses in advanced state of decomposition.

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LIST OF ABREVIATIONS

ADD: Accumulated Degree Days

TBS: Total Body Score

PMI: Postmortem Interval

CT: Cemetery of Terrassa

CBMN: Cemetery of Montjuïc

CBCLL: Cemetery of Collserola

TS: Total Skeletonization

WPM: skeletonization with Wet Putrid Matter

DPMD: skeletonization with Dry Putrid Matter and partial Desiccation

M: Mummification

SWPM: Saponification with Wet Putrid Matter

ADINDET: Adult Indeterminate

ADS: Adult Senile

ADM: Adult Mature

ADJ: Adult Young

SA: Subadult

TN: Minimum Temperature

TM: Average Temperature

TX: Maximum Temperature

PPT: Accumulated rainfall during 24 hours

HRM: Average relative humidity

HRN: Minimum relative humidity

RS: Sunlight during 24 hours

VVM: Average wind speed measured at a height of 10 m

VVX: Maximum wind speed measured at a height of 10 m

Eto: Evapotranspiration

Chapter 1 **INTRODUCTION**

We owe respect to the living: to the dead we owe only the truth.

Voltaire, Première lettre sur Oedipe

When human remains are discovered in the field there are many questions that have to be answered. The correct answer to those questions depend on knowledge of the decomposition process of human remains, on a proper elaboration of the biological profile, and on the interpretation of the taphonomic effects caused by different agents, i.e. differential decomposition, disarticulation and/or lost of bone elements. More accurate interpretation of time since death should also be intended. In the case of remains in advanced decay it is a very complex task because of the large range of variables that can affect the final cadaveric state. The importance of the context of the finding should also be acknowledged, because the anthropological expert needs to have a clear idea on if he/she is dealing with a recent case or "cold case", or with remains from archaeological or cemetery context (Haglund and Sorg, 1997; Rogers, 2005; Schmitt et *al*., 2006; Rogers, 2010; Christensen et *al.*, 2014; Nociarová, et *al*., 2014a).

1.1 **Anthropology and its forensic implications**

Anthropology is a discipline that can be defined as the study of humankind and, in the Anglo-Saxon context, it can be divided in four subdisciplines. The first one is Socio-cultural Anthropology, which aims to reconstruct and understand cultural groups. The second one is Linguistic Anthropology, which is interested in the origins of language and their evolution over time. The third one is Archaeology, which focuses on reconstructing the history of past populations through the study of artifacts and structures that were left behind by those populations. The last one, Physical Anthropology, studies the evolution of humans, their adaptations, variation and biological origins, and the focus of study is the populations. Furthermore, each subdiscipline of Anthropology is divided into more specialized areas of study. One of these specialized areas of study is Forensic Anthropology, which belongs to Physical Anthropology. Forensic Anthropology is defined as the application of theories and methodologies of Physical Anthropology to resolve legal matters, especially linked to the recovery and analysis of human remains. The practice of Forensic Anthropology involves estimating the sex, ancestry, age and stature from unknown human remains, and analysing the presence of individual characteristics, trauma, pathological lesions or other anomalies that may help in the identification of the individual. Usually, the examined material consists of largely or completely skeletonized remains, commingled, and/or taphonomically altered human remains (Ubelaker, 2006; SWGANTH, 2010; Tersigni-Tarrant and Shirley, 2013; Christensen et *al*., 2014).

1.2 **Taphonomy and its forensic implications**

In 1940, Ivan Efremov defined the term taphonomy for the first time, in order to explain the process of "the transition of animal remains from the biosphere into lithosphere". Efremov defined the taphonomy as the law of burials. The taphonomic study tries to reconstruct what happened to the biological remains from the death until their discovery. The main interest is the study of the observed taphonomic effects and the determination of the responsible agents. Traditionally, taphonomy involves everything affecting a corpse from the moment of the death: the study of decay, disarticulation, transport, type of burial, depositional environments, diagenesis, and completeness of fossil record (Efermov, 1940; Nawrocki, 1995; Rogers, 2010; Armentano et *al*., 2012; Christensen et *al*., 2014; Pokines, 2014; Pokines, 2016).

Taphonomy is also applied to the medicolegal sphere, and its interest is the study of postmortem processes that affect the final preservation state of remains, and so it can help to reconstruct the circumstances around the death events (Haglund and Sorg, 1997; Christensen et *al*., 2014). Forensic Taphonomy as a part of Forensic Anthropology is useful for estimating the postmortem interval. It focuses on recent past of remains, and its understanding facilitates the comprehension of events that the remains have been exposed to (Haglund and Sorg, 1997; Ubelaker, 1997; Pokines, 2016). In addition, the knowledge of taphonomic processes in local environments is beneficial for searching human remains and for explaining the context of their discovery (Christensen et *al*., 2014).

1.3 **Anthropological Research Facilities**

The major knowledge linked to forensic taphonomy comes from the foundation of different anthropological facilities around the world and from the observational studies about decomposition and postmortem modification of human and non-human remains that take place in those facilities. This type of studies increased during the last years, but the most known one is probably the research facility founded in University of Tennessee in 1980. Bass founded this Anthropological Research Facility because of his error in estimating time since death in 1977. He had underestimated the postmortem interval of Colonel Shy by 113 years. He realized that more precise information in form of controlled specific research about postmortem interval and human decomposition was needed (Bass, 1984; Tersigni-Tarrant and Shirley, 2013; Christensen et *al*., 2014). There are many questions about the decomposition process and about the influence that various climates and geographic locations can have on the decomposition rate. Since the foundation of Bass' Anthropological Reasearch Facility, a lot of new decomposition research facilities were opened. The formation of this type of study started all around the world, primarily in United States (Western Carolina Human Identification Laboratory, Forensic Anthropology Research Facility (FARF) at Texas State University in San Marcos, the facility at Sam Houston State University, the Southeast Texas Applied Forensic Science Facility (STAFS), *etc.*), and recently in Australia (Sydney) (The Australian Facility for Taphonomic Experimental Research (AFTER)) (Bass, 1984; Tersigni-Tarrant and Shirley, 2013; Christensen et *al*., 2014; Williams, 2015).

Due to the unavailability of studies with similar conditions, and/or to the difficulties related to conducting experiments with human corpses, most researches used pigs (*Sus scrofa* domestica) as proxies for human remains in decomposition studies (Cockle and Bell, 2015). In the countries were the research with human remains is not permitted, non-human research facilities were created. The example of this is the decomposition research on pigs (*Sus scrofa* domestica) that began in Catalonia (2011) and in Montana, Ilinois, among others (Payne, 1965; Armentano et *al*., 2012; Tersigni-Tarrant and Shirley, 2013; Armentano et *al*., 2014; Roberts and Dabbs, 2015; Gutiérrez et *al.,* 2016;) and on other animal species in Australia, Knoxville, *etc*. (Reed, 1958; Fitzgerald and Oxenham, 2009). The problem of using non-human models is that research to establish the differences and similarities between human and non-human (especially pig) decomposition has not been conducted. As Cockle states, these studies only created a compendium of knowledge on pig decomposition, but not on human decomposition (Cockle and Bell, 2015).

1.4 **Postmortem interval**

The correct estimation of the postmortem interval (PMI) is one of the most important tasks in Forensic Anthropology/Medicine. Its correct estimation could be essential for the exclusion of possible assailants and/or for bearing out witnesses, as well as for narrowing down the list of decedents that the remains could belong to and so increasing the chances of personal identification. The PMI refers to elapsed time since death. The calculation of time since death is very controversial. Once soft tissue is broken down, estimation of PMI becomes more complicated and more acute (Megyesi et *al*., 2005; Pinheiro, 2006a). An understanding of the postmortem decomposition process is essential for establishing a more precise PMI. A uniform decomposition model that fit for all remains and all environmental conditions does not exist. PMI is highly dependent on cause of death, biological profile, local climate, and depositional state (Willey and Heilman, 1987; Sledzik, 1998; Campobasso et *al*., 2001; Knight and Saukko, 2004; Pinheiro, 2006a; Cardoso, et *al*., 2010; Rogers, 2010).

Often, only approximation can be made, and only the combination of different methods enables an acceptable estimation of PMI. When time since death implies decades, the correct estimation only from bare remains becomes even more complex, and it is even more difficult to differentiate between a potential "cold case" from a historic or archaeological case (Klepinger, 2006; Rogers, 2006; Ferreira and Cunha, 2013).

Forensic anthropologists usually estimate PMI by means of a combination of information about gross observations of the soft tissue decomposition and their knowledge of the particular environment of the region. Their conclusions are often based on the experience from anterior cases. The PMI estimation without consideration of the taphonomic context or depositional environment is considered as unacceptable and should be avoided (SWGANTH, 2010). More accurate methods for PMI estimation were developed by other disciplines, as forensic botany, entomology and biochemistry, which use quantitative methods. Forensic entomology shows to be actually more exact for the estimation of time since death. The use of forensic entomology is based on successions of insects that are associated with the stage of decomposition. Biomarkers in various organs of the body and their association to early decomposition stages were also studied to obtain more accurate PMIs (Rodriguez and Bass, 1983; Bass, 1984; Rodriguez and Bass, 1985; Mann et *al.*, 1990; Vass et *al*., 1992; Vass, 2001; Vass et *al*., 2002; Megyesi et *al*., 2005; Simmons et a*l.,* 2010).

Different elaborated PMI estimation methodologies (Rodriguez and Bass, 1983; Behrensmeyer, 1978; Galloway et *al*., 1989; Galloway, 1997) and their modifications (Janjua and Rogers, 2008; Parks, 2011; Ross and Cunningham, 2011) are often used in different contexts because they are useful to classify the decomposition state or bone degradation. However, these methods have limited practical applicability for the specific purpose of PMI estimating (Ferreira and Cunha, 2012). The method of "Accumulated degree days" (ADD) elaborated by Vass (2011) can be used for both aerobic and anaerobic environments, but it can only be applied to cadaveric remains under 1285 ADD, i.e., remains with soft tissue still present (pre-skeletonized stages). This thus does not solve the difficulties of forensic anthropologists when analysing skeletal remains. This ADD method bases on the observation that temperature, moisture and partial pressure of oxygen have the greatest influence on human decomposition. Vass states that decay of soft tissue ceases at 1285 ± 110 ADDs. The work of Vass is based on subjective personal observations and has not been validated yet by other researchers in other regions (Wilson-Taylor, 2013). Another method, "Total body score" (TBS), presented by Megyesi and collaborators (2005), is the most commonly used nowadays. This method was elaborated only from retrospective studies, by evaluating and scoring body state using pictures of actual forensic cases. This technique demonstrates the importance of temperature as the major factor affecting decomposition rate. In this method the prediction of ADD and the decomposition state of corpse need to be analysed (Wilson-Taylor, 2013). The TBS should be used for corpses deposited superficially, without presence of saponification, and day temperature has to be known (Carter and Tibbett, 2008; Ferreira and Cunha, 2012). Ferreira and co-workers indicate strong limitations of these methods in practical cases of Forensic Anthropology. As first obstacle they mention the impossibility to obtain daily temperatures for each region where a body can be found because not all regions have professional meteorological stations. If daily temperature is known, this is temperate of air, but the temperature that affects the decomposition process is the one on the cadaveric decomposition island, i.e. the temperature of the surface for corpses decomposed on the ground or the temperature of the soil if the decomposition took place underground. Moreover, there are numerous variables that may affect the decomposition rate, and so the PMI, such as those related to the environment/meteorology (abiotic and biotic), to the individual (age, sex, body constitution, illness, *etc*.), and other case-specific factors (trauma or bonding agents) (Carter and Tibbett, 2008; Ferreira and Cunha, 2012; Wilson-Taylor, 2013).

1.5 **Postmortem changes and corpse taphonomy**

Decomposition starts approximately four minutes after death, with cessation of vital functions. Nutrients are bounding into the surrounding ecosystems and become reincorporated into landscape. Human decomposition has different phases: the fresh corps varies from discoloration and bloating to decay resulting in skeletonization, and eventually, disarticulation and skeletal bone decomposition (diagenesis). Under certain conditions the preservation of corpses or parts of them can be observed. A soft tissue that was not treated artificially will undergo a process of autolysis and putrefaction. During putrefaction, the main role is played by bacteria that alter the soft tissue and induce subsequent rupture of their protein, carbohydrate and fat constituents. There are different ways to subdivide decomposition into substages. Often decomposition is subdivided into fresh stage, bloat and active decay (putrefaction), advanced decay and skeletonization. The rate of decomposition is not the same for bodies that are earthed, submerged in water, left above the ground and exposed to inclemencies (sun, shadow, cool basement, *etc*.) (Reed, 1958; Dix and Graham, 2000; Vass et *al*., 2002; Dent et *al*., 2004; Gennard, 2007; Rogers, 2010; Damann and Carter, 2014;).

1.5.1 **Autolysis (Fresh stage)**

Autolysis can be described as the self-digestion of cells and is a part of the early stage decomposition. The loss of oxygen transport and the interruption of adenosine triphosphate occur and, as a consequence, the breakdown of the cells and their digestion by intra and extracellular enzymes befall. Autolysis is immediately followed by the putrefaction, without any clear chronological delimitation between them (Vass et *al*., 1992; Gennard, 2007; Gonzalez-Fernández et *al*., 2011). The soft tissue of the corpse is the first to become modified after death and early postmortem changes are visible in form of *Mortis Triad*. *Mortis Triad* includes three modifications of the human body during the early stage. The first one is *Algor mortis* (postmortem cooling), which is defined as a cooling of the body, when normal body temperature drops down until it balances with ambient temperature due to the lack of regulatory systems. There are many factors that may affect the rate of cooling, but generally *Algor mortis* is observable during the first 10-12 hours since death. When blood is no longer pumped through the body by the heart, and so the discoloration of the body due to the gravitational setting of blood occurs, the stage of *Livor mortis* (postmortem hypostasis or lividity) is observed. Because of gravity, the declined parts of the body develop a reddish-purple appearance. *Livor mortis* can become observable as soon as 20 minutes after death, and become fixed approximately 8-12 hours after death. *Rigor mortis* (postmortem rigidity, rigor) initiates by 2-6 hours after death and may persist for 1 or 2 days. During this stage muscles stiffen. This starts in small muscle groups and the rigidity is expanded to the larger groups of muscles. All this process is a result of the decrease of cellular ATP and pH, and of the presence of calcium ions released from the sarcomers (Perper, 1993; Clark, 1997; Dix and Graham, 2000; Di Maio and Di Maio, 2001; Rogers, 2010; Gonzalez-Fernádez et *al*., 2011; Damann and Carter, 2014).

1.5.2 **Putrefaction**

Anaerobic bacteria start to break down the soft tissue when the body is out of oxygen. During the process of putrefaction, large molecules break down into smaller, simpler structures. Bacteria that play an essential role in this process primarily come from the body colonies in the respiratory and digestive system. Later, when the integrity of body is compromised, more bacteria immigrate from the surrounding environment to the corps. A bacterial infection present in the organism prior to death normally speeds up the beginning of the process of putrefaction. The progression of this process is not the same for all corpses and there are factors that will increase or decrease its rate. The rate of putrefaction varies for obese, fit, or thin people as well as for individuals with sepsis or dehydration before death. Corpses that are exposed on open areas and that become oxygenated will also have an increased the rate of putrefaction (Reverte Coma, 1999; Dix and Graham, 2000; Campobasso et *al*., 2001; Di Maio and Di Maio, 2001; Dent et *al*., 2004; Rogers, 2010;).

1.5.3 **Mummification**

Mummification is one of the exceptions to the general decomposition process, and it is described as a postmortem preservation stage. Under certain conditions the decomposition is interrupted and soft tissues are preserved because of their dehydration and minimal bacterial proliferation. Mummification may occur under any desiccator conditions as well as hot and dry environment, freezing conditions or when moving air desiccates or dries the soft tissue and so the putrefaction is prevented. Sometimes just some parts of the body are mummified. During the mummification, the skin shrinks and darkens. Internal organs may also desiccate. Time of mummification may vary depending on the surrounding environment, body conditions and cause of death. The mummified copses can be preserved during centuries if they were free of insect invasion or of inadequate manipulation. But in normal, not hermetic conditions, an evolution of mummified tissues is observed. Normally, after several years, the mummified soft tissue starts to disintegrate because of insect action or mould action. There are two types of mummification: natural and artificial (when various chemical substances are used) (Reverte Coma, 1999; Dix and Graham, 2000; Knight and Saukko, 2004; Forbes et *al*., 2005c; Gennard, 2007; Rogers, 2010; Grenčík, 2011).

1.5.4 **Adipocere formation**

Adipocere is another postmortem decomposition product. Adipocere formation is also known as saponification and is defined as the preservation of the body because of body fat transformation into waxy or soapy substances. It is a natural type of corpse preservation and can be formed from any body fat. Conditions required for adipocere formation are humid and anaerobic environment between others. Hydrolysis of saturated fatty acids is responsible for its formation. Forbes et *al*. (2005c) state that adipocere can be formed not just in wet environment but also in dry soils. Saponification takes place because decomposition is inhibited due to fatty acids that retard the growth of putrefactive bacteria. Adipocere formation may occur in the whole body, just in internal organs or just in some parts of the body. The number of by-products is a result of hydrolysis and hydrogenation processes. Generally, different types of adipocere can be observed, depending on whether fatty acids combined with sodium, potassium, calcium or magnesium. The first type is fresh adipocere, which is soft and wet and has greyish colour and strong odour. Normally, this is indicating an early decomposition process and means that fatty acids were adhered to sodium or potassium ions. When appearance of adipocere is dry, hard, brittle and whitish in colour, it indicates that adipocere is older. In that case, cleaved fatty acids react with magnesium or calcium. Adipocere formation occurs under different environmental conditions, but it is also gender- and age-depended. There are studies that demonstrate that saponification of women and children tend to be more prevalent. Adipocere will also disintegrate when exposed to oxygen, and it has been shown that this may occur in 10 years. (Reverte Coma, 1999; Dix and Graham, 2000; Vass, 2001; Forbes et *al*., 2002; Forbes et *al*., 2005a; Gennard, 2007; Bruin, 2010; Rogers, 2010; Grenčík, 2011).

1.5.5 **Skeletonization**

Dent et *al*., (2004) defined the skeletonization as "the removal of soft tissue from bone". When skeletonization is observed, only bare bone, cartilage and some hairs are visible. This stage increases the error for PMI estimation. The rate of skeletonization differs as consequence of environmental and depositional conditions (Dix and Graham, 2000; Gennard, 2007; Rogers, 2010).

1.5.6 **Diagenesis**

When all soft tissue is washed away from the corpse and only bare skeleton is exposed, the bone also undergoes a series of decomposition processes. This natural process of decomposition is known as diagenesis. During this stage the proportion of organic and inorganic components of bone and the surrounding environment are altered. The bone can absorb the components from the soil (surface), and so exchange the ions. The collagen content of bone is degraded by the action of bacteria. The mineral portion is also degraded because of the loss of hydroxyapatite by weathering, which reduces the integrity of the bone resulting in its disintegration. These changes in osteological material can be examined by using light microscopy, scanning and transmission electron microscopy, and mass of fluorescent spectrometry (Vass et *al*., 1992; Rogers, 2010, Christensen et *al*., 2014).

1.5.7 **Skeleton disassociation**

It is important bear in mind that all skeletons were previously corpses that underwent the above-mentioned postmortem changes. Skeletons are also under taphonomic modifications that may affect their final preservation stage. In this sense, gravity, fluvial, vegetal and animal action and own decomposition action may affect the final deposition of remains (Duday, 2009).

After placing the corpse in the tomb and after decomposition of soft tissue taking place, some movement of bones and so disassociation of articulations may occur. The difference in the term “articulation” in medical and archaeological contexts has to be highlighted. In medical context, articulation refers to the joint itself, including bone, ligaments, aponeurosis and muscles. From the archaeological point of view, articulation refers to just bone segments without soft tissues (Duday, 2009). In order to correctly understand the post-depositional movements of bone elements, it is necessary to understand the consequence of soft tissue decomposition, the sequences of skeleton disassociation or disintegration of connective tissues, and the potential amplitude of skeletal elements (Roksandic, 2002).

Articulations in the archaeological context may be divided by their persistence in time. Time and order of destruction or failure of articulation vary considerably with funerary practices and the conditions of the body. Some articulations are lost almost immediately and others persist for a longer time. Duday and co-authors defined two types of articulations: labile articulations and those that are persistent. Labile articulations are those whose whole integrity is broken down earlier. When these labile articulations are preserved, maybe a short time between death and entombment pass by, and/or we are possible in front of a primary burial. Some small bones from the cervical spine, hands and distal foot, or fragile bones from the scapula-thoracic union, are those that form the labile articulations. Duday describes the persistent type of articulation as that that persists beyond the process of decomposition. The bone connections that suffer great biomechanical stress are those more persistent (articulation between occipital and atlas, lumbar spine region, articulation between L5 and sacrum, sacrum-ilium, acetabulofemoral and knee and ankle articulation, tarsus) (Duday et *al.*, 1990; Roksandic, 2002; Duday and Guillon, 2006; Duday, 2009).

Not only the articulation type determines the final position of the body segments. The environment where decomposition took place, as well as circumstances around the death deposition (position of corpses), are also important. It is very important to consider the type of clothing that the deceased dressed during decomposition. Generally, clothes offer a protective barrier against weather, and partly against insects. Clothing usually consists of several sections that variously cover the different parts of the body. On the other hand, wrapping is also common and usually includes using one single piece of material around the deceased. The wrapping process can be arranged in various ways and it can exert widespread or localized pressure on certain anatomical areas depending on its arrangement around the corps. In addition, the character of the disassociation of articulations will not be the same for corpses decomposed in a filled space or in empty space, as well as corpses in primary or secondary deposits. Decomposition in empty space (in a void) is characterised by higher articular disassociation and by movement of skeletal elements. The rank of this movement and disassociation is linked to the effects of gravity and also highly dependent on the position of the corpse. The void can be simulated by coffin, burial chamber, wooden framework, *etc*. Generally, bone without any soft tissue is exposed to potential disequilibrium in relation to the space occupied by the corpse, and so it is expected to fall into this space when it decomposes. If this fall did not happen, it means that something had prevented its disequilibrium. Some obstacle gave the support to the bone. One of the factors that prevent the fall could be presence of soil or clothes. Decomposition in a filled space indicates slow replacing of soft tissue in decay by soil particles, and so the articular association is maintained (Duday et *al.*, 1990; Roksandic, 2002; Duday and Guillon, 2006; Bouqin et *al.*, 2013).

1.6 **Intentional modification on the corpses**

Once the vital functions cease, corpses are subjected to different procedures. These procedures may include forensic or thanato- treatments, when experts manipulate the body. The interest of these procedures varies.

1.6.1 **Autopsy**

There are essentially two types of autopsies, those done in hospitals, called clinical autopsies, and those executed in a medicolegal context, called forensic autopsies. The intention of clinical autopsies is to clarify or confirm diagnosis that were not sufficiently clear during the patients' stay in the hospital/ health institution or because the diagnosis of the patient was unknown. Physicians have to examine carefully the deceased body before its burial. Not all corpses pass undergo a forensic examination. Corpses where cause of the death is not clear or that are suspected to have gone through a violent death need to be forensically evaluated. Forensic autopsy is realized under the direction of a legal authority. These autopsies focus on violent deaths, suicides, or sudden deaths. The objective of a forensic autopsy is the determination of cause and manner of death. There are some differences between the procedures of forensic and clinical autopsies, but generally the process of autopsy starts with external examination, followed by internal examination and complementary studies. For internal examination, the skull and other body cavities have to be opened for exploration of internal organs (Pinheiro, 2006b; Pomara et *al*., 2010; Garamendi González and López Alcaraz, 2011; Nociarová et *al*., 2014a).

1.6.2 **Thanatopraxy**

Once the corpse is moved to a funeral home, it is treated before it is exposed to the family and subsequently earthed or cremated. Principally, this includes thanatopraxy and thanatoaestetic treatments.

The thanatopraxy treatment includes the washing and disinfection of the corpse, and all the methods of mortuary praxis that allow the conservation and exposition of the corpse with all health securities. The treatment necessary for a corpse will depend on its conditions. The body may undergo an embalming process that includes the injection of chemicals into the vascular system. There are different methods for embalming and it varies among funeral homes and embalmers. The aim of embalming is the temporal preservation of the body during the funeral ceremony or body transport to another country. When just a partial treatment of the corpse is performed, the aspiration of blood, gases and other body fluids takes place. Filling the nostril and/or oral cavities with cotton is also usual. A specially produced mouth former was used before too. The function of cotton packing or mouth former is to prevent leakage of fluids, and to facilitate the shaping of lips. Sewing of upper and lower jaws together is another practice in thanatopraxy. This can be done in different ways: they can be just tied together, which is the method actually more used, or injector needles can be inserted in each gum line and attached by wire, which holds the mouth closed. The latter is an old technique that is actually not widely used. In the ocular socket, an eye cup is placed. An eye cup is a thin, plastic and transparent disc used to shape the eye and keep the eyelid closed. The concave surface is smooth and it is placed direct over ocular globe. The convex surface of the eye cup is spiny and facilitates the gripping of the inner surface of the eyelids. When ocular globes are removed, cotton beads can be placed under the eye cups. During thanatopraxy, clothes are also modified. To facilitate the dressing of the decedent, the clothes are cut on their posterior side. In some cases, the funeral home wraps the decedent with a funeral sheet. Another sign of thanatopraxy and/or clinical treatment are the diapers used to reduce the possibility of fluid leakage during the funeral ceremony (Berryman et *al*., 1991; Nociarová et *al*., 2014a; personal consultation with embalmers).

As a special case of funeral practice, an enzyme and microorganism pack is placed into the coffin before its deposition in the niche. This product should be a decomposition accelerant that promotes liquefaction and digestion of fats, proteins, starch, and cellulose. This product is activated by water or body fluids (Nociarová et *al*., 2014a).

1.6.3 **Thanatoaestetic**

During thanatoaestetic praxis, the face, hair, neck, hands, and nails are mainly treated because of the exposition during ceremony. When the decedent presents some disfiguring trauma, wax is commonly used for cosmetic restoration of the face. Different lotions for hydrating of the exposed parts can be used, and subsequent use of cosmetic make up is also common (Berryman et *al*., 1991; Nociarová et *al*., 2014a; personal consultation with embalmers).

1.6.4 **Funerary ritual in Spain**

The funeral customs differ among countries. In some countries the coffin with human remains is earthed in the ground while in other countries, including Catalonia, the coffins with corpses are placed in cement vertical structures called niches that may be located over or underground or in pantheons. The maximum high of niches also varies among countries and cemeteries.

In Catalonia the customary treatment of deceased individuals includes cleaning, disinfection, clothing and placing in the coffin. Typically, the lower and upper jaws are tied together. In Catalonia, the embalming process is not a routine practice and just some corpses undergo this procedure, for example when they are transported to other or from other countries. In some cases, a partial treatment of the body takes place, and the aspiration of visceral cavities is needed. After the funeral ceremony, the coffin is taken to the cemetery and placed into sepulchres (niches or pantheons). Inhumation takes place after at least 24 hours from the death.

Exhumations can occur as a consequence of lack of space within cemeteries. In order to store the bags with exhumed human remains, special building or spaces, known as ossuaries, are built in cemeteries. According to the Spanish mortuary health laws, the transfer of human remains to ossuaries can be carried out only after five years from the inhumation. When the term of temporary concession expires, the remains can be transfer to the ossuary. When this happens, exhumation of unclaimed human remains takes place (DOGC 2528-28.11.1997; BOP 240, 2000; Ordenanza de Cementerios, 2007; Nociarová et *al*., 2014a).

1.7 **Antemortem lesions and personal identification**

In Forensic Anthropology, description and determination of pathological or traumatic lesions can be useful in addition to the elaboration of a biological profile for individual identification. Unique skeletal characteristics may help to distinguish one person from another. The observation of these characteristics and other abnormal skeletal conditions can also help clarify the cause and manner of death. If the antemortem data can be compared to postmortem data, the list of missing people can be narrowed down and personal identification can be confirmed. The exhaustive evaluation of possible pseudopathologies, antemortem alterations, degenerative diseases, congenital disorders, metabolic disturbances, neoplasias, rheumatic diseases, infectious disorders, circulatory diseases, and traumatic lesions should be done (Breitmeier et *al.*, 2005; Cunha, 2006). This information can help the identification of the deceased, and so detailed examination of remains has to be done using radiological methods if possible, as well as macroscopically.

Chapter 2 **JUSTIFICATION OF THE THESIS**

Nowadays, principally in USA, all cases presented in court have to obey Daubert standards, which provide a rule of evidence regarding the admissibility of expert witnesses' testimony. There is a lack of experimental studies linked to human decomposition in Spain, which is strictly related to the lack of guides or manuals that can be used during court testimonies. This absence of guidelines prompted this study.

The idea of this experimental study came from the lack of information about postmortem interval in the local conditions of Catalonia. Vass and his co-workers in their paper about the determination of time since death stated that "a method that is reliable can be applied worldwide under a variety of conditions and circumstances" (Vass et *al*., 1992). It is evident from various cases that a uniform model that will fit all the cases does not exist. Each corpse and each climate location are unique and therefore experimental works about human decomposition that fit with concrete climate factors of each zone are needed.

There are no anthropological research facilities in Europe as those founded in USA. Therefore, the interest is to carry out research about human decomposition and decomposition rates under partial control of the conditions. This will facilitate information useful in both Forensic Anthropology/Medicine and Archaeology. Unclaimed human remains exhumed in cemetery contexts can be used as proxy for researches run in USA. Research with remains from cemeteries allows using numerous human remains, partially controlling extrinsic and intrinsic conditions, as well as having in some cases some basic antemortem information about the deceased. These types of analyses can be considered as a first step for the study of human remains decomposition.

Chapter 3 **OBJECTIVES**

The main aim of this thesis is to investigate both extrinsic and intrinsic taphonomical variables that may affect the final cadaveric state of human remains from different cemeteries and so interpret the decomposition of the human corpse and the factors that have an influence on it in Mediterranean climates. Whit this aim, the following specific objectives have been established:

I. To categorize the observed cadaveric states of human remains from cemetery context by their time since dead, searching for an eventual temporal pattern.

II. To test if there are differences in the observed cadaveric state among cemeteries and, if so, to define their causes, in order to understand the dynamics of every cemetery.

III. To evaluate the influence of the external (meteorological data, burial place, clothing, *etc*.) and internal (age, sex, cause of death) factors on the observed cadaveric state.

IV. To verify the relevance of some personal characteristics (including the biological profile of the person) in the identification process of a verification in a cemetery.

V. To identify the artefacts linked to cemetery remains in order to differentiate between remains from civil cemeteries and those that come from archaeological or clandestine inhumations.

VI. To describe and evaluate the observed joint disassociation pattern of the exhumed corpses/skeletons and its association to funerary practices.

Chapter 4 **MATERIALS AND METHODS**

“I see no more than you, but I have trained myself to notice what I see”.

Sherlock Holmes, *The Adventures of the Blanched Soldier.*

4.1 **Study sample**

For this study three state cemeteries from Barcelona were analysed: Cemetery of Terrassa (CT; Societat Municipal de Serveis Funeraris de Terrassa), Cemetery of Montjuïc (CBMN) and Cemetery of Collserola (CBCLL) (Cementerios Barcelona A.S.). Cemetery of Terrassa is located on the Catalan Pre-Coastal Range, Cemetery of Montjuïc on the Catalan Coastal Depression, and Cemetery of Collserola on the Catalan Coastal Range. All of these three cemeteries have a Mediterranean climate (Figure 1).

During this research, unclaimed human remains were exhumed. The access to the unclaimed human remains was facilitated by cemetery authorities (La Societat Municipal de Serveis Funeraris de Terrassa; Cementeris de Barcelona A.S.) to the Universitat Autònoma de Barcelona for the observational study. An official agreement of collaboration with cemetery authorities and a health license were approved. The exhumations started in Cemetery of Terrassa in March of 2013 and finished in Cemetery of Montjuïc in February of 2015. In total, 301 corpses were exhumed.

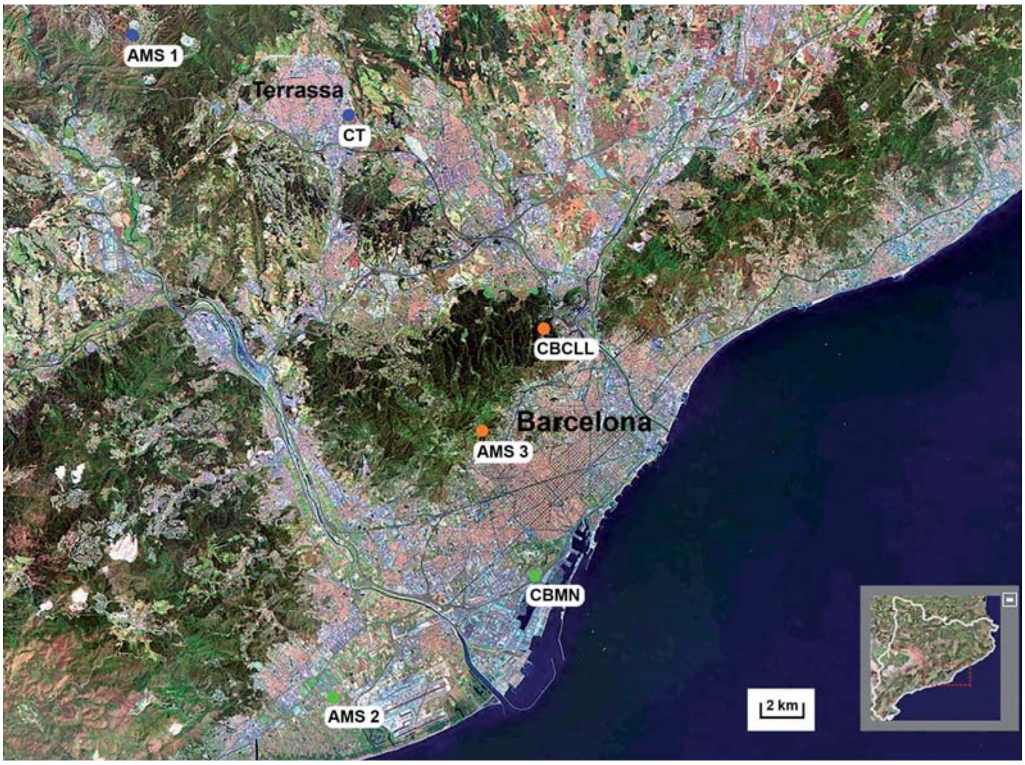


Figure 1. Aerial map of the location of the cemeteries; Cemetery of Terrassa (CT; blue point), Cemetery of Collserola (CBCLL; orange point), and Cemetery of Montjuïc (CBMN; green point); source *Google maps*. AMS1 (Automatic Meteorological Station Vacarisses); AMS2 (Automatic Meteorological Station Viladecans); AMS3 (Automatic Meteorological Station Observatori Fabra).

4.1.1 **Terrassa**

Cemetery of Terrassa was built in 1932 and designed by architect Melcior Vinyals i Muñoz. It extends 11 hectares and contains approximately 30000 sepulchres, including underground burials, niches and pantheons. The cemetery has the character of park or garden with structures of niches of maximum seven storeys high (Figure 2) (http://funerariaterrassa.cat/cementiri-4/).

Figure 2. Map and aerial photo of Cemetery of Terrassa.

4.1.2 **Montjuïc**

Cemetery of Montjuïc was funded in 1883 by the municipal architect Leandro Albareda and today it contains more than 155227 tombs in an area of 560 000 m^2. It is located in one of the rocky slopes of Montjuïc hill in Barcelona. In this cemetery, there are underground burial, pantheons and niches with six storeys high at the most (Figure 3) (http://www.cbsa.cat/cementiri-monjuic/).

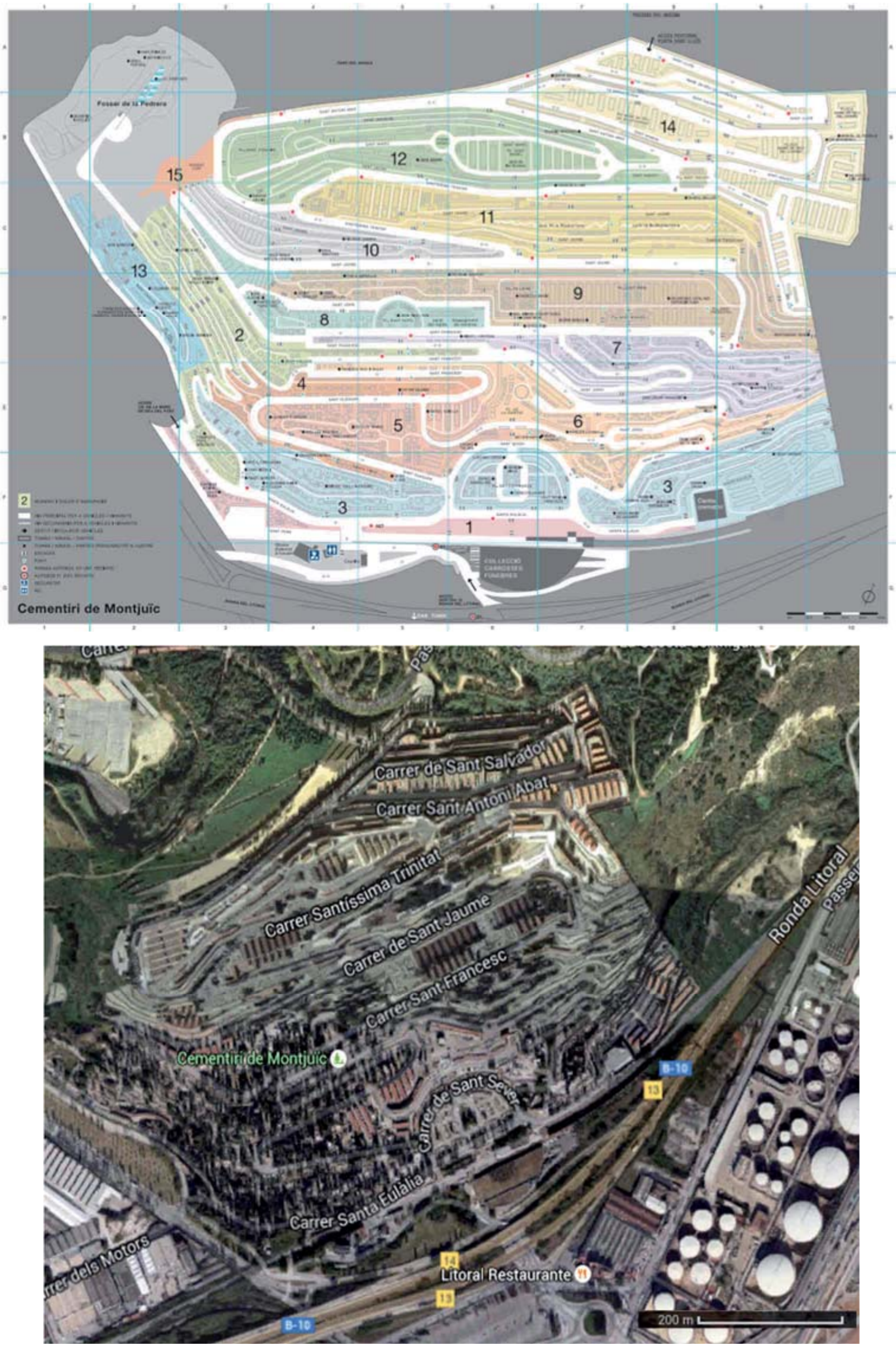


Figure 3. Map and aerial photo of Cemetery of Montjuïc.

4.1.3 **Collserola**

The Cemetery of Collserola was inaugurated in 1978, and it is extends 180 hectares on the forest area of one side of the Collserola Mountain. This new cemetery was funded when the Cemetery of Montjuïc could not be further expanded in the end of 1960. This cemetery is located between the three municipalities of Barcelona, Cerdanyola del Vallès and Montcada i Reixac. The area is divided into 18 sectors organized in an orthogonal layout with three or four blocks of tombs with generally five storeys high. The character of this cemetery is similar to a natural park with a lot of vegetation. Pantheons, underground burials and niches may also be found in this cemetery (Figure 4) (http://www.cbsa.cat/cementiri-collserola/).

Figure 4. Map and aerial photo of Cemetery of Collserola.

4.2 **Variables**

In the begging of this research, the *exhumation sheet* (Annex) was elaborated. It includes the information about exhumation process, and all the information associated to the biological profile of the deceased individual, the cause of death if available, the deposition state, the description of the cadaveric state, the information about clothing, the state of articulation if observable, the observed fauna, schemes of body/skeleton, *etc*., are recorded there (sex, age, ancestry, stature/weight, illness/pathology/trauma) (Martin and Saller, 1975; Ferembach et *al*., 1980; Masset, 1982; Lovejoy et *al*., 1985; Krogman and Iscan, 1986; Brothwell, 1987).

The deposition state refers to information about the situation of niche in the cemetery. This includes the height of the niches in relation to the total high (number of row), type and measurements of the coffin, presence of plastic body bag, presence of other cloth tissue inside of coffin, and presence of pillow.

Information about clothing was also recorded: the type of clothing (cloth or funerary sheet), number of layers for three different parts of the body, and the state of conservation of clothes. The presence of different objects, including personal objects, was observed too.

As mentioned above, this document was used during the intervention in the cemetery. In all cases, day of exhumation was recorded to calculate time since death/postmortem interval (PMI).

The anthropological intervention took place in the same day of exhumation or in an interval of two days at the most.

4.3 **Meteorological data**

The meteorological data was solicited from the meteorological service of Catalonia (www.meteocat.cat). After consultation with this service, the three nearest automatic meteorological stations to each cemetery were identified (Figure 1). The date of start of meteorological measurements varies among stations. The meteorological data that were obtained for each station are the following: temperature (minimum, average, maximum), accumulated rainfalls, relative humidity (minimum, average), global solar irradiation, wind velocity measured at a height of 2 meters (average, maximum), wind velocity measured at a height of 10 meters (average, maximum), and evapotranspiration.

-Automatic Meteorological Station Vacarisses (coordinates: 1.91500, 41.59252)

This station is located in the area of Vallès Occidental, and meteorological data obtained from this station were used for individuals exhumed from Cemetery of Terrassa because of their similar environmental conditions and their closeness (approximately 10 km in aerial distance). The measurements of meteorological data in this automatic meteorological station started on February 15th 1996.

-Automatic Meteorological Station Viladecans (coordinates: 2.03787, 41.29928)

This station is situated in the area of Baix Llobregat, and meteorological data obtained from this station were used for individuals exhumed from Cemetery of Montjuïc because of their similar environmental conditions and their closeness (approximately 10 km in aerial distance). The measurements of meteorological data in this automatic meteorological station started on April 29th 1993.

-Automatic Meteorological Station Observatori Fabra (coordinates: 2.12388, 41.41843)

This station is situated in area of Barcelonès, and meteorological data obtained from this station were used for individuals exhumed from Cemetery of Collserola because of their similar environmental conditions and their closeness (approximately 5 km in aerial distance). The measurements of meteorological data in this automatic meteorological station started on November 3rd 1995.

4.4 Anthropological and Taphonomical assessment

Interventions in all cemeteries follow a specific determined order. The procedure started with the opening of the niche and finished with the deposition of the remains in a plastic body bag and their placement in the ossuary. Normally, the study took place in a specific zone of each cemetery, without public access. In the case of Cemetery of Terrassa, and the Cemetery of Collserola, outer separated zones were used for this purpose. In the Cemetery of Montjuïc, the research took place in a thanatopraxy room in the crematory installation.

4.4.1 Niche opening

This part of the procedure was done by funeral technicians. The remains were found in the niche in two different ways, depending on character of the niche. If the niche was individual, just one coffin was deposited inside. If the niche was familiar, one coffin and other remains in body bags could be deposited inside (two or more individuals). The coffin and/or body bags with remains were pulled out as carefully as possible to avoid movement of skeletal elements.

4.4.2 **Remains transfer**

After opening the niche, the remains in coffins or body bags were transported to a separate zone for their study away from public access. In the case of Cemetery of Montjuïc, the remains were deposited in a cooler, while in the case in Cemetery of Terrassa the remains were saved in space specially enabled for this study, which was a new building in the moment of the study. Cemetery of Collserola facilitated for the storage a separated room close to zone where the study took place. Normally, the study took place in the same day or within the next two days after exhumation of the remains.

4.4.3 **Verification I**

Before the examination and description of the remains, verification of information took place. In this step just a simple comparison of the deceased name in the list facilitated by funeral home/cemetery and information recorded on the coffin or body bag was done. If the information was consistent, the external examination of corpse was the next step.

4.4.4 **External examination**

External examination consisted in the observation and description of the coffin, clothes and body. The position of the deceased individual in the coffin or body bag was also described. The basic information about coffin type (wood/conglomerate) and measurements and form (rounded, rectangular, crystal window presence, *etc*.) was recorded. Then, the position of body was described (*Exhumation sheet,* see Annex).

Clothing was observed too and type of clothing (cloth/funerary white sheet) was described. The number of pieces and layers of clothing was also counted. The presence of other cloth material, such as blankets, and also the way in which the body was covered, was recorded. When all description of clothing was done, clothes were cut for corpse observation.

The presence of fauna was also documented in this step.

4.4.5 **Verification II**

When naked corpse or skeleton was exposed, the estimation of the biological profile using the anthropological methodology was made. The obtained information on the biological profile was compared to the information that funeral home/cemetery provided.

4.4.6 Codification

If the results of Verification II agreed with the biological profile, the individual was subsequently codified in order to maintain anonymity. The code varies between cemeteries and includes the abbreviation of the cemetery and the number of niche that had been studied. Therefore, all corpses from Cemetery of Terrassa were codified as CT (Cemetery of Terrassa); those from Montjuïc as CBMN (Cemetery of Barcelona Montjuïc); and CBCLL was used for those from Collserola (Cemetery of Barcelona Collserola). The abbreviation followed with the number of exhumation in the order in which they were performed (for example, CT56 means exhumed niche number 56 of Cemetery of Terrassa). If more than one body was in the same niche, a decimal number indicated the number of individual (CBMN89.2 means second individual of the exhumed niche number 89 of Cemetery of Montjuïc). Name and surname of decedent were never used for this study from this moment of codification on.

4.4.7 Cadaveric state description

The cadaveric state was described for 7 anatomical parts separately (skull and mandible; thorax; superior extremities; hands; abdomen; inferior extremities; and feet). The overall cadaveric state was also evaluated describing the corpse as a whole. The anterior and posterior parts of body were also examined, as well as the presence and type of skin adnexa. In the beginning of the study ten different cadaveric states were described (Nociarová et *al*., 2014b); total skeletonization (TS), skeletonization with dry putrid matter (DPM), skeletonization with wet putrid matter (WPM), desiccation/mummification (M), saponification (S), corification (C), skeletonization with desiccation (SD), skeletonization with dry putrid matter and desiccation (DPMD), skeletonization with wet putrid matter and saponification (WPMS), and skeletonization with wet putrid matter and desiccation (WPMD). For specific statistical analysis the cadaveric states were grouped into five or three groups. The five groups of cadaveric state maintain: **total skeletonization** (TS), and **mummification** (M) as groups apart. Groups of DPM and SD were aggregated into one state of **skeletonization with dry putrid matter and partial desiccation** (DPMD). WPMD and WPM were aggregated into a state of **skeletonization with wet putrid matter** (WPM). S and WPMS were aggregated into a state of **saponification with wet putrid matter** (SWPM). The three groups of cadaveric state used during study are: **total skeletonization** (TS), **wet cadaveric state** (WC) (including skeletonization with wet putrid matter, and saponification with wet putrid matter), and **dry cadaveric state** (DC) (including skeletonization with dry putrid matter and partial desiccation, and mummification).

4.4.8 **<u>Internal examination</u>**

Internal examination differed depending on the cadaveric state. If the body was mummified, the thorax and abdomen were opened for internal exploration, whereas the interior of the skull was observed through the foramen magnum. In this step, different instruments were used for the opening of cavities (scalpels, garden shears, scissors, anatomical tweezers, *etc*.). The presence/absence and state of conservation of internal organs was recorded.

In the case of partially or totally skeletonized remains, the internal description included a description of the articulation state/pattern. In all cases, basic odontological features were recorded.

All traumatic and pathological lesions were recorded. The macroscopic observation of antemortem and perimortem lesions as well as postmortem alterations were described.

Antemortem data on the exhumed individuals were requested to Generalidad de Catalunya, Observatori Salud (Barcelona). The cause/circumstances of death were special focus of interest.

4.4.9 **<u>Photo documentation</u>**

All the Anthropological/Taphonomical procedure mentioned above was completed with an exhaustive photo documentation. The corpses were photographed both dressed and naked (bare skeleton), firstly entire and then divided in parts (superior, medial, and inferior) in anterior view. In the case of conserved bodies, the posterior part of the corpse was also photographed. In the case of skeletal remains, the photo of the part of bone that was in contact with substrate was taken. All pathological and traumatic lesions, articulation and anatomical variation were also photographed.

4.5 **Statistical analysis**

<u>Non parametric test</u>

All statistical analyses were performed using IBM© SPSS 22.0.0.0., and R- Deducer. Most data did not follow a normal distribution, and thus nonparametric tests were performed.

Kruskal-Wallis tests were used to assess the differences among groups for numerical data. In case significant differences were found, the Mann-Whitney test with the Bonferroni correction was employed to determine between what pairs of groups differences were significant.

The association between pairs of qualitative variables was tested using Chi-squared tests or Fisher's exact tests (depending on the sample size for each test and the percentage of expected frequencies with less than 5 cases). For statistical analysis, the cadaveric state of the remains was grouped and coded in 5 groups (total skeletonization, skeletonization with wet putrid matter, skeletonization with dry putrid matter and partial desiccation, mummification, saponification with wet putrid matter), except for those cases in which the size of sample was to small to properly compute the test with the above-mentioned statistical software. In those cases, only three groups of cadaveric state were used: total skeletonization, wet cadaveric state and dry cadaveric state.

Chapter 5 **RESULTS**

"Who saw him die?"

"I" said the fly

"with my little eye, I saw him die"

Anon, Who killed Cock Robin

5.1. Reference sample

The exhumation works for this study started in Cemetery of Terrassa (CT) in March of 2013 and finished in Cemetery of Montjuïc (CBMN) in February of 2015. In total 301 corpses were exhumed. The number of exhumed corpses varied in each cemetery, and no selection of individuals was conducted. Remains that were exhumed included both sexes and all age categories (predominantly adults) with and without traumatic or pathologic lesions. During this study the importance laid on the individuals with basic antemortem information: the date of funerary service or date of death; sex and age of the deceased; and when available the cause/manner or circumstances of the death. The total number of 301 corpses does not include the corpses without any antemortem or funerary information. In some cases in Cemetery of Montjuïc (12) and in Cemetery of Collserola (CBCLL) (10), corpses without any information were studied. In those cases, just photographic documentation and description of cadaveric state was done, but those corpses were not taken in consideration for this study neither for the statistical analyses. In other cases, incomplete antemortem information was available. In the case of niches where more than one individual were hosted, not all inhumed individuals had known date of death or information about age or sex (39 multiples niches in total, CT: 37 with a maximum of 9 corpses inside of one niche; CBMN and CBCLL: 1 with maximum of 2 corpses).

5.1.1 Size of sample

Table 1 and Figure 5 summarize the sample used for this study. In the Cemetery of Terrassa, 169 corpses were exhumed. The first exhumation was done on March 12th 2012 and the last one on May 19th 2013. In total twenty-four anthropological interventions took place in this cemetery.

In the case of Cemetery of Montjuïc, the exhumation works included 106 corpses (those with antemortem data) during fifteen anthropological interventions. The first exhumation took place on May 9th 2013 and the last one on February 6th 2015. In addition, 12 corpses without antemortem data or depositional information were exhumed. As mentioned above, those 12 corpses were excluded from the study.

Cemetery of Collserola was the place where fewer corpses were exhumed. Just 26 corpses with antemortem data were available for this study during four anthropological interventions. The exhumations started on December 4th 2013 and finished on February 19th 2015. Because of difficulties in terms of availability of funerary personal for exhumation during the study, we decided to finish the study in this cemetery. Ten corpses that did not have any antemortem or depositional information were also exhumed, but they were excluded from the study.

The more ancient corpse of this study was exhumed in Cemetery of Terrassa and was buried in 1937 (in the CBMN: 1942; in the CBCLL: 1944). The more recent corpse of the study also was from Cemetery of Terrassa and was inhumed in 2009 (CBMN: 2008; CBCLL: 2008).

Table 1. Number of analysed corpses in each cemetery that were used for this study.

Cemetery	Cemetery Abbreviation	Analysed Corpses	Percentage (%)
Terrassa	CT	169	56.1
Montjuic	CBMN	106	35.2
Collserola	CBCLL	26	8.6
Total		**301**	**100%**

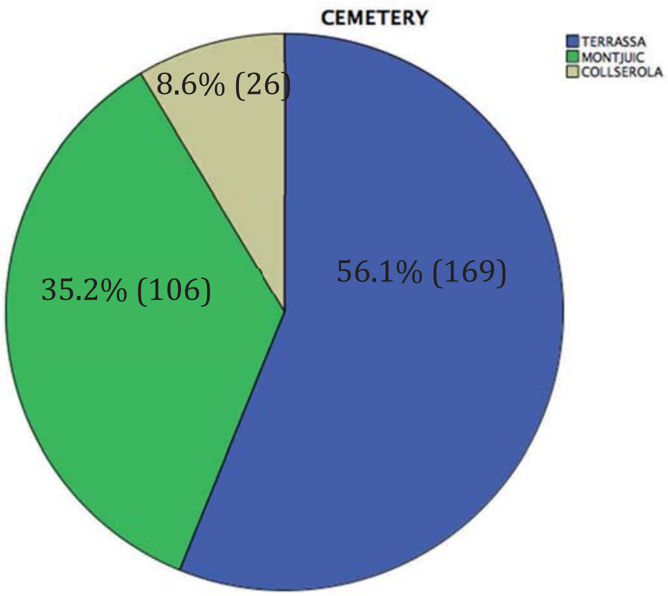


Figure 5. Distribution of exhumed corpses among cemeteries.

5.2. **Sex distribution**

In 93.4% (281) of cases from a total of 301 exhumed corpses, it was possible to know the sex of deceased after confirmation by the anthropological analysis. Taking into account all individuals with available sex information from the three cemeteries, 44.5% (125) of corpses belonged to male individuals, while 55.5% (156) belonged to female individuals (Figure 6). In Cemetery of Terrassa, information about sex of individuals was available in 88.2% (149 corpses), with 48.3% (72 cases) of feminine individuals and 51.7% (77 cases) of male individuals. Cemetery of Montjuïc provided 106 corpses with available information about sex of individuals; 63.2% (67 cases) of exhumed individuals were feminine, and 36.8% (39 cases) were males. In the case of Cemetery of Collserola, all exhumed corpses disposed of known sex, with 65.4% (17 cases) of feminine individuals, and 34.6% (9 cases) of male individuals (Figure 7).

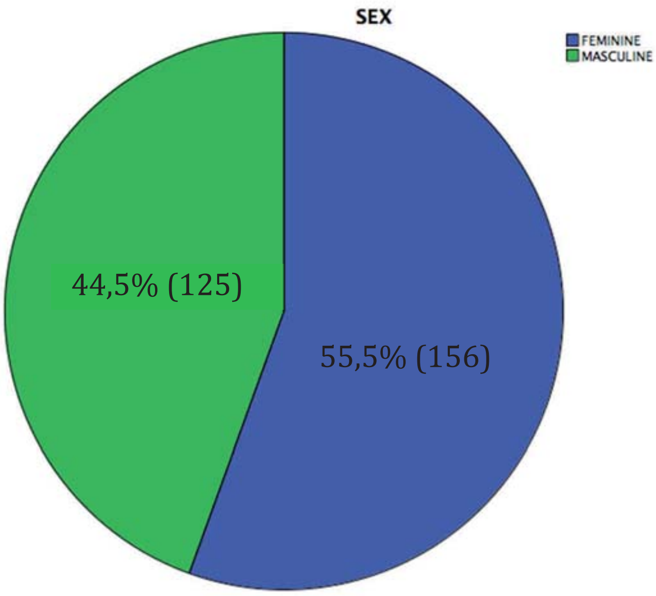


Figure 6. Sex distribution of individuals with available information about sex (93,4%) in all the cemeteries.

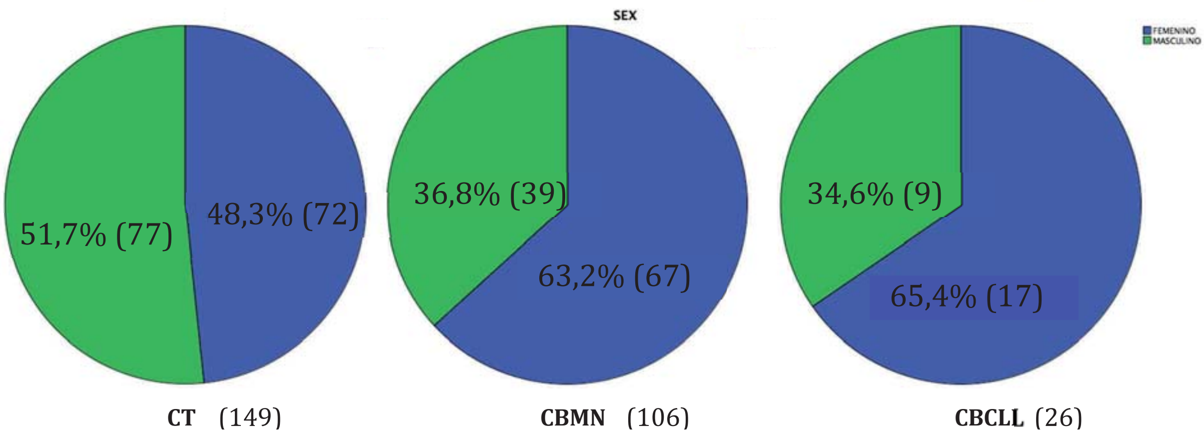


Figure 7. Sex distribution of individuals in each cemetery separately (CT: Cemetery of Terrassa; CBMN: Cemetery of Montjuïc; CBCLL: Cemetery of Collserola).

5.3 **Age distribution**

Most of the exhumed individuals from all three cemeteries were adult, older than 21 years of age. 19.6% of the individuals did not have available information about their exact age, and so age group (adult or subadult) was estimate by means of classical anthropological approaches (Crétot, 1978; Krogman and Iscan, 1986; Brothwell, 1987; Ubelaker, 1989; Scheuer and Black, 2000;). From the total number of 301 exhumed corpses, 9.6% (29) remained as the adult indeterminate group (ADINDET) after anthropological analysis. Important part of the exhumed corpses, concretely 76.4% (230), pertained to the adult senile group (ADS) (more than 61 years). Only 8.6% (26) belonged to the adult mature group (ADM) (41-60 years), and 3.3% (10) to the adult young group (ADJ) (21-40 years). The smallest group of exhumed individuals, 2.0% (6) were the subadults (SA) (0-20) (Figure 8). The mean age of exhumed individuals was 72.6 years (SD 20.11 years).

When each cemetery was analysed separately, in CT, 8.3% (14) of the exhumed individuals were determined just as adult indeterminates. 78.1% (132) of the corpses were adult senile individuals, 5.9% (10) adult mature individuals, and only 5.3% (9) were adult young individuals. The subadult group was the one with lowest representation, only 2.4% (4) (Figure 9).

In the case of CBMN the age distribution is similar, with the predominating group of the adult senile individuals, which represent 76.4% (81). The senile group was followed by 11.3% (12) of individuals from the adult indeterminate group, 9.4% (10) of adult mature individuals, and 1.9% (2) of individuals from the subadult group. In Montjuïc the group with the lowest representation were the adult youngsters, with only 0.9% (1) (Figure 9).

When age distribution in CBCLL was analysed, only three out of the five age groups were represented: 65.4% (17) of individuals were from the adult senile group, 23.1% (6) from the adult mature group, and 11.5% (3) from the adult indeterminate group (Figure 9). Individuals from the subadult or adult young groups were not observed.

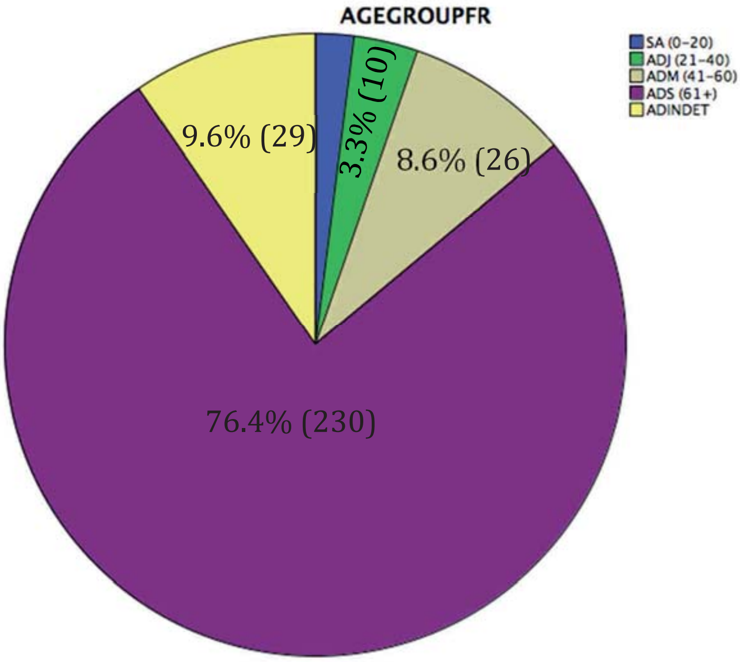


Figure 8. Age distribution of individuals with available information about age (90.4%) and those determined as adults indeterminate because of lack of age information (9.6%) in all three cemeteries.

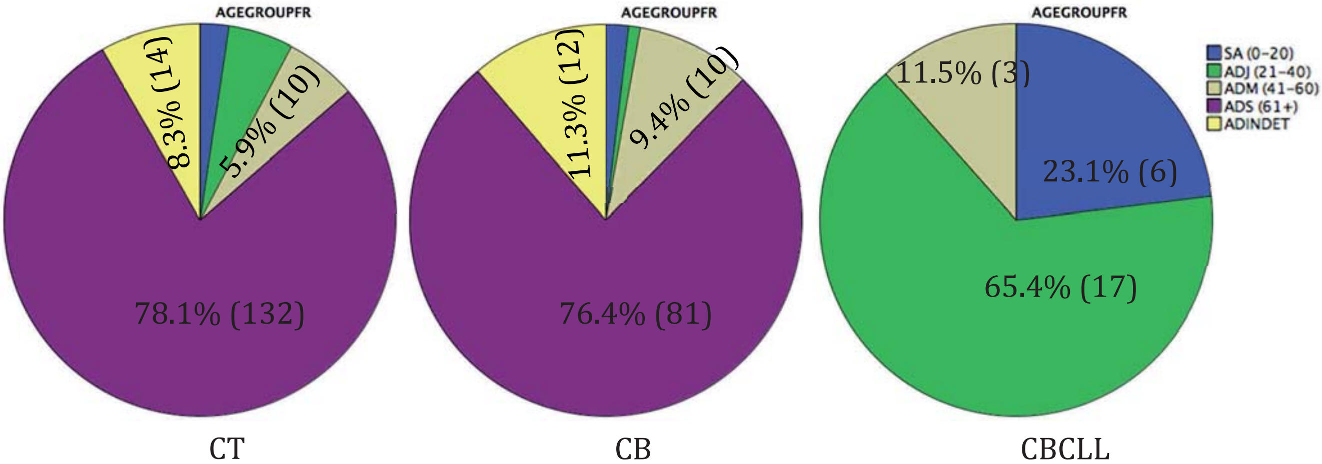


Figure 9. Age distribution of individuals in each cemetery separately (CT: Cemetery of Terrassa; CBMN: Cemetery of Montjuïc; CBCLL: Cemetery of Collserola).

5.4 **Artifacts**

During fieldwork in cemetery different artifacts that seemed to be linked to funerary and other practices that corpses underwent before they were earthed were observed. Artifact may be defined as any feature or object, product of extrinsic agent (autopsy or funerary treatment) that is not naturally present in human corpse. The artifacts can be found near and/or on the corpses. The major part of study about artefact was done in Cemetery of Terrassa, where they clearly predominated (Nociarová et *al*., 2014a) (Table 2).

The artifacts were divided into four types according to treatment/practice performed previously:

1. Autopsy practice (Figure 10).
2. Thanatopraxy: sewing of upper and lower jaw together (Figure 11); cotton packing (Figure 12); embalming of the body, aspiration trocar button (Figure 13); eye cups (Figure 14); posterior cut of clothing (Figure 15); remains of cosmetic wax; presence of diapers (Figure 16); and presence of decomposition acceleration products (an enzyme and microorganisms pack) (Figure 17).
3. Funeral practice: coffin wear; fungal growth (Figure 18); sawdust from coffin adhering to body (Figure 19); unpigmented fauna (Figure 20); and circular hair loss in the posterior part of skull (Figure 21).
4. Forgotten objects and those associated with funeral customs, autopsy practice or thanatopraxy (Figure 22), and personal objects (Figure 23).

Figure 10. Skull with signs of autopsy and absorbent material inside of cranial cavity.

Figure 11. Sewing of upper and lower jaws together (a). Waxed thread rest in upper jaw and cotton packing of mouth and nostril are observed (b)

Figure 12. Cotton packing of nostril and mouth.

Figure 13. Presence of trocar button in the anterior part of abdomen (red arrow).

Figure 14. Presence of eye cups.

Figure 15. Posterior cut of cloths

Figure 16. Diapers presence.

Figure 17. Decomposition accelerant product.

Figure 18. Fungal growth on the deceased face and right hand.

Figure 19. Sawdust from coffin adhering to skull.

Figure 20. Presence of living unpigmented fauna (red circle).

Figure 21. Circular hair loss in the posterior part of skull.

Figure 22. Presence of some forgotten objects (catheter or chirurgic gloves) in/on the deceased body.

Figure 23. Presence of some undetermined personal objects (a, b), presence of gold ring on the right hand (c), and artificial cardiac peacemaker (d).

As mentioned above, most of these artifacts were observed in the case of Cemetery of Terrassa. The most frequent artifact observed was the cotton packing, followed by posterior cut of clothes and presence of diapers (Table 2). The coffin wear trait was also frequent. The cadaveric state conditioned the presence and observation of cemetery artifacts.

Based on the results of this study, and taking into account their origin and frequency, the artifacts found near and/or on the corpses can be classified into two group: those highly indicative, and those just suggestive of the cemetery origin of remains (Nociarová et *al*., 2014a).

Table 2. Artifacts observed during exhumations in cemeteries of Terrassa, Montjuïc, Collserola (Catalonia, Spain), and indication of cemetery origin of each one (1-2).

Type of artifacts	Number of cases observed			Indication of cemetery origin
	CT	**CBMN**	**CBCLL**	
Autopsy practice	11	5	5	1
Sewing of upper and lower jaw	9	3	0	
Cotton packing *buccal*	44	52	2	
nostril	40	38	4	
buccal + nostril	37	30	3	
Embalming	0	0	0	
Aspiration trocar button	1	0	0	
Eye cup	2	4	1	
Clothes posterior cut	64	36	14	2
Diapers presence	37	40	5	
Waxes rest	0	0	0	
Decomposition accelerant product	2	4	0	
Coffins wear	23	29	2	
Fungal growth within the face or hands	12	24	6	
Sawdust from coffin adhering to body	7	9	2	
Unpigmented fauna	4	19	4	
Hair circular loss in the posterior part of skull	20	5	2	
Objects forgotten and associated with funerary, autopsy practice or thanatopraxy	4	2	1	

Indication of cemetery origin: highly indicative of cemetery context (1); suggestive of cemetery context (2).

5.5 **Cadaveric state**

Along the research cadaveric states were modified (see Chapter 4). Finally, for the statistical analysis, only 5 cadaveric states were described. In some statistical analyses only three cadaveric states were used because of the sample size or because of the purpose of the statistical analysis itself.

Total skeletonization (TS) (Fig. 24): Defined when at least 80% of body or anatomical parts were totally skeletonized without presence of desiccated skin or putrid matters.

Figure 24. Total skeletonization (TS) of skull, thorax, and right hand.

Skeletonization with dry putrid matter and partial desiccation (DPMD) (Figures 25): Described when less than 80% of body or anatomical parts were skeletonized and a high presence of dry putrid matter and partially desiccated skin and/or ligaments was observed.

Figure 25. Skeletonization with dry putrid matter and partial desiccation (DPMD).

Skeletonization with wet putrid matter (WPM) (Figure 26): Described when less than 80% of corpse was skeletonized and presence of wet putrid matter was observed.

Figure 26. Skeletonization with wet putrid matter (WPM) of thorax.

Mummification (M) (Figure 27): Describe when most part of corpse or anatomical parts presented skin desiccation.

Figure 27. Mummification (M) (overall corpse, hands, and face).

Saponification with wet putrid matter (SWPM) (Figure 28): Corpses or anatomical parts in the state of saponification with wet putrid matter were those that presented whitish/greyish, liquid or solid mass of adipocere combined with wet putrid matter. Different types of saponification were observed. In most cases, saponification was described because of a soft, wet, and amorphous paste found deposited on declined parts of body or under body. Hard, resistance and whitish form of saponification was observed too. In this case the saponification was also amorphous and deposited under the corpse. Just in one case (CT) the saponification of a female right thigh maintaining the form was seen (Figure 28f).

In some cases, the same corpse presented different cadaveric states (Figure 29).

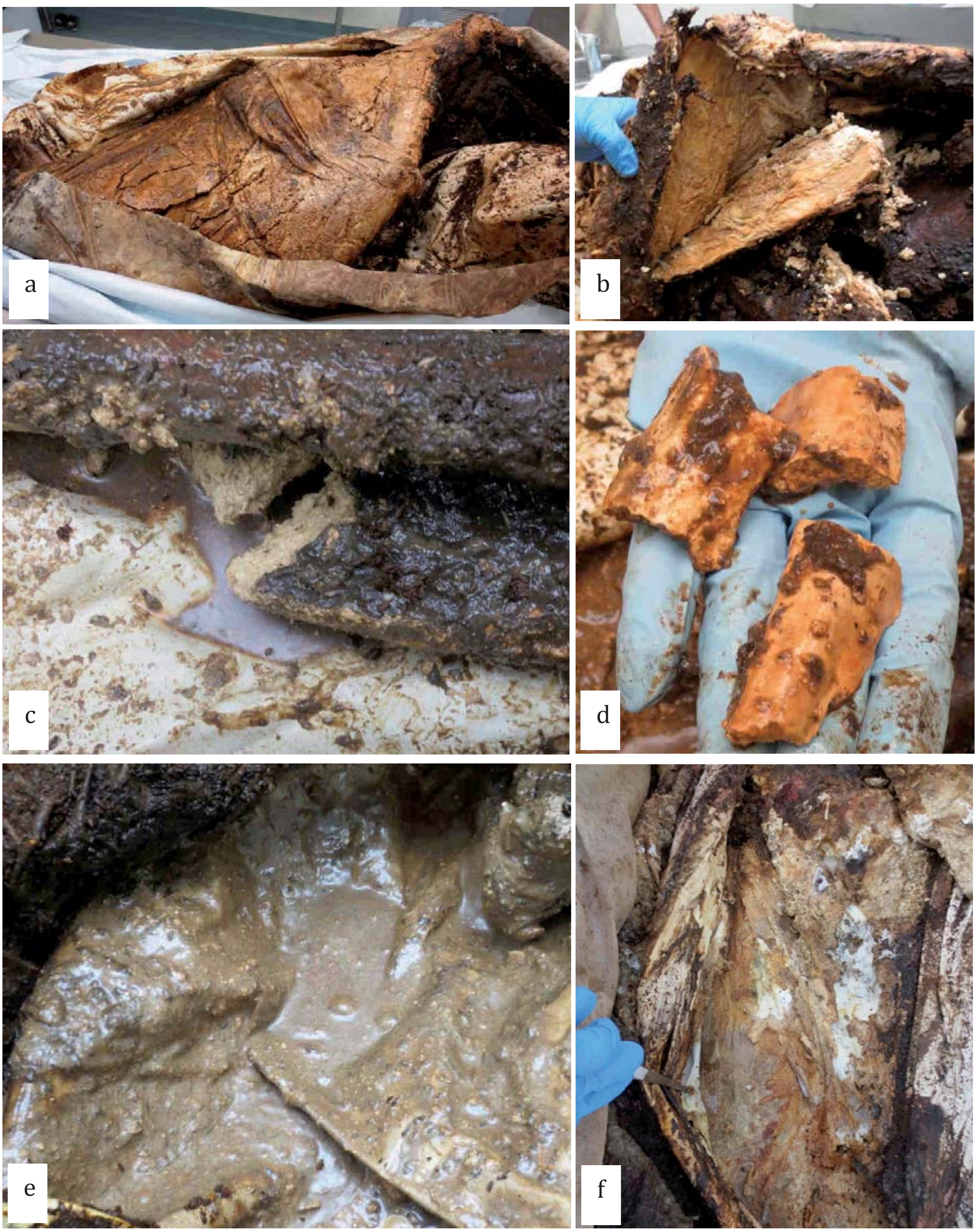


Figure 28. Different types of saponification; hard and block forming saponification under corpse (a), and (b); hard but brittle form of saponification (c), and (d); soft, amorphous and wet saponification (e); saponification that maintained form of thigh (f).

Figure 29. Different cadaveric states in one corpse: mummification of the face (a); skeletonization with wet putrid matter (b), and saponification of right thigh (c), CT74.

The frequency of different cadaveric states (five cadaveric states) for each anatomical part was described (Figure 30). All the anatomical parts were found mostly in DPMD state. Lower limbs and feet were the parts that presented the greatest frequency of SWPM.

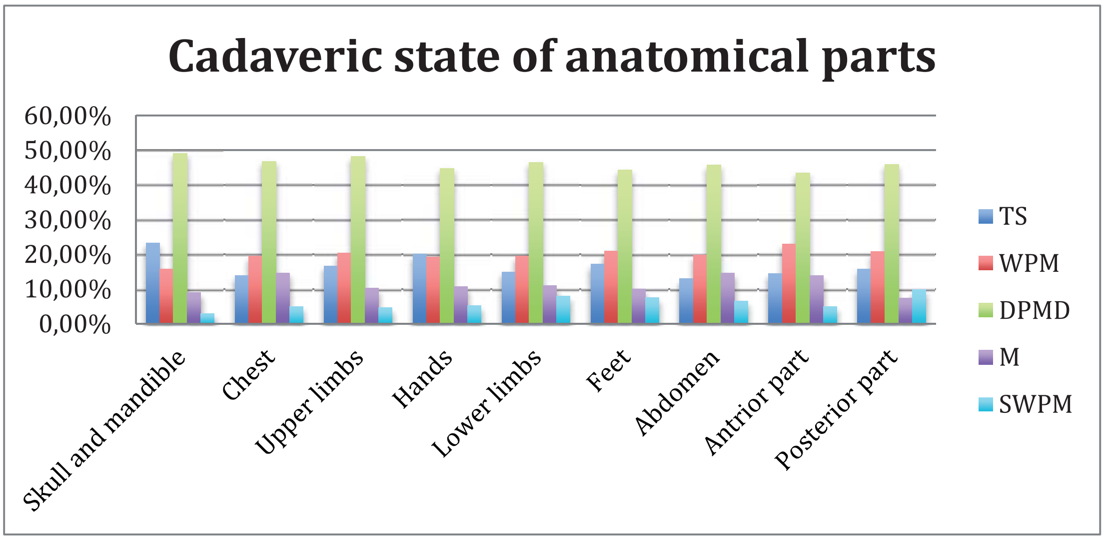


Figure 30. Description of observed cadaveric state (TS= total skeletonization; WPM= skeletonization with wet putrid matter; DPMD= skeletonization with dry putrid matter and partial desiccation; M= mummification; SWPM= saponification with wet putrid matter) for each anatomical part.

The relative frequencies of the five cadaveric states in each cemetery (CT, CBMN, CBCLL) for overall corpse are displayed in Figure 31.

In all anatomical parts Collserola presents no TS and a greater frequency of WPM than Montjuïc and Terrassa. In Montjuïc all anatomical parts display a higher frequency of SWPM than Collserola and Terrassa (in the latter it is almost non-existent). Terrassa showed the highest frequency of TS. Because of the small size sample in cadaveric states, reduction just into three groups of cadaveric state (total skeletonization, dry cadaveric state, and wet cadaveric state) was realized. There were a significant association between the cemetery and states of conservation for overall corpse (Chi-squared: χ^2=28.46; $p<0.05$). The results confirmed that in Collserola was observed higher number of corpses in wet state than in Montjuïc or Terrassa. Corpses from Cemetery of Terrassa presented higher number of total skeletonization or dry state of conservation (Figure 32).

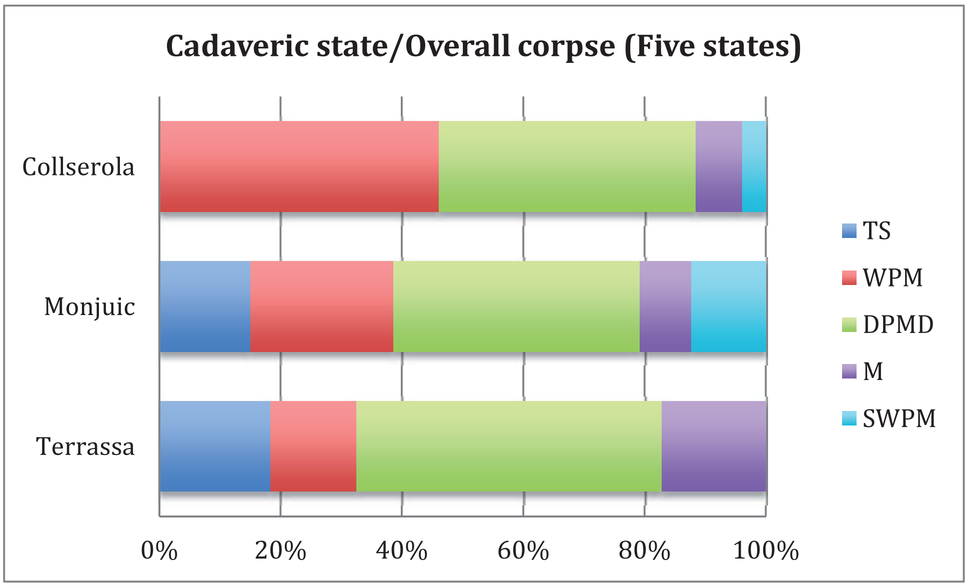


Figure 31. Frequency of five cadaveric states for overall body in each cemetery (TS: Total Skeletonization; WPM: skeletonization with Wet Putrid Matter; DPMD: skeletonization with Dry Putrid Matter; M: Mummification; SWPM: Saponification with Wet Putrid Mater).

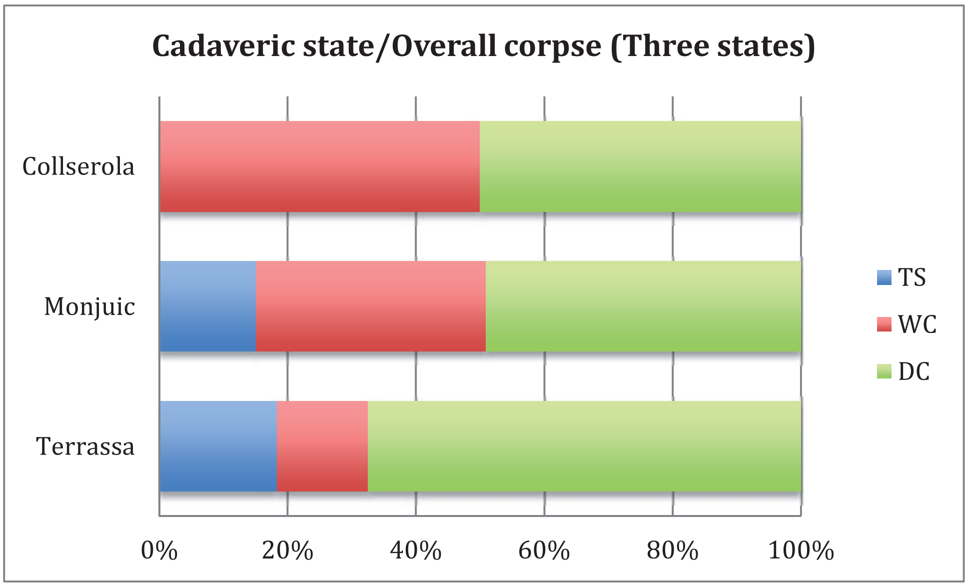


Figure 32. Frequency of three cadaveric states for overall body in each cemetery (TS: Total Skeletonization; WC: Wet Cadaveric state; DC: Dry Cadaveric state).

5.5.1 **<u>Integrity of corpses.</u>**

The integrity of the corpses was observed in 66.4% (200 cases) of the individuals. This is in reference to tissue conservation of the anterior and posterior part of body. The remaining 33.6% were not complete or were disarticulated in body bags. States of M or SWPM were considered as those with better integrity, while TS, WPM or DPMD as those with less integrity.

The anterior and posterior parts were evaluated separately. In 80% (160 cases) of the observed cases (200), the anterior and posterior parts were equal in integrity. In 12.5% (25) the anterior part had a better integrity than the posterior. In 7.5% (15) the posterior part had a better integrity (Chi-squared for uniform distribution: χ^2=196.75; p<0,05). In the cases where the posterior part had a better integrity than the anterior part, wet cadaveric state (SWPM) was observed in the posterior part. Considering only mummified bodies (cadaveric state of the overall corpse) or mummification of anatomical parts, the anterior part was more conserved in integrity than the posterior part. The posterior part of mummified corpses displays a more advanced degree of soft tissue degradation (Figure 33).

Figure 33. Head of individual CBMN09 (a, b, c) where advanced disintegration of soft tissue in part of the skull in contact with the bottom of the coffin/pillow can be observed. Individual CBMN80 (d, e): anterior view and more accelerated disintegration of the posterior part of the thorax.

5.6 **Postmortem interval**

5.6.1 **Differences in postmortem interval among cemeteries.**

Postmortem interval (PMI) was not available for all the exhumed individuals because of the lack of date of inhumation or death in some of them. The calculation of PMI was possible in 268 cases and the mean PMI is 22.63 years ± 15.97 years (mean of 8267.08 days; SD= 5834.86 days).

Eleven different groups regarding PMI were created. The first group included three individuals with a PMI between 2 and 5 years (731-1825 days). This was followed by 74 individuals with a PMI of 5-10 years (1826-3650 days), 39 individuals with a PMI of 10-15 years (3651-5475 days), 30 with a PMI of 15-20 years (5476-7300 days), 26 with a PMI of 20-25 years (7301-9125 days), 23 with a PMI of 25-30 years (9126-10950 days), 17 individuals with a PMI of 30-35 years (10951-12775 days), 10 with a PMI of 35-40 years (12776-14600 days), 15 with a PMI of 40-45 years (14601-16425 days), 14 with a PMI of 45-50 years (16426-18250 days), and 17 individuals with a PMI higher than 51 years (>18615 days) (Figure 34).

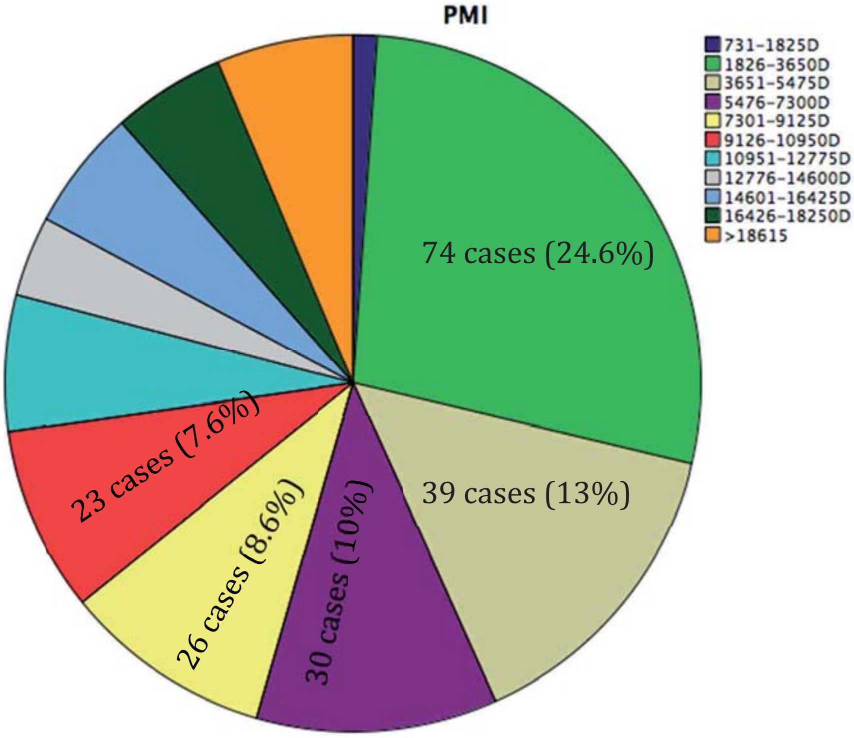


Figure 34. Relative frequency of PMI ranges: 731-1825D (2-5 years); 1826-3650D (5-10 years); 3651-5475D (10-15 years); 5476-7300D (15-20 years), 7301-9125D (20-25 years), 9126-10950D (25-30 years), 30-35 years (10951-12775 days), 12776-14600D (35-40 years), 14601-16425D (40-45 years), 16426-18250D (45-50 years), >18615D (>51 years).

Differences in PMI among the five degrees of cadaveric state were assessed. The first focus of interest was to explore the differences in PMI among bodies with different overall cadaveric states, separately for each cemetery (Figure 35). In Cemetery of Terrassa TS and DPMD tend to have higher PMI than WPM or M. In Cemetery of Montjuïc TS tend to have higher PMI than corpses in other cadaveric states (WPM, DPMD, M, SWPM). In Cemetery of Collserola M tend to present lower PMI than WPM or DPMD.

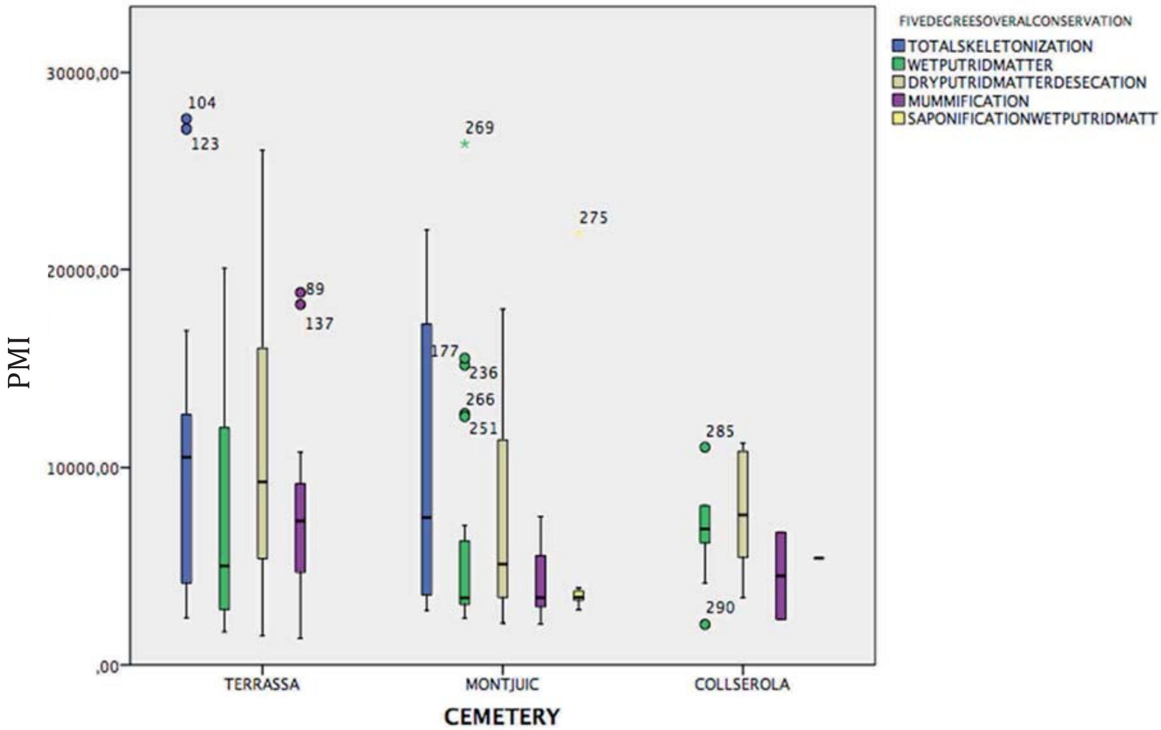


Figure 35. Boxplot of PMI for each cemetery separately, and for each cadaveric state of the overall corpse.

Differences in PMI among cadaveric states for all cemeteries together were tested. The calculation was made for different anatomical parts (skull/inferior jaw; chest; upper limbs; hands; lower limbs; feet; abdomen; anterior and posterior part of body) and for the overall body too. There were significant differences in PMI among cadaveric states for all anatomical parts (Kruskal Wallis: χ^2 in Table 3). Mann Whitney tests were performed to assess pairwise differences between groups. Bonferroni correction was applied, and thus differences were considered significant when $p<0.005$. Mann-Whitney tests with statistically significant results are shown in table 3.

In the case of upper limbs (Kruskal Wallis: $\chi^2=15.59$; $p<0.05$) and anterior parts of body (Kruskal Wallis: $\chi^2=10.15$; $p<0.05$), significant differences in PMI among cadaveric states were displayed. However the pairwise comparisons assessed using Mann Whitney tests corrected by Bonferroni failed to find significant differences.

Table 3. Results of Kruskal Wallis and Mann-Whitney test with Bonferroni correction (p<0.005) between pairs of cadaveric states.

	Kruskal Wallis (χ^2)	Direction of the difference	U statistic (Mann-Whitney)
SKULLS/MANDIBLES	18.75	M <TS	452
		M < DPMD	1087
CHESTS	26.61	WPM <TS	653
		M <TS	436
		SWPM <TS	127
		WPM < DPMD	2371.5
		M < DPMD	1642.5
		SWPM < DPMD	443
HANDS	17.49	SWPM < TS	185
		SWPM < DPMD	438
LOWER LIMBS	30.38	SWPM < TS	201
		SWPM < M	202
FEET	23.55	SWPM < TS	258
		SWPM < DPMD	478
		SWPM < M	159
ABDOMENS	23.55	WPM < TS	631.5
		M < TS	426
		SWPM < TS	134
		WPM < DPMD	2364
		M < DPMD	1577.5
		SWPM < DPMD	513
POSTERIOR PARTS	14.84	SWPM < TS	165
		SWPM < DPMD	521
OVERALL CORPSE	21.48	WPM < DPMD	2474
		SWPM < DPMD	407

(TS: Total Skeletonization; WPM: skeletonization with Wet Putrid Matter; DPMD: skeletonization with Dry Putrid Matter and partial desiccation; M: Mummification; SWPM: Saponification with Wet Putrid Mater). Only statistical significant differences for the Mann-Whitney tests are shown. Differences are considered statistically significant when p<0.005 (Bonferroni correction).

Considering all anatomical parts and the overall corpse, it was statistically confirmed that TS always displayed a longer PMI, followed by remains with DPMD. Similarly, remains with DPMD presented a higher PMI in the niche than the M. There were also some PMI difference between remains with WPM and those with SPWM. Remains with SWPM were inhumed in the niche for the shortest time (Figure 36).

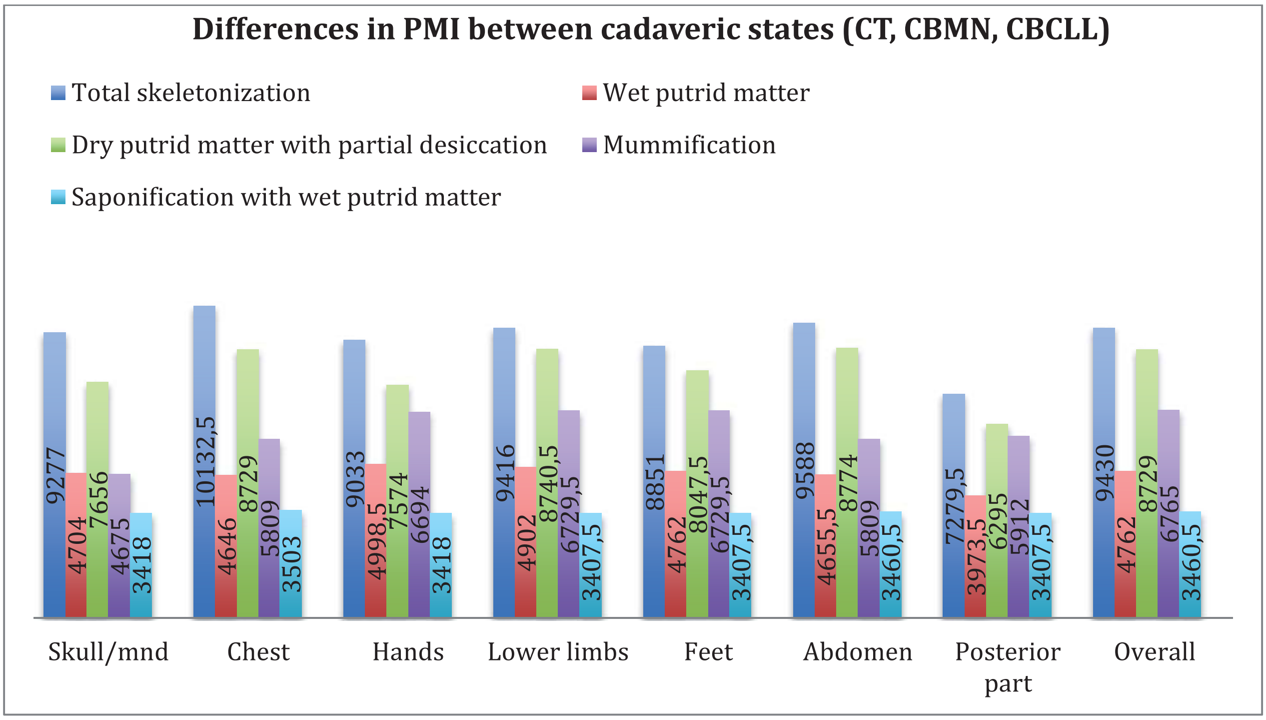


Figure 36. PMI in each cadaveric state for overall corpse and for different anatomical parts, for all cemeteries together.

Association between the PMI of each individual and its cadaveric state for the overall corpse was confirmed statistically (Chi-squared: χ^2=60.32, $p<0.05$). An increase of the PMI is associated with a slight increase of TS, DPMD, and a decrease of WPM and M. In the case of SWPM, a clear tendency was not observed (Figure 37, Table 4).

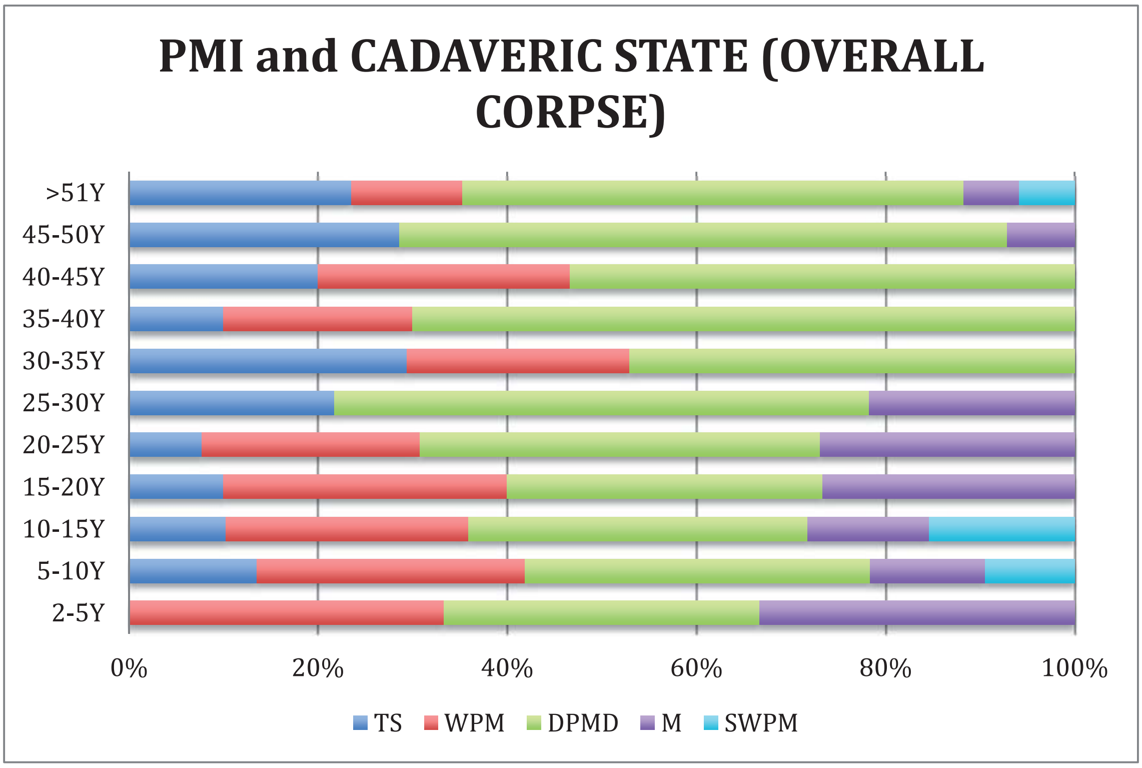


Figure 37. Relative frequencies of the five cadaveric states for different PMI ranges.

Table 4. Number of cases and percentage of each PMI range for each cadaveric state (for overall corpse).

	CADAVERIC STATE FOR OVERALL CORPSE					
PMI	**TS**	**WPM**	**DPMD**	**M**	**SWPM**	**TOTAL N**
2-5Y	0	1 (0.37%)	1 (0.37%)	1 (0.37%)	0	3
5-10Y	10 (3.73%)	21 (7.84%)	27 (10.07%)	9 (3.36%)	7 (2.61%)	74
10-15Y	4 (1.49%)	10 (3.73%)	14 (5.22%)	5 (1.87%)	6 (2.23%)	39
15-20Y	3 (1.12%)	9 (3.36%)	10 (3.73%)	8 (2.98%)	0	30
20-25Y	2 (0.75%)	6 (2.24%)	11 (4.10%)	7 (2.61%)	0	26
25-30Y	5 (1.87%)	0	13 (4.85%)	5 (1.87%)	0	23
30-35Y	5 (1.87%)	4 (1.49%)	8 (2.98%)	0	0	17
35-40Y	1 (0.37%)	2 (0.75%)	7 (2.61%)	0	0	10
40-45Y	3 (1.12%)	4 (1.49%)	8 (2.98%)	0	0	15
45-50Y	4(1.49%)	0	9 (3.36%)	1 (0.37%)	0	14
>51Y	4 (1.49%)	2 (0.75%)	9 (3.36%)	1 (0.37%)	1 (0.37%)	17
TOTAL N	41	59	117	37	14	**268**
TOTAL %	15.30%	22.01%	43.66%	13.81%	5.22%	**100%**

Statistical tests were run with all five cadaveric states to test whether there were differences in PMI among cemeteries. There were confirmed significant differences in PMI among cemeteries in the case of DPMD (Kruskal Wallis: χ^2=6.42; $p<0.05$) and M (Kruskal Wallis: χ^2=6.38; $p<0.05$). Mann Whitney tests with Bonferroni correction were performed, but failed to find significant differences ($p>0.016$) (Figure 35).

5.6.2 **Postmortem interval in Cemetery of Terrassa**

In the case of overall corpse, there were displayed significant differences in the PMI among different states of conservation (Kruskal Wallis: χ^2= 8.332; $p<0.05$). However the pairwise comparisons assessed using Mann Whitney tests corrected by Bonferroni failed to find significant differences ($p>0.0083$).

There were significant differences in PMI among the cadaveric states for chest (Kruskal Wallis: χ^2= 15.62; $p<0.05$), abdomen (Kruskal Wallis: χ^2= 17.24; $p<0.05$), and anterior part of corpses (Kruskal Wallis: χ^2= 15.62; $p<0.05$). Mann Whitney tests were performed to assess pairwise differences between groups. Bonferroni correction was applied, and thus differences were considered significant when $p<0.0083$ (Table 5).

Generally, significant differences in PMI among cadaveric states of WPM, DPMD and M were confirmed.

Table 5. Results of Mann-Whitney test with Bonferroni correction ($p<0.0083$) between pairs of cadaveric states.

	Direction of the difference	**U statistic (Mann-Whitney)**
CHESTS	WPM <DPMD	394
	DPMD <M	559
ABDOMENS	DPMD < M	525
ANTERIOR PARTS	DPMD < M	559
	WPM < DPMD	394

(WPM: skeletonization with Wet Putrid Matter; DPMD: skeletonization with Dry Putrid Matter and partial desiccation; M: Mummification). Only statistical significant differences for the Mann-Whitney tests are shown. Differences are considered statistically significant when $p<0.0083$ (Bonferroni correction).

In the case of Cemetery of Terrassa, M was generally the cadaveric state with the highest PMI, followed by DPMD and by TS. Skeletonization with wet putrid matter (WPM) was the state with the lowest PMI (Figure 38).

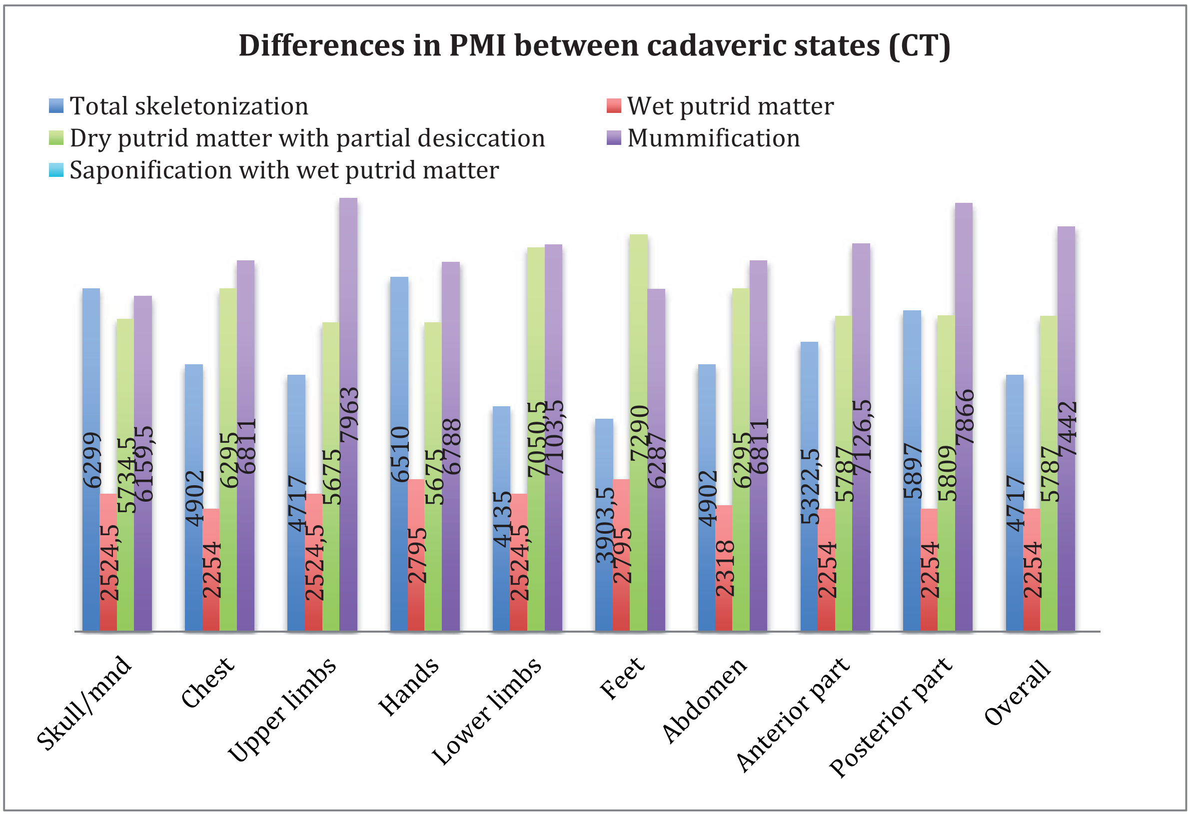


Figure 38. PMI in each cadaveric state for overall corpse and for different anatomical parts in Cemetery of Terrassa.

5.6.3 <u>Postmortem interval in Cemetery of Montjuïc</u>

There were significant differences in PMI among the five cadaveric states for overall corpse (Kruskal Wallis: χ^2= 10.54; $p<0.05$), skull and jaw (Kruskal Wallis: χ^2= 12.64; $p<0.05$), upper limbs (Kruskal Wallis: χ^2= 10.02; $p<0.05$), hands (Kruskal Wallis: χ^2= 10.02; $p<0.05$), lower limbs (Kruskal Wallis: χ^2= 14.70; $p<0.05$), feet (Kruskal Wallis: χ^2= 14.39; $p<0.05$), abdomen (Kruskal Wallis: χ^2= 13.00; $p<0.05$), anterior part of corpse (Kruskal Wallis: χ^2= 10.14; $p<0.05$), and posterior part of corpse (Kruskal Wallis: χ^2= 13.26; $p<0.05$). Mann Whitney tests were performed to assess pairwise differences between groups. Bonferroni correction was applied, and differences were significant ($p<0.005$) only for skull and jaw, lower limbs, feet, and posterior part (Table 6). In the remaining analysed parts, Mann-Whitney tests corrected by Bonferroni failed to find significant differences.

Table 6. Results of Mann-Whitney test with Bonferroni correction (p<0.005) between pairs of cadaveric states.

	Direction of the difference	U statistic (Mann-Whitney)
SKULLS/MANDIBLES	M <TS	42
LOWER LIMBS	SWPM < DPMD	199
POSTERIOR PARTS	M <TS	9
	SWPM <TS	41
FEET	SWPM < TS	60
	SWPM < DPMD	191

(TS: Total Skeletonization; DPMD: skeletonization with Dry Putrid Matter and partial desiccation; M: Mummification; SWPM: Saponification with Wet Putrid Mater). Only statistical significant differences for the Mann-Whitney tests are shown. Differences are considered statistically significant when p<0.005 (Bonferroni correction).

Corpses inhumed in Cemetery of Montjuïc, displayed that, generally, TS was the cadaveric state that presented the highest PMI, followed by DPMD, and by corpses/anatomical parts that were M, SWPM or WPM (Figure 39).

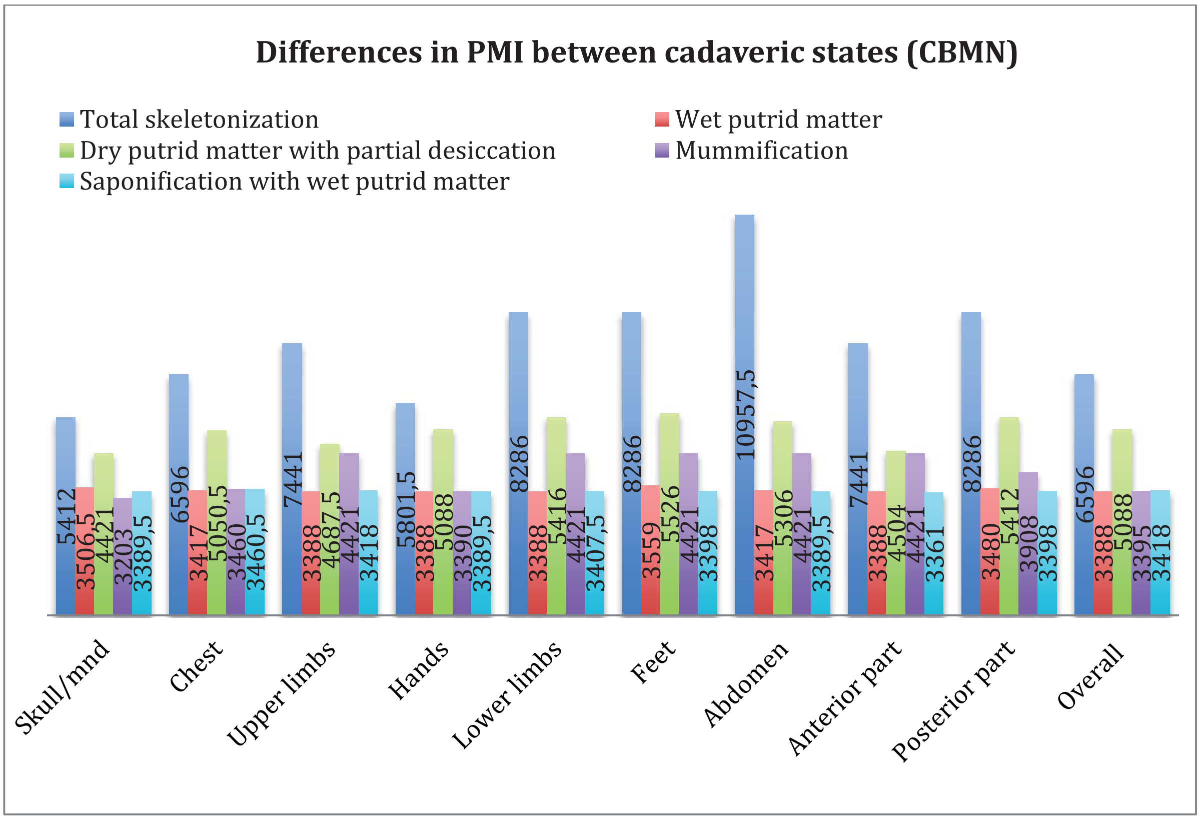


Figure 39. PMI in each cadaveric state for overall corpse and for different anatomical parts in Cemetery of Montjuïc.

5.6.4 **<u>Postmortem interval in Cemetery of Collserola</u>**

In the case of Cemetery of Collserola the sample was smaller than in the other cemeteries (26 corpses). For this reason the five cadaveric states were not as represented as in the other cases. No cases of TS (overall corpse), and few cases of M and SWPM were observed for all the anatomical parts and for the overall corpse. As the number of cases in some cadaveric states was very low to have enough statistical power in the tests, they were aggregated into 3 groups (see Chapter 4). No cases of TS were observed, 13 corpses were in wet cadaveric state and 13 were in dry cadaveric state. Mann-Whitney test did not show significant differences in PMI among the conservation groups of the corpses in cemetery of Collserola ($p>0.05$). Nevertheless, a tendency can be observed. For the overall corpse (and five cadaveric states), there is slightly higher PMI in corpses in state of DPMD than in corpses in state of WPM. The following in PMI would be those displaying M. Anatomical parts presented more similar PMI between DPMD and WPM, and between remains that were M and SWPM presence (Figure 40).

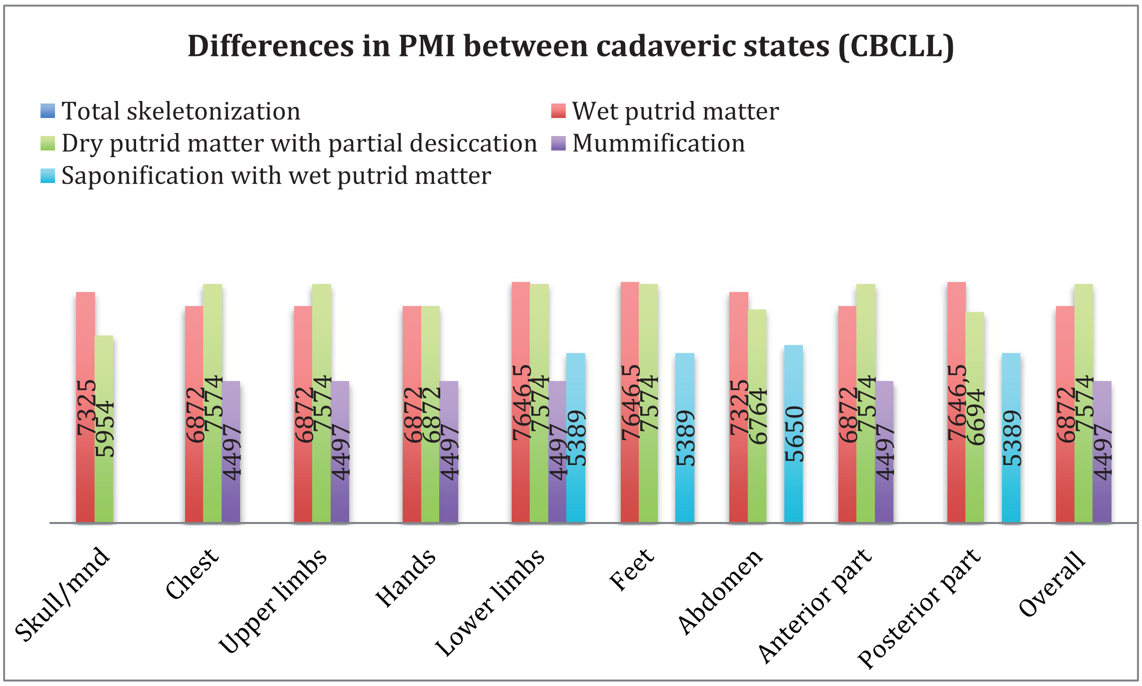


Figure 40. PMI in each cadaveric state for overall corpse and for different anatomical parts in Cemetery of Collserola.

5.7 **Association between cadaveric state and sex of individuals**

Most of exhumed individuals (93.4%, 281 individuals) had known sex, after confirmation by the anthropological analysis, and so association between five cadaveric states and sex of exhumed individuals could be analysed. Nevertheless, no significant association between sexes and cadaveric states were displayed (Chi-squared: χ^2= 2.71; p>0.05).

5.8 **Differences in cadaveric state among age groups**

Age of individuals also varied among exhumed corpses. Individuals were grouped into five age groups. For the analysis only four of them were used: subadults (5), young adults (10), mature adults (23), and senile adults (204). The group of adults indeterminate (59) was eliminated because of the uncertainty of their age. However, no significant differences in cadaveric state for overall corpse among age groups (Kruskal Wallis: χ^2=2.52; p>0.05).

5.9 **Year season of inhumation**

As day of death/inhumation varied among individuals, it was interesting to know if the season when individual died affects the conservation of the corpse. Four seasons were specified: spring (21/3-20/6); summer (21/6-22/9); autumn (23/9-20/12); and winter (21/12-20/3). They were used as proxies for general weather (warm/cold, humid/dry), in order to determine if the climatic characteristics of the first stage of death could significantly contribute to the evolution of preservation. Analysing all cemeteries together, 88.7% of individuals (267) had known season of their death. 32.6% (87) of exhumed individuals dead in winter, 24.3% (65) in summer, 22.8% (61) in autumn, and 20.2% (54) in spring (Figure 41).

Statistical test did not display significant association between overall cadaveric state and season of the year in which the body was buried (Chi-squared: χ^2=5.82; p>0.05).

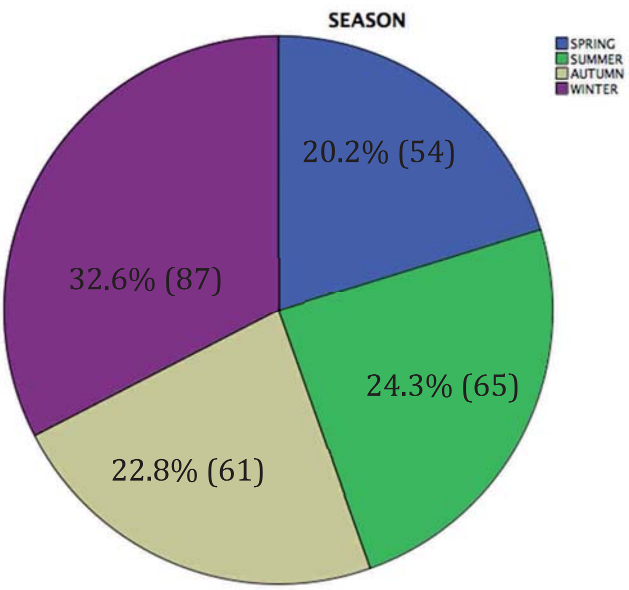


Figure 41. Distribution of individuals by season of death using all cemeteries together.

5.10 **Autopsy presence and cadaveric state**

All cemeteries were analysed together. Only 7% (21) of the total 301 corpses underwent an autopsy. 4% (12) of corpses underwent a complete autopsy (skull and thorax opening), 2% (6) underwent only thorax opening, and 1% (3) skull opening.

The association between presence/absence of autopsy and the five cadaveric states of overall corpse was analysed. Fisher's exact test confirmed a significant association between the performance of autopsy and the state of conservation of the overall corpse. Corpses that were submitted to autopsy tend to be more commonly TS, SWPM, WPM and M than those that were not submitted to autopsy, whereas the latter tend to be more commonly DPMD (Fisher's exact test: $p<0.05$) (Figure 42).

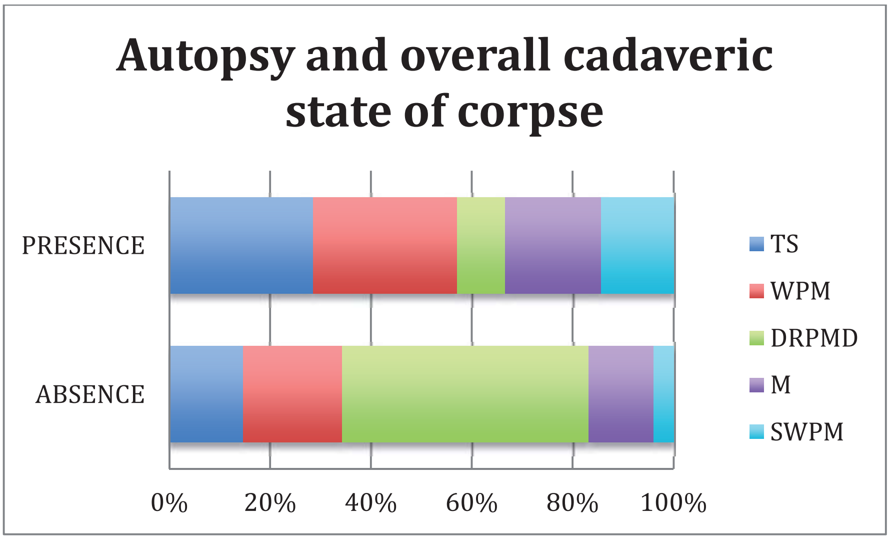


Figure 42. Presence of autopsy and overall conservation of the corpse.

5.11 **Autopsy body bag presence and cadaveric state**

The association between presence of autopsy body bag and overall cadaveric state of the corpses was significant (Chi-squared=30.77; $p<0.05$). When autopsy body bag is present, there is an increase of wet cadaveric state (WPM, SWPM) and a decrease of dry cadaveric state (DPMD, M) (Figure 43).

When anatomical parts are analysed separately, corpse similar pattern is observed. In the case of lower limbs (Chi-squared: χ^2= 59.52; $p<0.05$), feet (Chi-squared: χ^2= 53.76; $p<0.05$), abdomen (Chi-square: χ^2=41.66; $p<0.05$), and posterior part of body conservation (Chi-squared: χ^2=33.29; $p<0.05$) the statistical analyses showed significant increase of SWPM if body bag was present. An exception was seen in the case of skull, where the analysis displayed an increase of M when body bag was present (Chi-squared: χ^2= 15.26; $p<0.05$) (Figure 44).

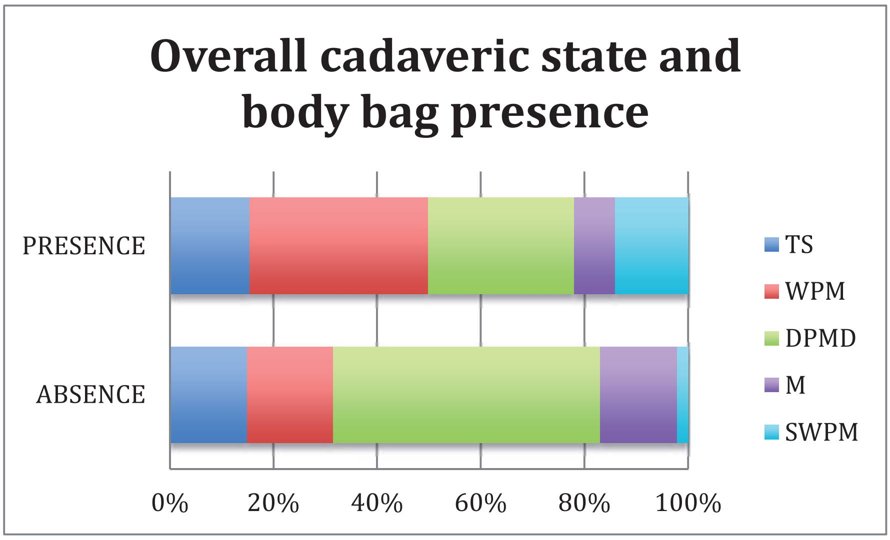


Figure 43. Presence of autopsy body bag and overall cadaveric state of the corpse.

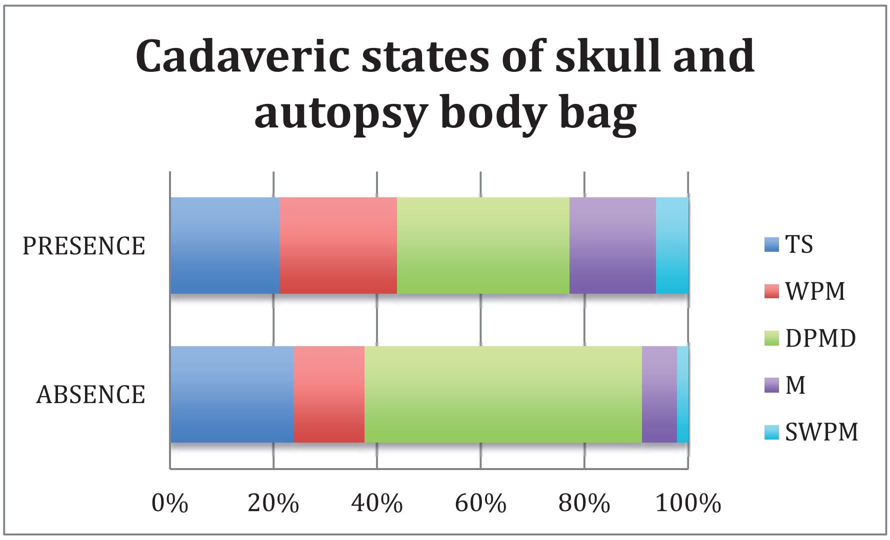


Figure 44. Cadaveric state of skull and autopsy body bag presence/absence.

5.12 **Diapers presence**

The influence of diaper presence was statistically examined. The results showed a significant association between diaper presence and the conservation of abdomen (Chi-squared: χ^2=15.67; p<0.05) and anterior part (Chi-squared: χ^2=12.45; p<0.05). The results for the posterior part were not significant (Chi-squared: χ^2=7.10; p>0.05).

In abdomens with diapers presence there was a decrease of TS and an increase of M (Figure 45). In the case of the anterior part with presence of diapers, there is a decrease of WPM and an increase of DPMD and M (Figure 46).

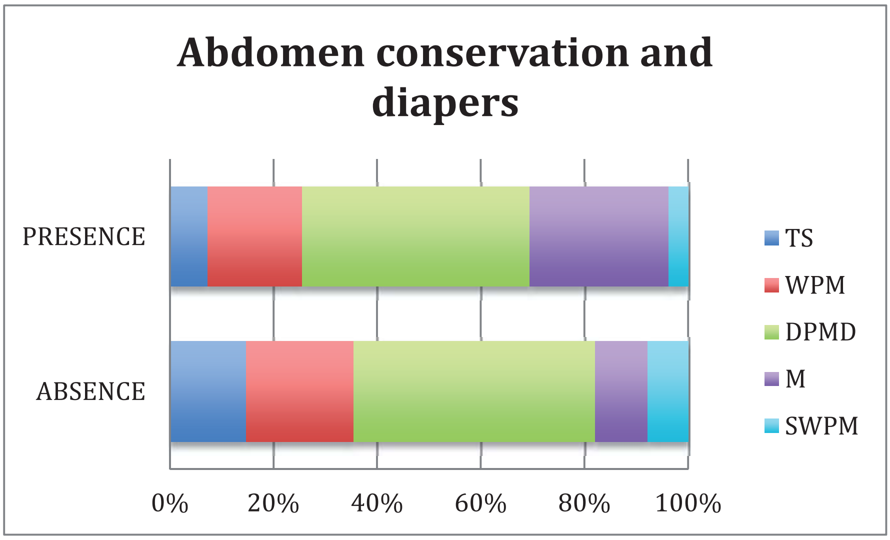


Figure 45. Cadaveric state of abdomen and diapers presence/absence.

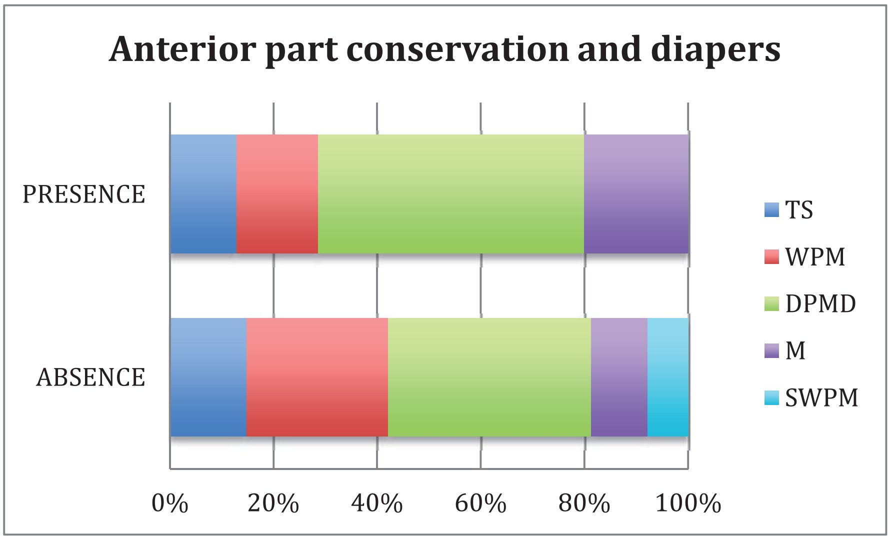


Figure 46. Cadaveric state of anterior part and diapers presence/absence

5.13 **Type of clothing**

There were three different combinations of clothing: clothes, funerary sheet and the combination of both types. Clothes are the garments that the family of the deceased family used to dress it. The number of layers may vary depending on the cloth. Funerary sheet is the clothing that the funerary service used. The type and number of layers of the funerary sheet may vary among cemeteries. In some cases, the corpse can be dressed with the combination of both types of clothing, always with cloth in direct contact with body, which is after wrapped into a funerary white sheet (Figure 47). Therefore, the number of layers is higher than in the two previous cases.

Figure 47. Female individual (CBMN57) dressed with the combination of funerary sheet (a) and cloth (b).

Type of clothing was positively observed in 74.8 % (225) of cases. Most individuals, 67.6% (152), were dressed with clothes, followed by 22.2% (50) of individuals wrapped in funerary sheet. Only 10.2% (23) were dressed in combination of cloth and funerary sheet (Figure 48).

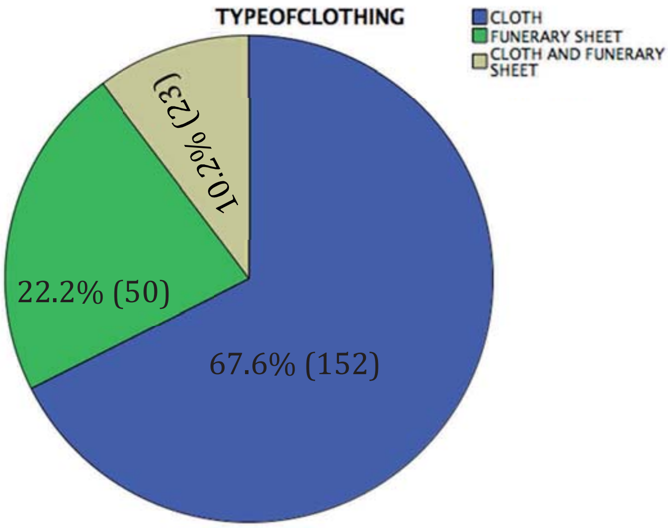


Figure 48. Type of clothing that corpses were dressed on.

The influence of type of clothing on cadaveric state was statistically examined. Association between type of clothing and the three cadaveric states (total skeletonization, dry cadaveric state and wet cadaveric state) was analysed. There was a significant association in the case of upper limbs (Chi-squared: $\chi^2=11.74$; $p<0.05$), hands (Chi-squared. $\chi^2=10.20$; $p<0.05$), lower limbs (Chi-squared: $\chi^2=10.51$; $p<0.05$), and feet cadaveric state (Chi-squared: $\chi^2=12.19$; $p<0.05$). Generally, cloth or combination of cloth with funerary sheet displayed very similar results in all examined cases, where an increase of dry conservation is observed.

The corpses dressed on funerary sheet displayed higher frequency of wet conservation and lower frequency of dry conservation. This could not be interpreted in a straightforward way, and so the association between type of clothing and body bag presence was analysed (Chi-square: $\chi^2=39.31$; $p<0.05$). There is a clear association between the absence of body bag and cloth (Figure 49), which explains the association between cloth and dry conservation. The association between other type of clothing and conservation type is not possible to explain by the presence or absence of body bag.

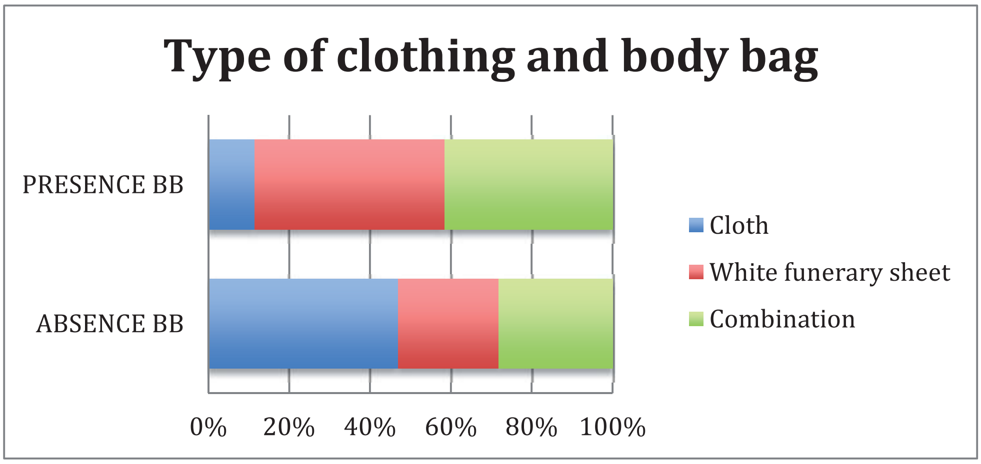


Figure 49. Type of clothing and presence or absence of body bag.

5.13.1 **Clothing layers and body conservation**

As mentioned above, number of layers that formed the individual clothing varied. The corpses with clothing were evaluated for clothing layers in three separate parts. Superior part corresponded to superior part of the body (from hips up to the head), and inferior part to inferior part of body (from hips down to the feet). The third part corresponded to middle part of corpse, where the previously mentioned parts normally overlapped. The diapers presence was not included in this layers count.

Not all cases could be used for this analysis because of lack of information about clothing type or layers in the moment of visual examination, due to state of clothing conservation. The superior part could be examined in 48.2% (145), middle part in 47.5% (143), and inferior part in 44.5% (134). The middle part was the one with more layers, formed in some cases by 7 different layers (1.4%). Superior (1.4%) and inferior (1.5%) parts had 6 layers at the most. In the superior part, most individuals, 46.2% (67), had two layers, followed by 22.8% (33) with three layers, 22.1% (32) with only one layer, 6.2% (9) with four layers, and 1.4% (2) individuals with five layers and six layers. The middle part of body was covered by 3 layers in 34.3% (49), two layers in 29.4% (42), four layers in 17.5% (25), one layer in 10.5% (15), five layers in 3.5% (5), six layers in 3.5% (5), and seven layers in 1.4% (2). The inferior part of the corpse was covered by one layer in 59% (79), by two in 27.6% (37), by three layers in 9.7% (13), by four or six layers in 1.5% (2), and by five layers in 0.7% (1) (Figure 50).

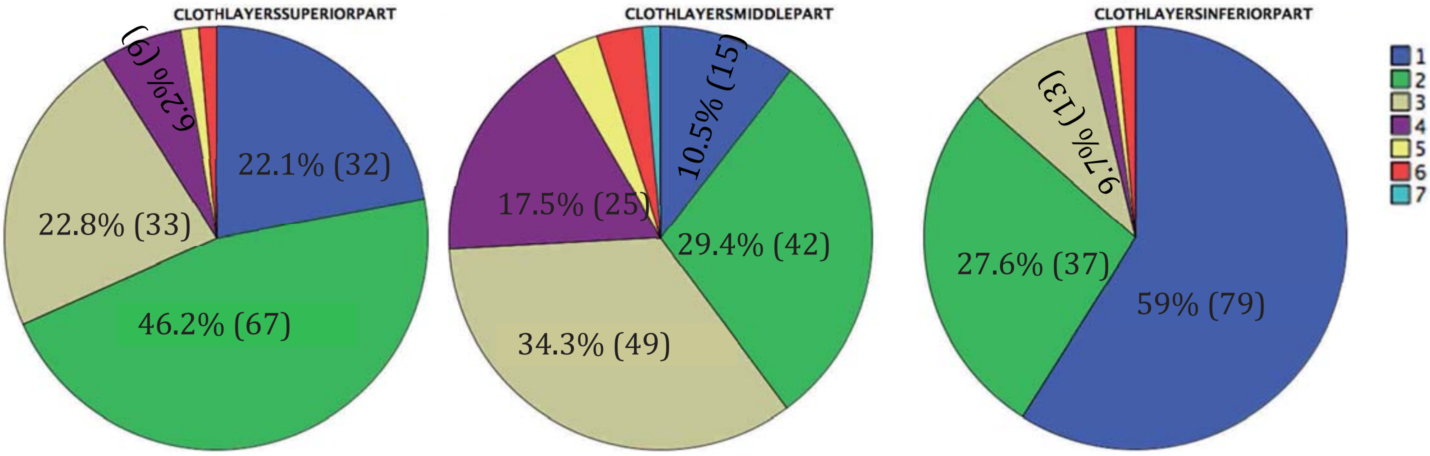


Figure 50. Number of clothing layers in the superior, middle, and inferior part of corpse.

The influence of the number of layers on cadaveric state was analysed too. Differences in clothing layers among the cadaveric state were tested in chest, upper limbs, abdomen, lower limbs, anterior, posterior part of body and overall corpse. Statistically significant differences were only found for the lower limbs (Kruskal Wallis: $\chi^2=9.75$; $p<0.05$). However, Mann Whitney tests with Bonferroni correction did not find statistically significant differences in any pairwise comparison ($p>0.005$).

5.14 **Relative niche height**

In Spain the custom is to inhume the deceased in vertical cement structures named niches. The maximum height of these structures varies among cemeteries. There is a presumption that the height of the niche where the body is deposited affects the body conservation/decay because of the insulation, humidity or aeration. As the maximum height of the structures varied, relative height was calculated (maximum height/real height where the body was deposited). Each cemetery was first statistically analysed separately. However, Mann Whitney test shows significant differences in niche relative height among bodies with different degrees of conservation only in Collserola cemetery ($U=30$; $p<0.016$). These differences were between WPM, which were generally inhumed in the highest (the last one) niche, and DPMD, which were in the penultimate niche.

Statistical analyses were also run for all cemeteries at once. There were significant differences in the relative niche height among states of overall conservation (Kruskal Wallis: $\chi^2= 14.2$; $p<0.05$). Mann Whitney tests showed that corpses in SWPM were deposited in relatively higher niches than those DPMD ($U=348$; $p<0.005$) or those that were M ($U=104$; $p<0.005$).

5.15 **Organs, hair, body hair and nails conservation**

The presence of organs in different cadaveric states of the corpses was examined. In 13.3% (40) of the total number of exhumed corpses (301), organs were observed. There was an increase of organ preservation when corpses are mummified (M). Organ preservation is less frequent tissue integrity has been lost, especially when TS occurs (Chi-squared: $\chi^2=0.20$; $p<0.05$) (Figure 51).

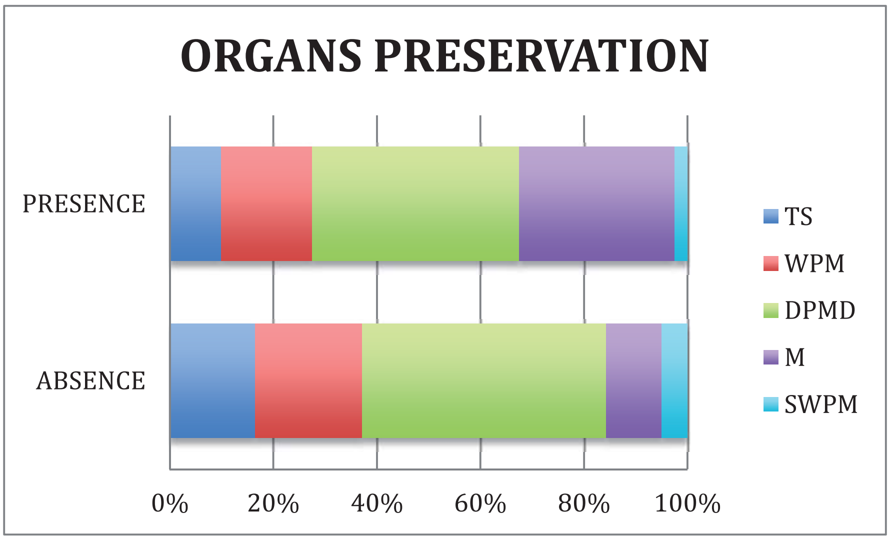


Figure 51. Organs preservation in different cadaveric states.

The organs that had been observed were parts of the heart, guts, pleura, lungs, diaphragm, eyes, and brain. When the brain was preserved, it was found in dusty form (Figure 52). Sometimes presence of feces and/or undigested aliments was noticed (Figure 53).

Figure 52. Preservation of different organs; guts (a); brain (b); eye balls (c); organs from thorax cavity-lung, pleura, diaphragm (d); detail of right lung (e)

Figure 53. Presence of undigested aliments.

The conservation of hair also depends on the preservation of the skull (270 cases, 89.7% from total 301). In 58.5% (157 of 270 cases), hair was observed (Figures 54). Statistical analyses demonstrated that more conservation of the body leads to a higher frequency of hair preservation. Hair preservation is more frequent in M or SWPM, and less frequent in skeletonized skulls (Chi-squared: χ^2=12.90; $p<0.05$) (Figures 55).

Figure 54. Hair preservation in different individuals' skulls.

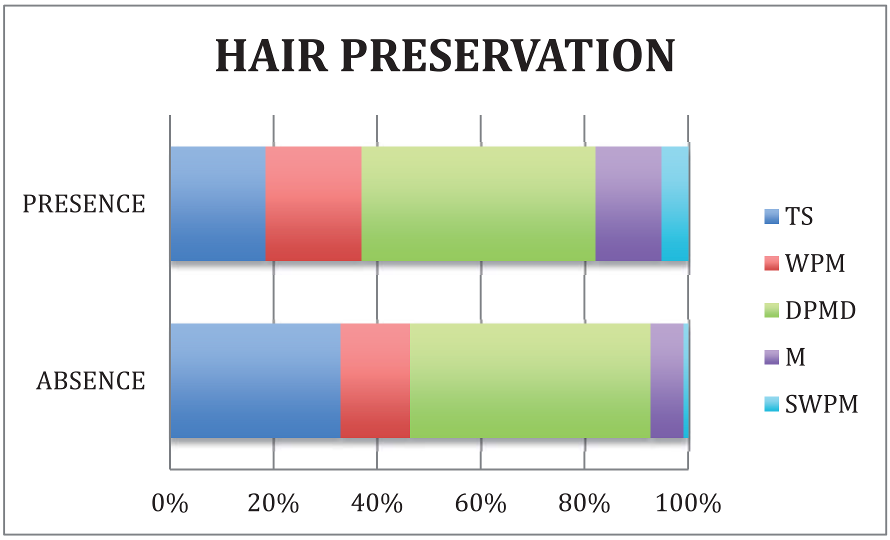


Figure 55. Hair presence in different cadaveric states of the skull.

Presence of body hair was observed in 30% (81 of 270 cases) from total number of individuals (301). Eyebrows, eyelashes, moustache, beard, hair on legs, arms, chest, armpit, and/or pubic hair were considered (Figures 56). There was more frequent body hair preservation in M or in WPM (Chi-squared: χ^2=9.74; $p<0.05$). A lower frequency of body hair was noticed when the body presented loss of soft tissue integrity (TS, DPMD, SWPM) (Figures 57).

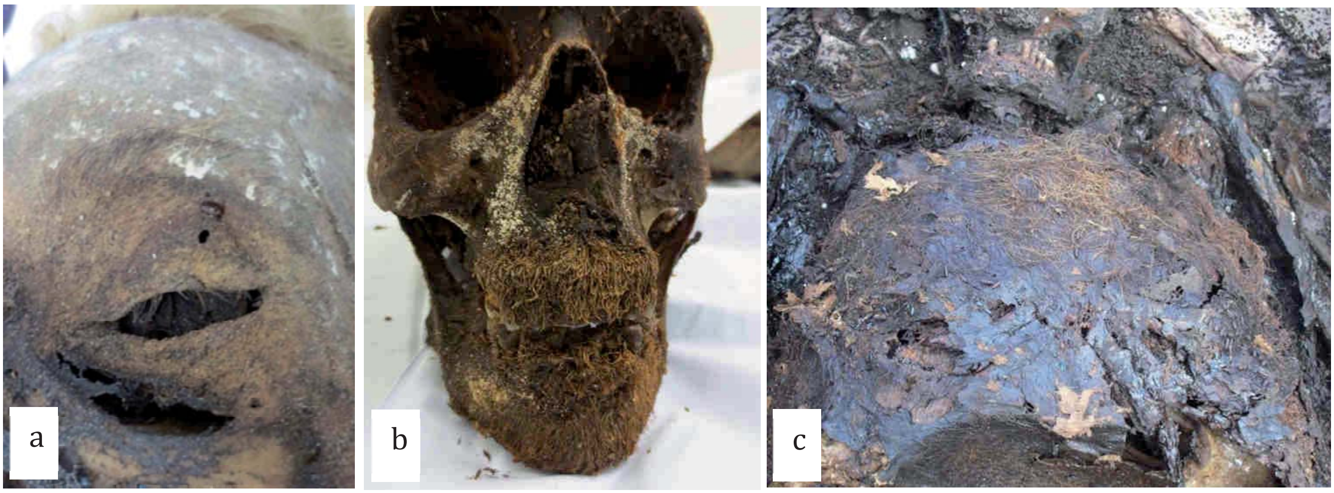


Figure 56. Body hair presence in: left eyebrow and eyelashes (a); moustache and beard (b), and chest hair (c).

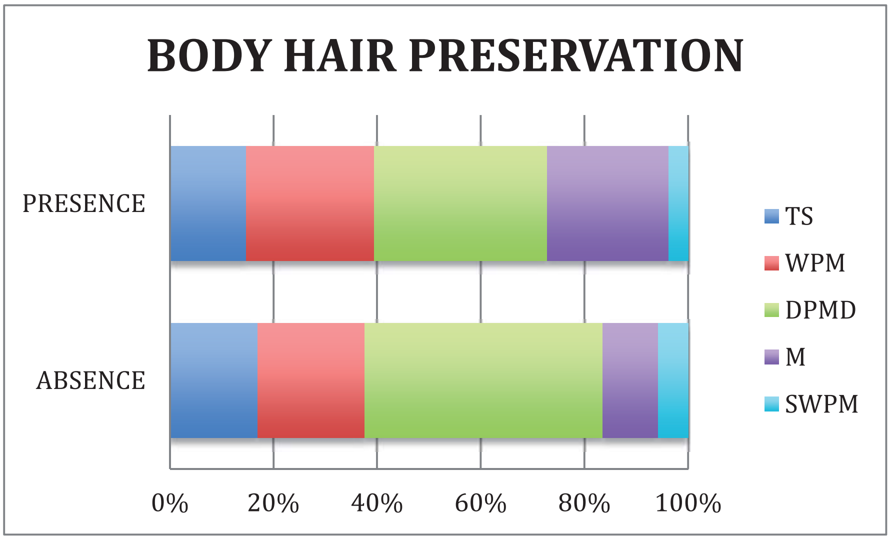


Figure 57. Body hair presence in different cadaveric states of the corpse.

Only in 14.1% (38 cases) of 270 Individuals, nails were observed. Likewise in hair and body hair, the preservation of nails is linked to tissue conservation (Figures 58). In mummified corpses (M) there was a higher frequency of nail preservation, while in corpses with loss of tissue integrity a lower frequency of nail preservation was observed (Chi-squared: χ^2=27.64; $p<0.05$) (Figures 59).

Figure 58. Nails presence *in situ*.

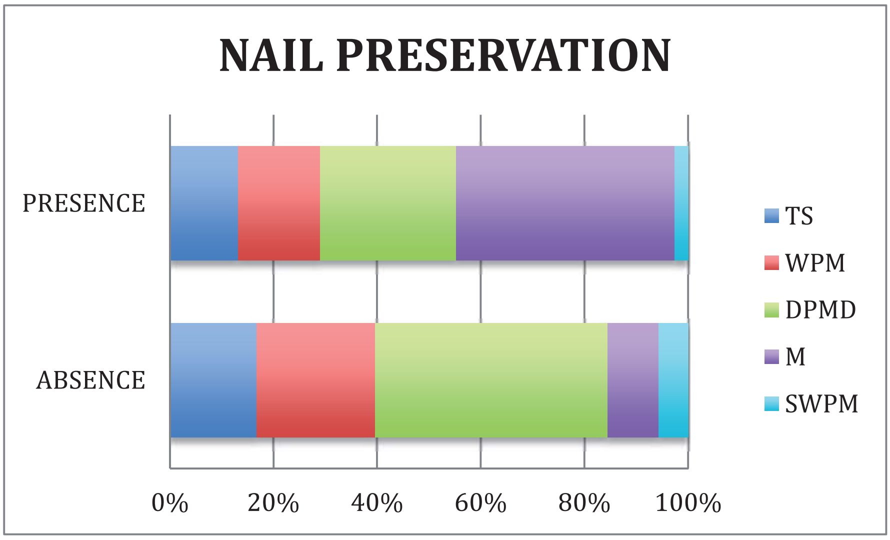


Figure 59. Nail preservation in different cadaveric states of the corpse.

5.16 **Meteorological data**

The influence of meteorological conditions on the different cadaveric states of the overall corpse (five cadaveric states) was examined. The meteorological data that were examined are: temperature (minimum=TN, average=TM, maximum=TX), accumulated rainfall during 24 hours (PPT), average relative humidity (HRM), minimum relative humidity (HRN), sunlight during 24 hours (RS), average wind speed measured at a height of 10 m (VVM), maximum wind speed measured at a height of 10 m (VVX), and evapotranspiration (Eto). All these variables may have different influences on the evolution of decomposition of corpses, depending on the moment in which they act. For this reason, all of these meteorological variables were retrieved for the day of inhumation/death, and for periods encompassing the first seven and thirty days after inhumation/death, first six months after inhumation/death, and the first five years after inhumation/death.

First, the statistical analysis was performed for all cemeteries together. Kruskal Wallis tests showed that there are significant differences in some meteorological data among cadaveric states within cemeteries.

In the case of MonthHRM (Kruskal Wallis: $\chi^2=13.99$; $p<0.05$), YearTN (Kruskal Wallis: $\chi^2=9.60$; $p<0.05$), YearTM (Kruskal Wallis: $\chi^2=9.68$; $p<0.05$), Kruskal Wallis test displayed significant differences among cadaveric states, but the pairwise comparisons assessed using Mann-Whitney tests corrected by Bonferroni ($p<0.005$) failed to find significant differences. There were not statistically significant differences among cadaveric states in any variable of the day of death/inhumation and of the first seven days. Generally, a long-term exposure to meteorological variables had a greater effect on the different conservation of corpses.

Skeletonized corpses with dry putrid matter with partial desiccation (DPMD) were exposed to less amount of rainfall during the first month (mean=1.12; median=0.6; SD=1.48) (MonthPPT) than corpses in SWPM (mean=2.39; median=2.35; SD=1.53) (Mann-Whitney: U=132; $p<0.005$) for the overall corpse.

Corpses in saponification with wet putrid matter (SWPM) were exposed to higher minimum relative humidity (mean=57.8; median=57.5; SD=1.93) (6monthHRN) than bodies in M (mean=56.38; median=57; SD=0.93) (Mann-Whitney: U=19; $p<0.005$).

When meteorological data during the first year were examined, only the influence of sunrise (YRS) was confirmed statistically. Total skeletonization (TS) (mean=15.92; median=16.1; SD=0.36) (Mann-Whitney: U=29; $p<0.005$), WPM (mean=15.89; median=16; SD=0.35) (Mann-Whitney: U=87; $p<0.005$), DPMD (mean=15.975; median=16.05; SD=0.31) (Mann-Whitney: U=109; $p<0.005$) and M (mean=16.03; median=16; SD=0.19) (Mann-

Whitney: U=25; p<0.005) had a lower exposition to sunlight than corpses in SWPM (mean=16.18; median=16.25; SD=0.15).

During the first five years after inhumation, differences in average temperature (5yearsTM), minimum temperature (5yearsTN), sunlight (5yearsRS), accumulated rainfall (5yearsPPT), and evapotranspiration (5yearsEto) was statistically significant.

In the case of average temperature (5yearsTM), corpses in SWPM were exposed to slightly higher temperatures (mean=16.27; median=16.3; SD=0.67) than TS corpses (mean=16.21; median=16.2; SD=0.11) (Mann-Whitney: U=36; p<0.005), corpses in WPM (mean=16.22; median=16.2; SD=0.96) (Mann-Whitney: U=100; p<0.005), DPMD (mean=16.25; median=16.2; SD=0.79) (Mann-Whitney: U=118; p<0.005), or M corpses (mean=16.15; median=16.2; SD=0.67) (Mann-Whitney: U=28.5; p<0.005).

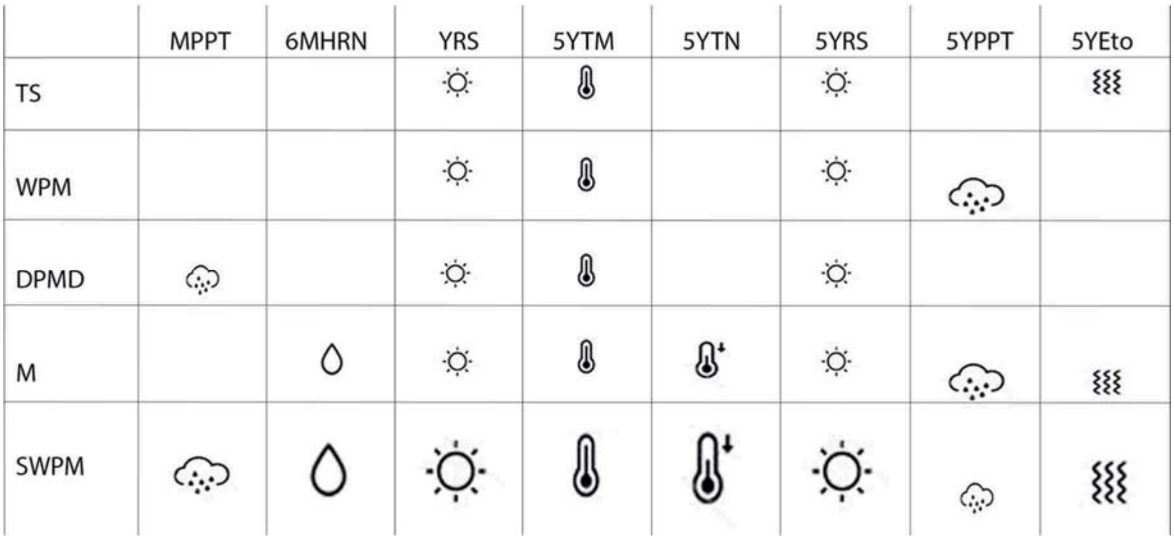
Concerning minimum temperature (5yearsTN), M corpses (mean=11.96; median=11.9; SD=0.91) (Mann-Whitney: U=29.5; p<0.005) were expose to a slightly lower minimum temperature (5yearsTN) than SWPM (mean=11.99; median=12; SD=0.57).

As regards to the amount of sunlight during first five years (5yearsRS), TS corpses (mean=16.2; median=16.3; SD=0.22) (Mann-Whitney: U=33.5; p<0.005), WPM (mean=16.17; median=16.3; SD=0.23) (Mann-Whitney: U=51.5; p<0.005), DPMD (mean=16.18; median=16.3; SD=0.20) (Mann-Whitney: U=75; p<0.005) and M (mean=16.00; median=15.9; SD=0.28) (Mann-Whitney: U=13.5; p<0.005) presented a lower intensity of sunlight than corpses that were in SWPM (mean=16.34; median=16.3; SD=0.070).

Totally skeletonized (TS) corpses (mean=2.75; median=2.8; SD=0.79) (Mann-Whitney: U=36; p<0.005) or M (mean=2.71; median=2.7; SD=0.88) (Mann-Whitney: U=42; p<0.005) showed less evapotranspiration during the first five years of inhumation (5yearsEto) than SWPM (mean=2.8; median=2.8; SD=0).

Conversely, SWPM displayed slightly less of accumulated rainfall (mean=1.52; median=1.5; SD=0.32) (5yearsPPT) than WPM (mean=1.55; median=1.5; SD=0.56) (Mann-Whitney: U=111; p<0.005) or those that were M (mean=16.25; median=1.5; SD=0.78) (Mann-Whitney: U=33; p<0.005) (Table 7).

Table 7. Differences in meteorological data (columns) among five degrees of overall cadaveric states of corpse (rows). Bigger meteorological symbols indicate higher associations with the corresponding cadaveric state.



<u>Legend of meteorological data</u> (M= month; 6M= six months; Y= year; 5Y= five years). Temperature: minimum=TN, average=TM; accumulated rainfall (PPT), minimum relative humidity (HRN), sunlight (RS), evapotranspiration (Eto).
<u>Legend of cadaveric state:</u> TS= total skeletonization; WPM= skeletonization with wet putrid matter; DPMD= skeletonization with dry putrid matter and partial desiccation; M= mummification; SWPM= saponification with wet putrid matter.

A principal component analysis (PCA) using several variables that may influence decomposition (PPT, TM, VVM, NICHERELATIVE, HRM, RS, Eto) was performed. Figure 60 shows the scores of the first two PCs for the individuals of the sample. PC1 and PC2 explain 73.03% and 18.55% of total variation, respectively. Although they partially overlap with the distribution of the rest of the sample, corpses in SWPM and those TS present more concentrated distributions (Figure 60). Figures 61 and 62 display the loadings of each variable for PC1 and PC2, respectively. Corpses in TS state mainly have positive values of PC1, and so they tend to have experienced higher values of HRM, and slightly lower values of VVM (Figure 61). Corpses in SWPM have high positive values for PC2, and so they tend to have undergone higher values of TM, and RS2, and slightly lower values of VVM (Figure 62).

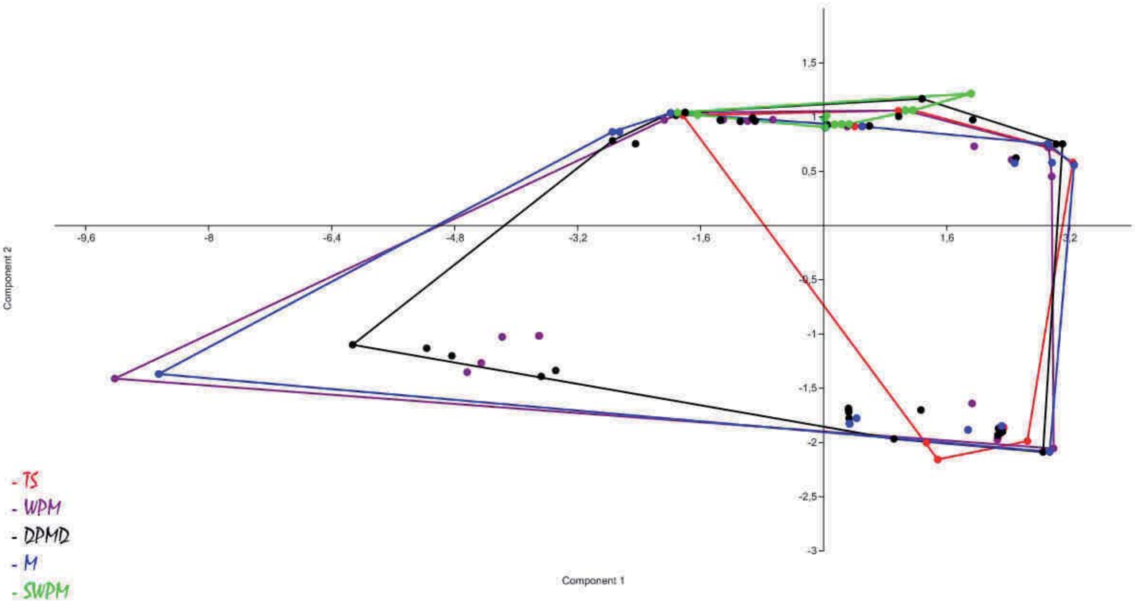


Figure 60. Scatterplot of the scores of the first two components of the principal component analysis performed using PPT, TM, VVM, NICHERELATIVE, HRM, RS and Eto. Convex hulls for each cadaveric state are shown.

PCA 1

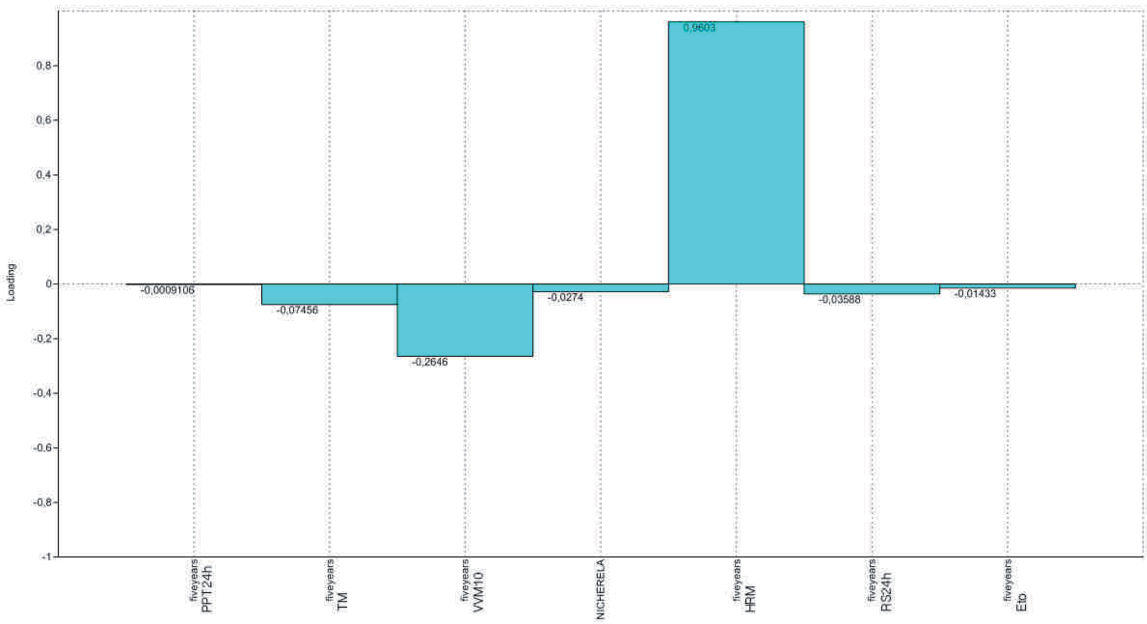


Figure 61. Loadings of each variable for PC1 of the principal component analysis performed using PPT, TM, VVM, NICHERELATIVE, HRM, RS and Eto.

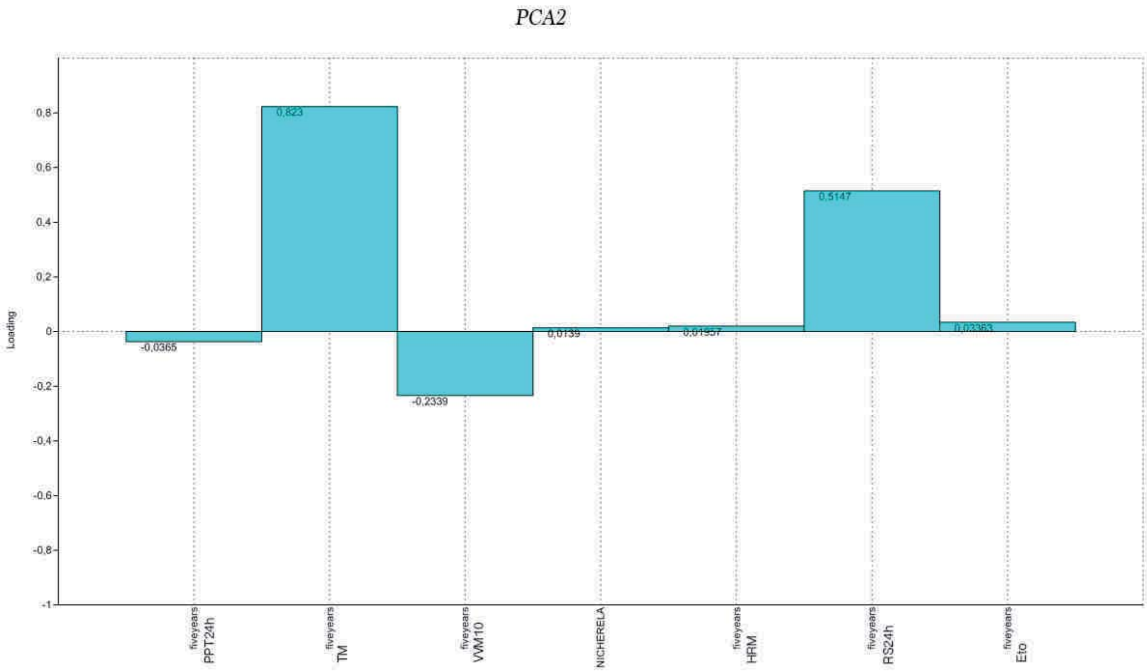


Figure 62. Loadings of each variable for PC2 of the principal component analysis performed using PPT, TM, VVM, NICHERELATIVE, HRM, RS and Eto.

Each cemetery was also examined separately. No significant differences were confirmed in the case of CT at any period.

In the case of Montjuïc, there were confirmed significant differences among corpse preservation states in the rainfall during first month (Kruskal Wallis: χ^2=12.59; p<0.05), and in sunlight during the first five years of inhumation (5YEARSRS) (Kruskal Wallis: χ^2= 13.34; p<0.05). Mann Whitney tests were performed, and only in the case of 5YEARSRS pairwise significant differences were confirmed after Bonferroni correction (p<0.005). Corpses in SWPM were exposed to higher intensity of sunlight (mean=16.33; median=16.3; SD=0.06) than WPM (mean=16.18; median=16.2; SD=0.20) (Mann-Whitney: U=51.5; p<0.005), and than M (mean=16.01; median=16.0; SD=0.24) (Mann-Whitney: U=13.5; p<0.005).

In the Cemetery of Collserola, test showed significant differences in sixmonthsPPT (Mann-Whitney: U=1.5; p<0.05), sixmonthsVVM (Mann-Whitney: U=0.5; p<0.05), yearPPT (Mann-Whitney: U=0.0; p<0.05), yearHRM (Mann-Whitney: U=2.0; p<0.05), and 5yearsRS (Mann-Whitney: U=4.0; p<0.05) always between WPM and DPMD. Skeletonized corpses with wet putrid matter (WPM) were exposed to higher intensity of rainfals during the first six months (mean=3.12; median=3.25; SD=0.29) and during the first year (mean=2.05; median=2.1; SD=0.1) than corpses in DPMD (sixmonthPPT: mean=1.45; median=1.45; SD=0.49) (yearPPT: mean=1.25; median=1.25; SD=0.21). Skeletonized corpses with wet putrid matter (WPM) were more exposed to average wind speed (mean=5.47; median=5.45; SD=0.96) than DPMD during the first six months (mean=5.1; median=5.1; SD=0.28).

Skeletonized bodies with wet putrid matter (WPM) were exposed to a higher average relative humidity during first year of inhumation (mean=73.45; median=74; SD=1.45) than DPMD (mean=70.3; median=70.3; SD=4.38), and higher intensity of sunlight exposition during first five years (mean=15.55; median=15.7; SD=0.3) than corpses that were preserved in DPMD (mean=15.25; median=15.25; SD=0.21213).

5.17 **Depositional state and articulations**

Body position in the coffin did not vary a lot among cemeteries. Corpses were deposited in two ways, directly in coffin or in the body bag. In 90.4% (272) of the cases it was possible to observe the depositional state of the corpse. There was clear predominance of corpses were deposited in body bag 74.3% (202) Only 25.7% (70) of corpses were deposited directly in the coffin (Figure 63). The remaining cases (9.6% (29) were found cornered in the niche without any shelter (coffin or body bag).

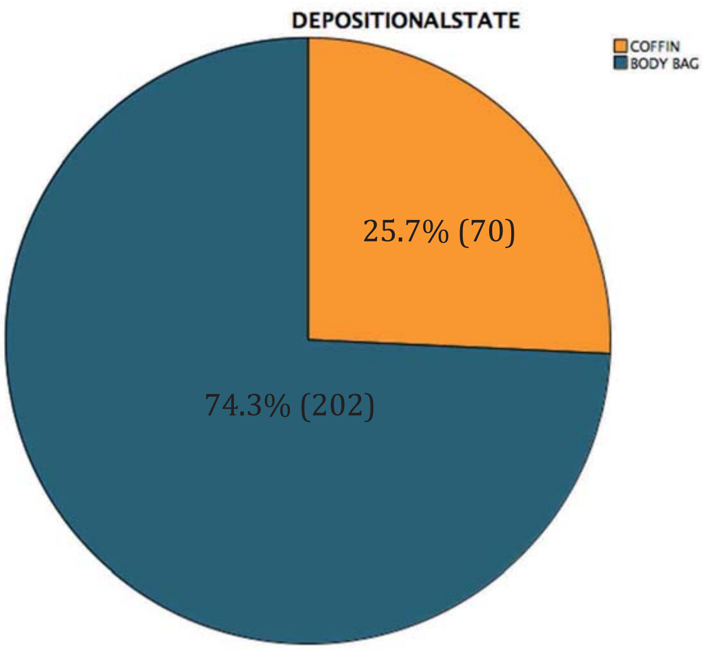


Figure 63. Depositional state (coffin vs. body bag) of corpses in all three cemeteries

Generally, the bodies lay in supine position in the coffin, but some were slightly lateralized to the left or right side. The head was also lateralized to left or right and sometimes supported on a pillow. The superior extremities were extended along the body or placed on the abdomen or inferior part of thorax. The inferior extremities were also extended or slightly flexed in the knees. Hands placed with the dorsal part facing anteriorly, or partly exposing the palmar face when they were extended along the body. Feet were held in "V" form (heels together and big toes separated) when inferior extremities were extended. They were slightly lateralized when the inferior extremities were lateralized too. In the case of remains deposited in a plastic body bag, the remains were moved and presented a more disordered pattern.

The way that articulations are maintained was also a focus of interest, in order to help explain the funerary ritual and taphonomical processes. Not all corpses were suitable for the study of articulation. Only bodies in advance stage of decay allowed the observation of the different articulations (total or partial skeletonization). Another requirement was that the body (skeleton) was not be altered by human manipulation during exhumation or transport. Therefore, only 54 of 301 cases could be employed for this part of the study. The statistical analysis showed that in corpses deposited in coffin there was a higher frequency of maintained articulation (92.6%). On the contrary, when the body was placed into a body bag, and so it was manipulated, there was a very high frequency of alteration in the articulations (98%) (Chi-squared: $\chi^2=157.58$; $p<0.05$) (Figure 64).

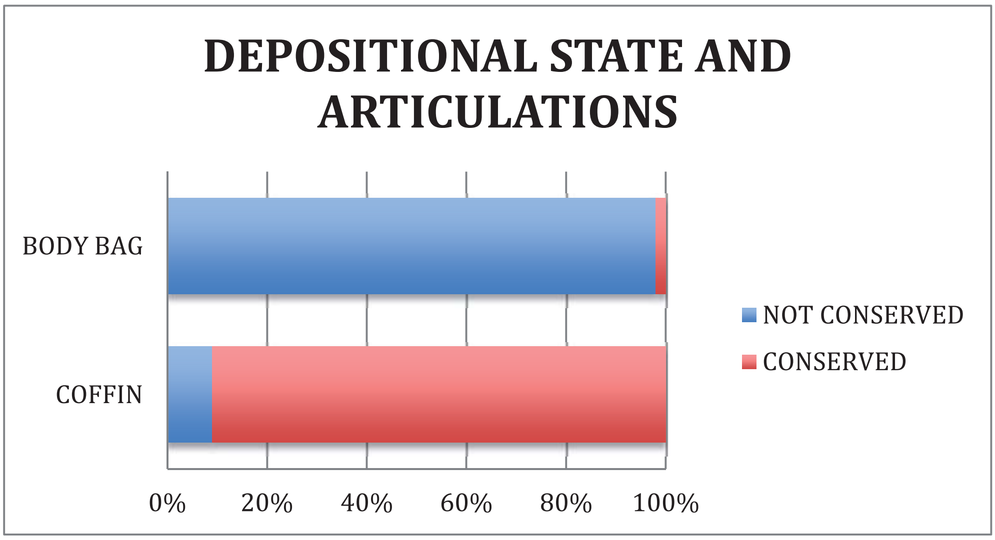


Figure 64. The predominance of articulation maintenance in the skeletons deposited in coffin is shown.

5.17.1 **Articulations**

In total, 54 corpses were examined. Only articulations without any pathologic or traumatic alteration could be evaluated. Although burial practices are similar, the articulation pattern varied within and between cemeteries. The variable degree of disarticulation and displacement was assessed. Most skeletons that were used for this study came from CT (49). The remaining 5 were from CBMN. No cases from CBCLL could be analysed.

In order to describe the preservation of joints, a manual on articulation description was prepared and an inter-observer test was performed. The first step was to specify the variables to be analysed and to establish a consensus on how they are named. From these observations and to facilitate the determination of the integrity of joints, a flowchart was designed (Figure 65):

1. If the preserved bone is found in its **correct anatomical location** (Correct anatomical position refers to the correct position of bone element in a healthy human body),
2. If the articular surfaces of **bone elements** are **faced/confronted**
3. If there is a **maintained physiological distance** between the bones that form the articulation (Figure 65).

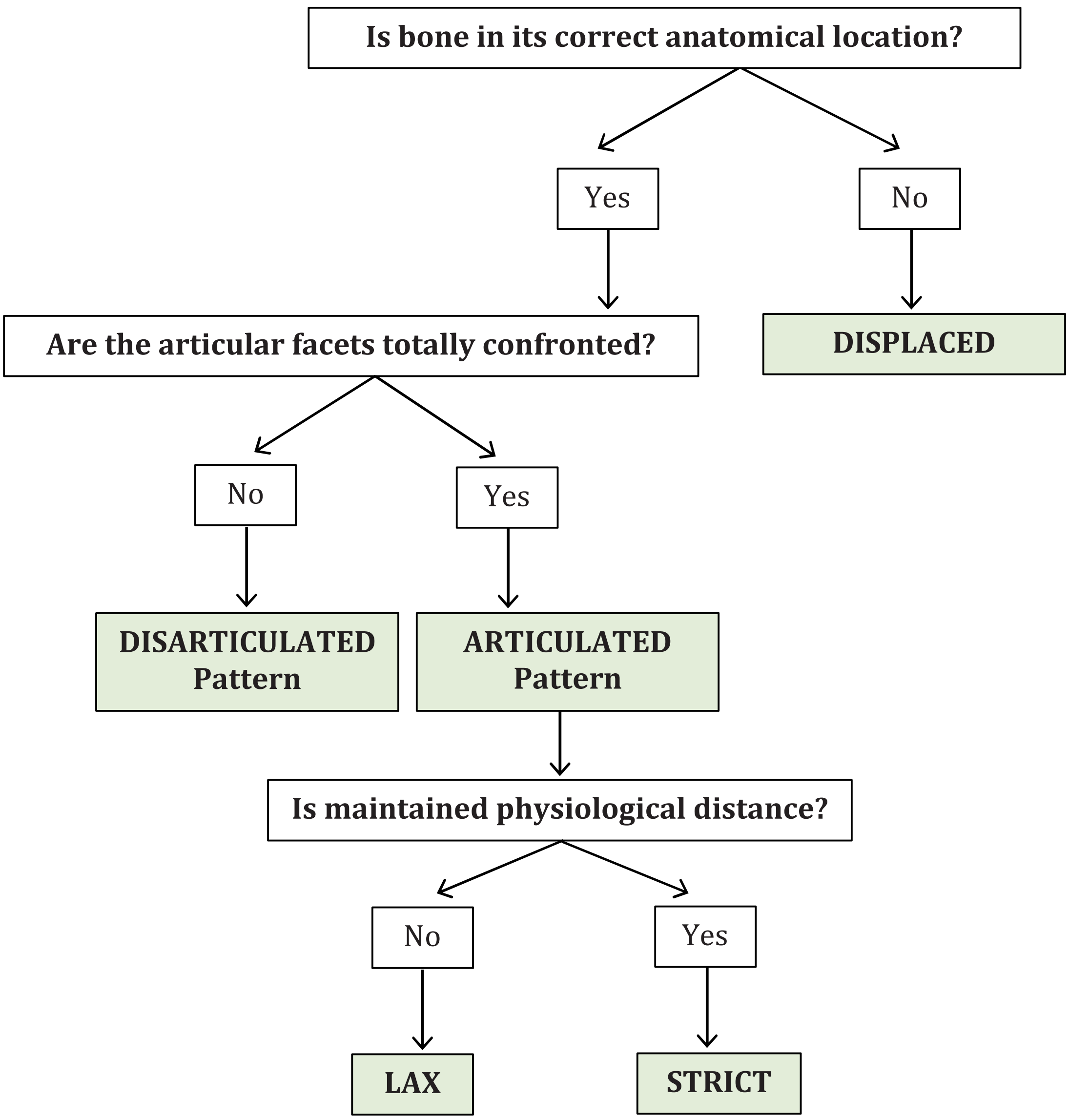


Figure 65. Assessment scheme of the articulation pattern

In order to grade this articulation variability, 4 types of articulation patterns were defined from these observations, and a subdivision of articulated patterns in two categories was done.

Displaced pattern of articulation occurs when a loss of spatial relation of articulation takes place. Therefore, the bone element is found out of its correct anatomical location (Figure 66).

Figure 66 . Example of displaced pattern; *os capitatum* is out of its correct anatomical position in the carpal row.

Disarticulated pattern of articulation is observed when the articular surfaces are not confronted but it is still possible to observe spatial relationship between them. In abstract sense, to rebuild this type of articulation, two or three movements are necessary. These movements could be done in the 3 principal axes (x, y, z) (Figure 67).

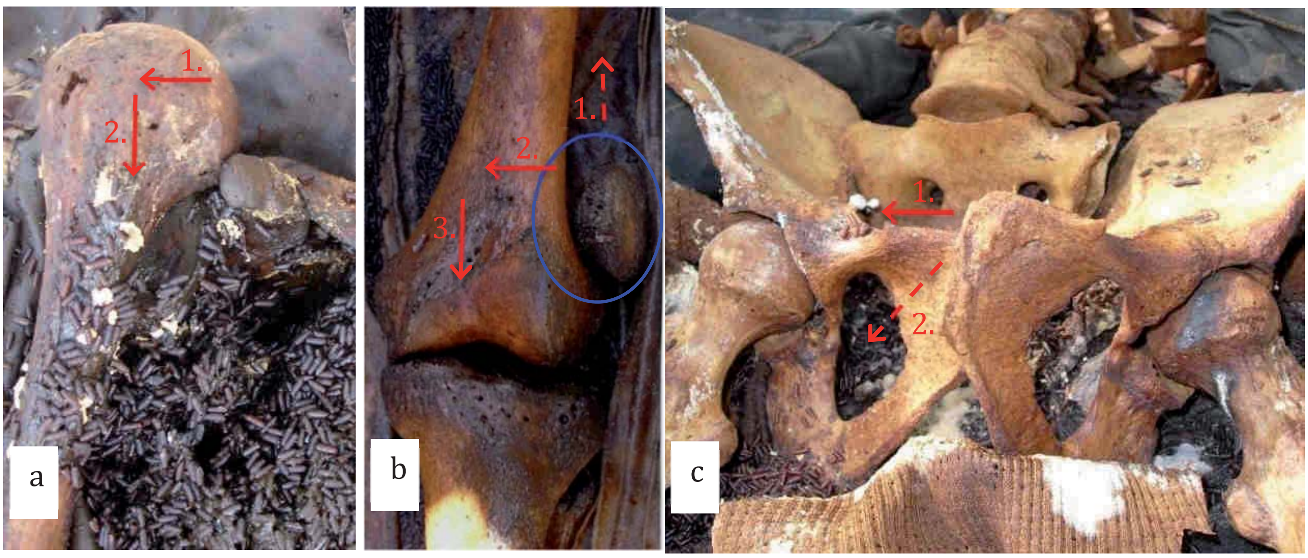


Figure 67. Example of disarticulated pattern; *caput humeri* (a.), *patella* (b.), and *os pubis* (c.) are in their correct anatomical position but their articular facets are not faced/confronted

In the case of the lax/coherent pattern of articulation, the articular surfaces are partially or totally faced with no correct physiological distance between them. It is necessary just one movement to fix this articulation and make it work, moving the element in the 3 principal axes (x, y, z) (Figure 68).

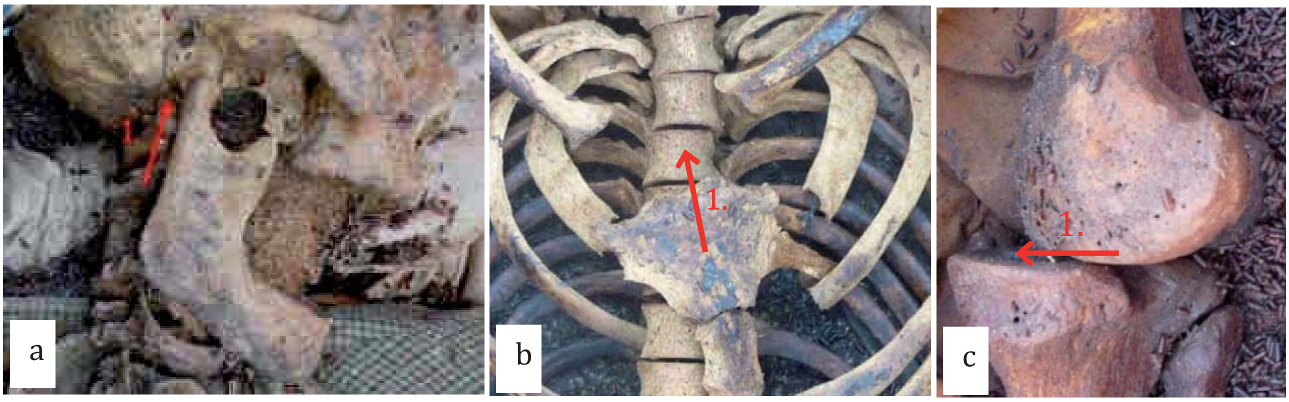


Figure 68. Example of lax/coherent pattern; inferior jaw in *temporo-mandibular* (a.), manubrium (sternum*)* (b.), and femur (c.) are in their correct anatomical position with their articular facets faced/confronted totally or partially, but without correct physiological distance.

Strict pattern of articulation is the pattern where correct physiological distance between articular superficies is conserved (Figure 69).

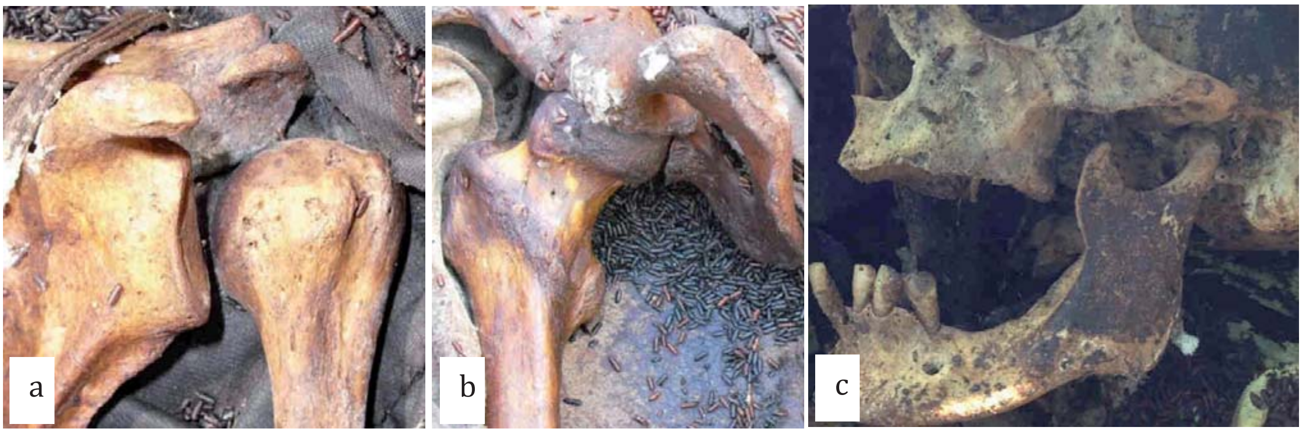


Figure 69. Example of strict pattern; *caput humeri* (a), *caput femuri* (sternum*)* (b), and inferior jaw in *temporo-mandibular* joint (c) are in their correct anatomical position with their articular facets faced/confronted totally, separated for the correct physiological distance.

An important factor that may affect the pattern of articulation is the type of clothes. Clothes protect the articulation against external factors and provide more stability to the articulation. The level of given stability depends on the type of clothing that the corpse is wearing. In corpses that are wrapped by funerary sheet, strict or lax type of articulation predominate, while corpses dressed with clothes showed more disarticulation.

The second step was to validate the classification method. Twelve observers were elected for the inter-observer test. The knowledge on human articulations, and experience in archaeology and anthropology varied among observers. The observers were provided the manual mentioned above and photos showing different articulation patterns. The inter-observer test displayed that most difficult to evaluate were the articulation of shoulder (humeral head and glenoid cavity), and hips (femoral head and acetabulum), whereas the evaluation of the elbow articulation (humeral distal end, head of radius, and olecranon fossa of ulna), and sacrum and iliac articulation were easier. The general percentage of coincidence, number of errors, and total score were calculated in the inter-observer test (Table 8). The results from the observers were compared to results of the developer of the method (observer 1). The total agreement of coincidence is the percentage total coincidence between observers. Total score refers to the closeness of the given answer to the correct one, and it is evaluated from 4 (correct) to 1 (the furthest from correct/opposite). Wilcoxon test was used to compare the observation of method developer with each one of the participants in the inter-observer test. Significant differences were found in one case ($p<0.05$).

Table 8. Results from the inter-observer test (general percentage of agreement (%), total score, and significance from Wilcoxon test).

Observer	Total agreement (%)	Total score*	Wilcoxon test (Sig.)
1	100%	208	-
2	78,85	192	0,642
3	78,85	190	0,642
4	48,08	159	0,43
5	48,08	162	0,010
6	51,92	159	0,302
7	88,46	197	0,516
8	46,15	155	0,250
9	61,54	180	0,144
10	50	163	0,435
11	59,62	177	0,864
12	50	162	0,344
13	57,69	179	0,297

*The maximum score was 208.

Generally, the articulation of the elbows was the best maintained followed by the distal part of radius and ulna and the *temporo-mandibular* joint. Elbows were also those with the greatest frequency of the strict type of articulation, followed by the radius and ulna distal joint, the femur and tibia joint, the shoulders, the hips, and the knees. In conclusion, most of the articulations were conserved in the strict type, except the articulations of the sternal end of clavicles and pubic symphysis, which mostly presented a lax type of articulation (Table 9).

Articulation between the manubrium and sternal body, the ribs with the sternum, the ribs with vertebrae, the vertebral column and feet is not included in table 9.

In most cases feet were dressed in socks and it was impossible to evaluate them without altering the original articulation. Socks maintained the feet in a strict articulation. Vertebral column presented in most cases a strict or lax type of articulation separated in blocks corresponding to the natural curvature of the column. Disarticulation was frequent between L5 and the base of the sacrum due to the natural curvature of the lumbar part of the spine and because the soft tissue that supports this part was lost.

Articulation between the manubrium and the sternal body and between the sternum and the ribs usually disarticulated because the thorax collapsed.

The vertebral articulation of the ribs persisted generally in a lax way.

All above-mentioned articulations were more sensible in the moment of removing the clothes and alteration of original articulation may have occurred. In some cases, sternum and ribs were stuck to the clothes.

Table 9. Number of cases of each examined articulation.

Articulation	Side	Strict	Lax	Disarticulated	Displaced	Cases/% (54/100%)
ATM	R	22 (40.7%)	12 (22.2%)	6 (11.1%)		40/74.1%
	L	17 (31.5%)	14 (25.9%)	10 (18.5%)		41/75.9%
CR/CVC	R	16 (29.6%)	6 (11.1%)	6 (11.1%)	3 (5.6%)	31/57.4%
CL/STERNUM	R	6 (11.1%)	16 (29.6%)	7 (13%)		29/53.7%
	L	8 (14.8%)	16 (29.6%)	5 (9.3%)		29/53.7%
SHOULDER	R	25 (46.3%)	10 (18.5%)	2 (3.7%)		37/68.5%
	L	29 (53.7%)	9 (16.7%)	3 (5.6%)		41/75.9%
ELBOW	R	40 (74.1%)	5 (9.3%)	1 (1.9%)		46/85.2%
	L	40 (74.1%)	2 (3.7%)	3 (5.6%)		45/83.3%
RAD/ULNADIST	R	33 (61.1%)	8 (14.8%)	2 (3.7%)		43/79.6%
	L	30 (55.6%)	7 (13%)	5 (9.3%)		42/77.8%
WRIST	R	22 (40.7%)	7 (13%)	8 (14.8%)		37/68.5%
	L	24 (44.4%)	8 (14.8%)	4 (7.4%)		36/66.7%
HAND	R	17 (31.5%)	7 (13%)	13 (24.1%)	1 (1.9%)	38/70.4%
	L	22 (40.7%)	4 (7.4%)	11 (20.4%)	1 (1.9%)	38/70.4%
PUB	R	15 (27.8%)	19 (35.2%)	3 (5.6%)		37/68.5%
SACILIAC	R	20 (37%)	13 (24.1%)			33/61.1%
	L	18 (33.3%)	13 (24.1%)	2 (3.7%)		33/61.1%
FEM/ACET	R	26 (48.1%)	6 (11.1%)	1 (1.9%)		33/61.1%
	L	28 (51.9%)	5 (9.3%)	1 (1.9%)		34/63%
FEM/TIB	R	31 (57.4%)	2 (3.7%)	1 (1.9%)		34/63%
	L	33 (61.1%)	4 (7.4%)			37/68.5%
KNEE	R	25 (46.3%)	4 (7.4%)	2 (3.7%)	2 (3.7%)	33/61.1%
	L	28 (51.9%)	3 (5.6%)	4 (7.4%)	1 (1.9%)	36/66.7%
TIB/FIB	R	27 (50%)	3 (5.6%)			30/55.6%
	L	30 (55.6%)	2 (3.7%)			32/59.3%
TIB/FIBDIST	R	29 (53.7%)	1 (1.9%)			30/55.6%
	L	29 (53.7%)	1 (1.9%)			30/55.6%
ANKLE	R	21 (38.9%)	4 (7.4%)	1 (1.9%)		26/48.1%
	L	19 (35.2%)	5 (9.3%)			24/44%

ATM: temporo-mandibular articulation; CR/CVC: cranium and cervical vertebrae column; CL/STERNUM: sternal end of clavicle; SHOULDER: humerus, glenoid cavity of scapulae; ELBOW: humerus, radius, ulna; RAD/ULNADIST: distal joint of radius and ulna; WRIST: distal epiphysis of radius and ulna with proximal row of carpals; HAND: articulation between carpals, metacarpals, and phalanges; PUB: articulation between left and right pubic symphysis; SACILIAC: articulation between sacrum and ilium of coxals; FEM/ACET: articulation between femoral head and acetabulum; FEM/TIB: articulation between femur and tibia; KNEE: femur, tibia, patella; TIB/FIB: articulation tibia and fibula; TIB/FIBDIST: distal joint between tibia and fibula; ANKLE: distal end of tibia and fibula with astragal.

5.18 **Other findings**

5.18.1 **Degenerative changes**

In 67.4% (203) of the individuals it was possible to observe different types of degenerative changes (edentulous jaws, arthritis, eburnation of articular facets, osteophytes, cartilage ossifications, and slimming of parietal bones). Almost all the adult individuals presented some kind of degenerative change (Figure 70).

Figure 70. Example of degenerative changes: osteophytes on cervical vertebrae C3-C4 (a), fusion of both innominate bones and sacrum (b), arthritic rim on proximal epiphysis of right ulna (c), arthritis on left shoulder joint (d), eburnation and arthritis on right knee (e), bilateral slimming of parietal bones (f), and total edentulism of upper and lower jaws (g).

5.18.2 **Antemortem treatment and lesions**

In 13.6% (35) of the individuals, antemortem treatment or lesions were observed, in form of hip or knee prostheses (4%, 12) and healed fractures and other skeletal lesions (7.6%, 23) (Figure 71). Taking into account that the majority of exhumations correspond to people living during the second half of 20th Century, it is not surprising to find evidences of medical treatments. However, the most frequent skeletal alterations noticed during this study were dental prostheses. This fact fits well with the elderly age of the vast majority of the individuals of this study.

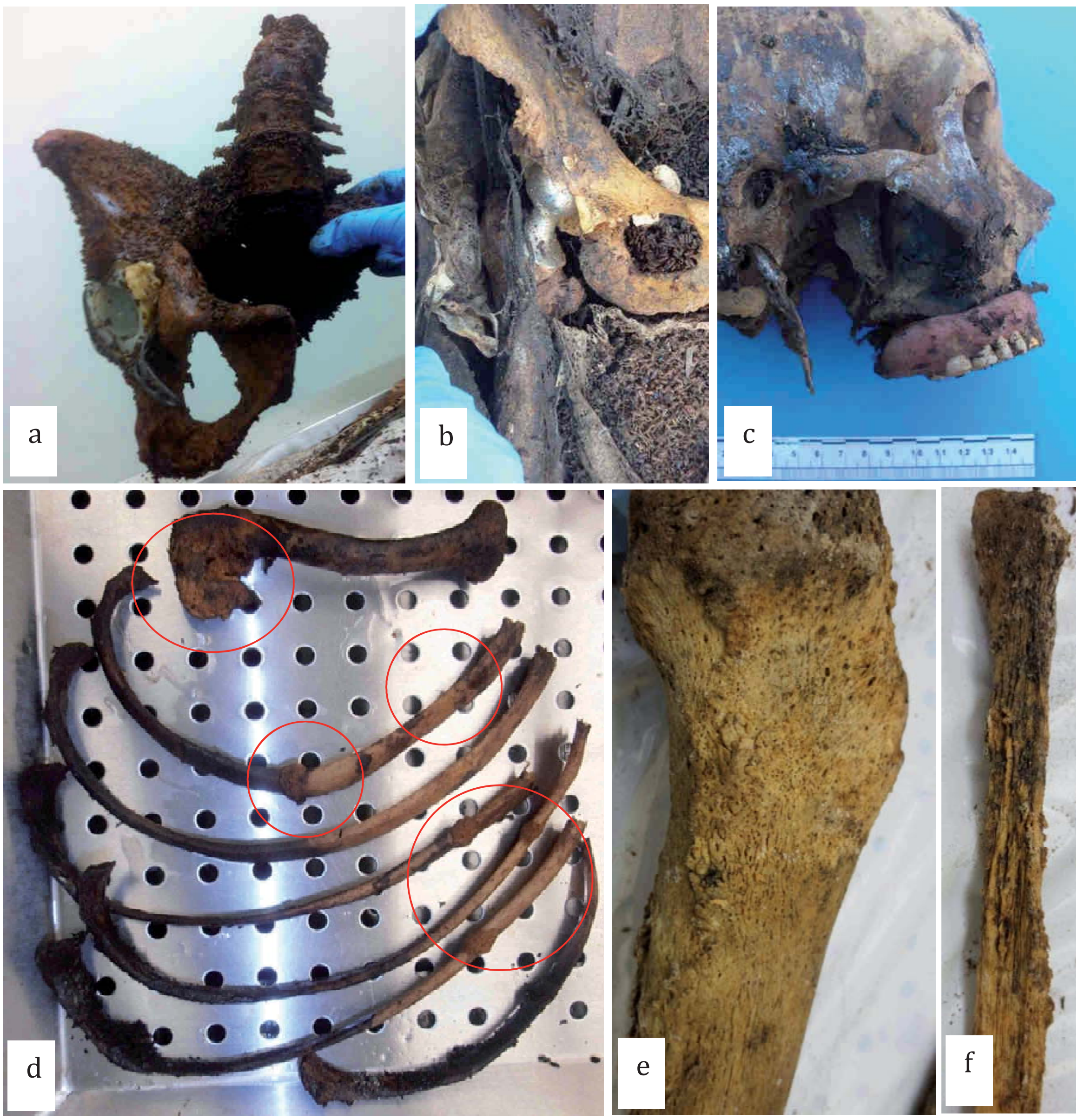


Figure 71. Example of antemortem treatment and lesions: *acetabular fosa* prosthesis (a), *caput femoris* prosthesis (b), female senile individual with superior dental prosthesis (c), antemortem healed fractures on right ribs and clavicle (red circles) (d), periostitis of the tibia and fibula in male adult individual CBMN64 (e, f).

Many of the above mentioned antemortem lesions or treatments could be considered as individual characteristics if detected during individual life. Other discrete traits that could be useful as individual characteristics or could help narrow down the list of victims if necessary were observed. A lot of dental prostheses (Figure 71) were found during this study, as well as other anatomical traits that could also be helpful (Figure 72).

Figure 72. First cervical vertebra with cleft in posterior arch (atlas bipartite) in male adult individual (a), presence of *pectus carinatum* in female adult individual (b), metopic suture in female adult individual (red arrow) (c).

5.18.3 **Calcifications**

Some calcifications were observed (Figure 73). The macroscopic description and photographic documentation was made. The location of the calcifications was described if possible, but in most cases their exact location could not be inferred because of the post-mortem manipulation of the remains.

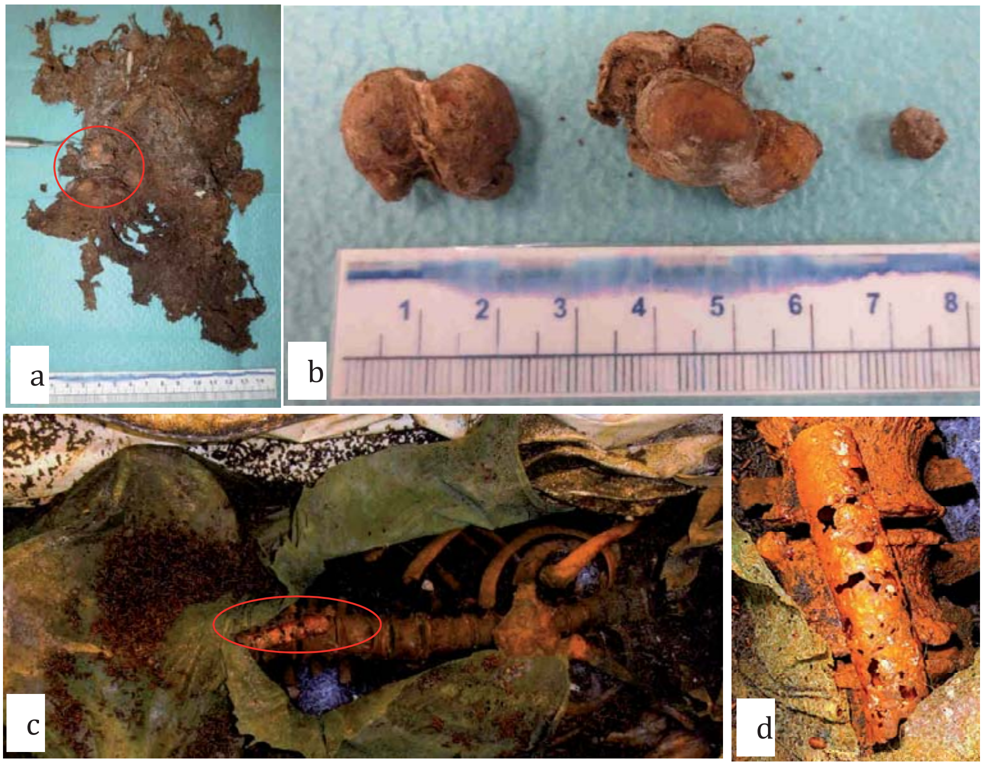


Figure 73. Stones found inside abdominal cavity of a 55-year old female suffering from digestive high haemorrhaging (a), the exact character of those stones was not known, detail (b). Calcified aorta (c), detail (d).

5.19. **Circumstances of death**

Not all exhumed individuals had available information about their circumstances of death. In the sheet from the cemeteries there was some general information about circumstance of death only in few cases. The circumstances of death were known in 33.2 % (100) of the individuals. The more common circumstance of death was cardiac failure (35%, 35 cases), followed by cases of infection (13%, 13 cases), neoplasms (primary or secondary) (12%, 12 cases), respiratory failures (9%, 9 cases), neurologic lesions (7%, 7 cases), hypovolemic shocks (4%, 4 cases), and finally, the both, traumatic lesions and renal failure in 2% (2 cases) (Figure 74). In 16% (16 cases) of cases, unspecified diseases were reported in the funerary sheet as circumstance of death.

Differences in cadaveric state among different circumstances of death were tested. However, no significant differences were confirmed (Kruskal Wallis: χ^2= 10.53; p>0.05).

Only in few cases the signs of circumstances of death could be observed. Signs of disease could also be observed in the skeleton of CBCLL 19 (65 years old woman) that had breast cancer. Metastasis was observed in form of lytic lesions on the skull (Figure 75).

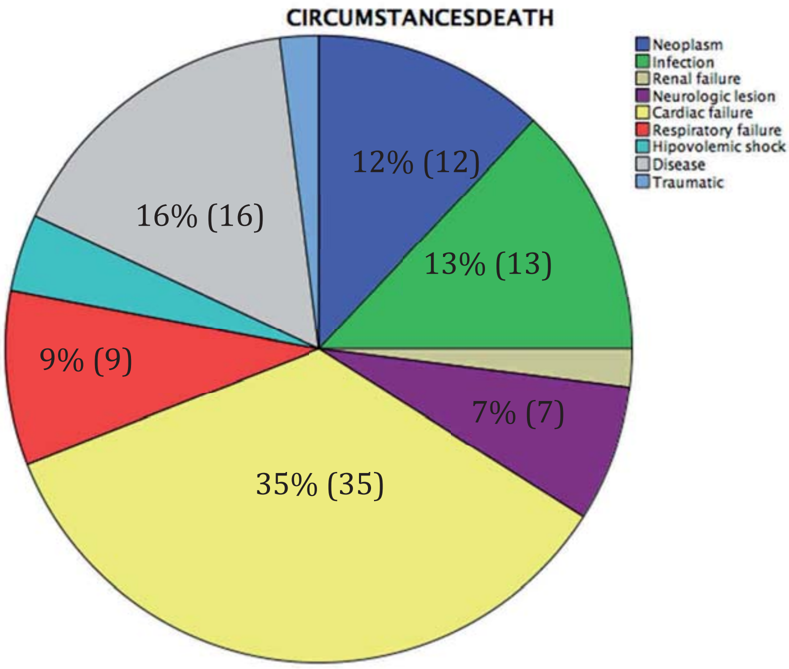


Figure 74. Graphic of cause of death from a total of 100 individuals with known cause of death for all cemete

Figure 75. Secondary neoplasms in form of lytic lesions on the skull CBCLL 19 (65 years old woman).

In 7 cases (2.3%) clear perimortem lesions were observed. Some of them were observed in soft tissues (Figure 76) and some others in skeletal elements.

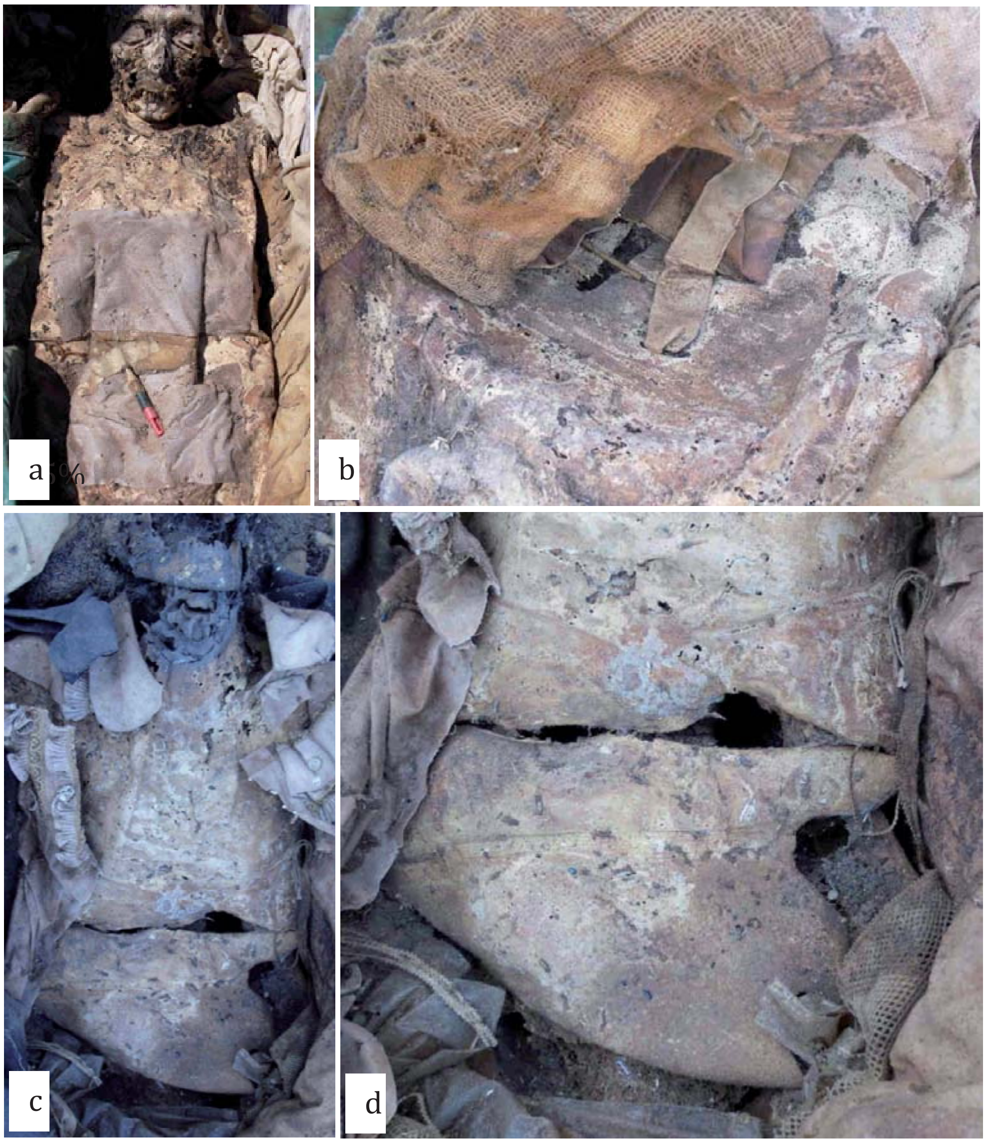


Figure 76. Above; example of 61-year old male individual with perimortem traumatism in anterior and lower part of abdomen (no regeneration was observed) (a), and detail of the lesion (b). Female individual with huge triangular perimortem incision on the anterior part of abdomen and bilateral inguinal region (c), and detail of the affected zone (d).

An example of bone perimortem injury was a fracture of the anatomical neck of the femur in an adult feminine individual (Figure 77). Another female individual (CT12) also presented multiple perimortem fractures in the superior and inferior limbs, pubic bones, sternum and head.

Figure 77. Perimortem fracture of the anatomical neck of left femur.

5.20 **Fauna**

Only in 88% (265) of the individuals the presence of fauna could be assessed, because of the manipulation of the body after exhumation (change of depositional state from coffin to body bag). In 90.2% (239 of 265 corpses) fauna was found. Most cases involved dead fauna (small beetles, moths, spiders) or empty *puparia* (89.5%). Three different *puparia* sizes were observed. The biggest one had around 1 cm in length, medium 0.5 cm approximately, and the smallest one observed during this study had less than 0.5 cm (Figure 78).

In few cases (10.5%) living fauna was detected (spiders, mealy bugs or cockroaches), and they were always observed together with dead fauna (Figure 79).

No significant association between fauna presence in coffin/body bag and the three cadaveric states of overall corpse was confirmed (Fisher's exact test: p>0.05). The relationship between fauna and the presence of lesions (perimortem trauma or autopsy) was not statistically confirmed either (Fisher's exact test: p>0.05).

In some cases of corpses with total or partial mummification (and also in some anatomical parts), marks left on the skin by insect action were seen. These were small and more or less circular damage of desiccated soft tissue (Figure 80).

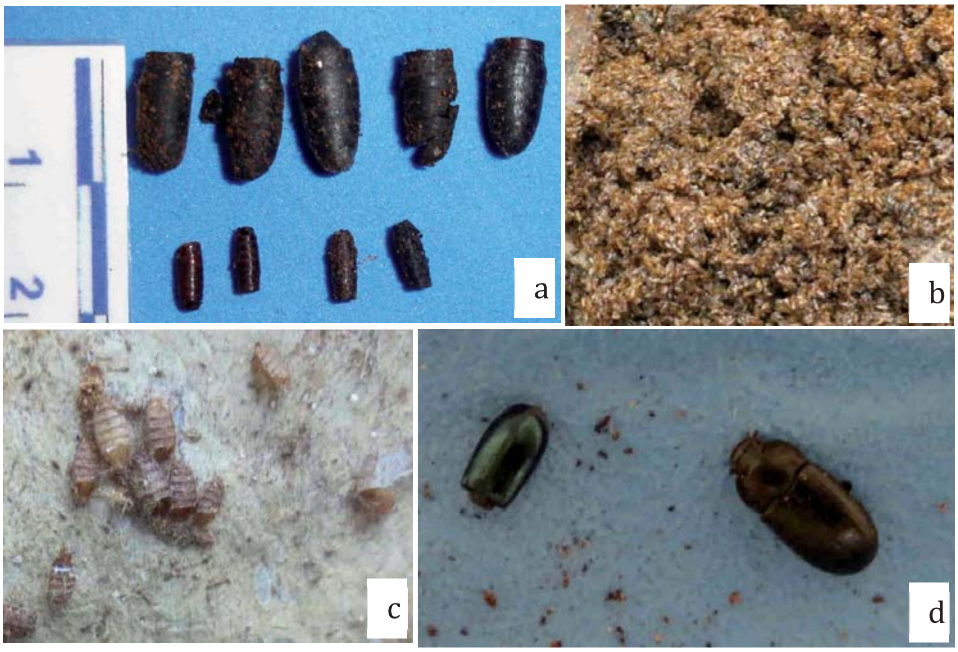


Figure 78. Detail of two sizes of *puparia* (the biggest one observed during this study, and an average one), (a); mass of empty *puparia*, the smallest one observed during this study (b); empty *puparia* adhered to the body (c); two types of beetles (d).

Figure 79. Some examples of living insect on/in the corpses.

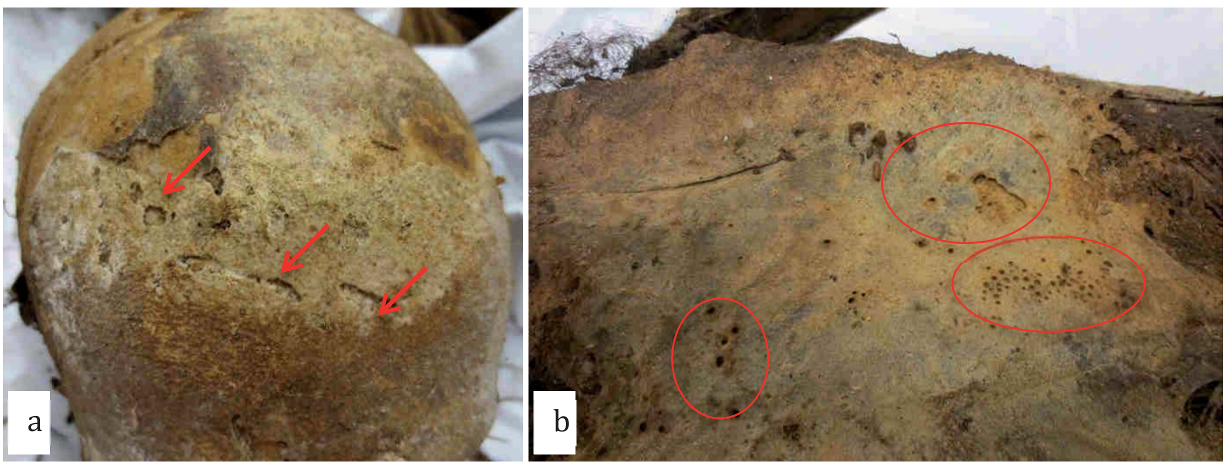


Figure 80. Red arrows indicate marks left by insect action on the frontal of the skull (a); on the posterior part of thorax (b).

Chapter 6 **DISCUSSION**

"Qu'est-ce que la taphonomie ? un outil.

Que peut-on faire d'un outil ? Tout.

Cela dépend du chercheur, de son objet d'étude et des buts recherchés".

A.Viel, 2002, *Le musée cannibale, GHK, Neuchatel : 231*.

6.1 **Context of the study**

A correct and precise interpretation of the decomposition stage is essential for the understanding of the context/origin of the remains. The decomposition process is strictly linked to the place where it occurred. In the archaeological/historical sphere, this information may be helpful to understand funeral rituals of ancient populations (Duday and Guillon, 2006). In forensic cases, this knowledge is essential for the correct estimation of the PMI and it may help to understand the circumstances of death of the individual (Pinheiro, 2006a, b).

Human decomposition is influenced by a number of extrinsic (including manipulation by human action), intrinsic factors and by the interaction between them. Therefore, each environment is different and produces a specific variation on the general pattern of human decomposition. The understanding of those factors is crucial in taphonomic studies (Galloway, 1997). There is a big interest in experimental research about decay, but because of obstacles linked to the availability of human remains, human decomposition is widely studied using non-human models, mainly *Sus scrofa domestica*. The use of non-human models has a set of limitations, i.e. different anatomy, articulation pattern (geometry of articulations), diet, constitution, and illnesses, among others. These variables hinder the observation of the effect of intrinsic factors on the decomposition process (Ferreira, 2012; Cockle and Bell, 2015).

In the USA, where research on donated human bodies is allowed, anthropological research facilities under controlled situations were created (e.g. ARF, Tennessee, *etc*.). Even in those controlled situations, investigations face different constraints, such as limited number of corpses, ethical problems, accessibility of space, negative public opinion, *etc*. In Europe, these kind of observational studies do not exist. In order to overcome the above-mentioned problems, studies of recent human remains from cemetery context are warranted. There are a few studies about cemetery remains, i.e. a recent article by Pokines (2016) and collaborators on taphonomic pattering of cemetery remains received at the office of medical examiners and articles by Rogers (2005) and Berryman et *al*. (1991) about the condition of remains from American cemeteries. Studies focusing on remains from European cemeteries deal with the recognition of cemetery context of remains that took place in Greece (Eliopoulos et *al*., 2011), and with the identification of corpses and PMI estimation in a Portuguese cemetery (Ferreira and Cunha, 2013). In these types of studies, Anthropology and Taphonomy play an important role in the proper comprehension of the events. Furthermore, they face important limitations, such as the lack of choice of the characteristics of the individuals and the exclusive observational nature of the investigation. In spite of this, the results obtained from cemetery studies provide information about human decomposition from particular and non-studied environments.

In an effort to elucidate the human corpse decomposition and the factors that may play an important role on it in Mediterranean climate, an investigation with human remains in cemetery context was performed. The present study is based on Anthropological and Taphonomic analyses of unclaimed human remains exhumed from three different cemeteries in Catalonia (Cemeteries of Terrassa, Montjuïc, and Collserola). Exhumations took place as a consequence of the lack of space in these cemeteries. In order to store the bags containing exhumed remains, special buildings (ossuaries) are built in the cemeteries. According to the Spanish mortuary health laws, the transfer of unclaimed human remains to ossuaries can be carried out 5 years after the inhumation (BOP 240 DE 6/10/2000). In total, 301 corpses were analysed, with a clear predominance of adult individuals, especially from the senile adult age group (> 60 years old), which is normal/obvious considering the cemetery context. The type of antemortem lesions, with a high number of cases of degenerative changes on bones, is also consistent with the old age of the exhumed individuals. Additionally, a slight predominance of female individuals was observed. The exhumed corpses are comparable to remains from a present (forensic) context, because of their antiquity, and so Anthropology and Taphonomy methods and theories were applied.

Therefore, this research is proxy to anthropology/taphonomic research facilities running in USA. The study could be run because of planned exhumation of unclaimed human remains in aforementioned cemeteries. Furthermore, there were individual characteristics that in the case of accessibility to antemortem data of deceased could help in his/her identification. There were confirmed that skeletal elements and teeth are good indicators of personal traits that are able to resist the decomposition process.

Unfortunately, antemortem data containing the information about the cause of death of the exhumed corpses could not be obtained during this study. This limited other kind of analyses affecting the variables of decomposition related to specific individual processes.

Different questions arose from the remains and could be related with the place where inhumation/deposition of corpse took place. The preservation of the remains made possible to analyse different types of cadaveric states, skeleton disassociation, PMI estimation, peri- and postmortem circumstances, forensic and thanatoaesthetic treatments, and other individual information that may be helpful in the corpse identification and its origin. Exploration of each analysed aspect and the corresponding statistical analysis permitted to extend the list of decomposition characteristics that are common in similar situations such as the cemetery context. These questions are discussed in the following sections: **cadaveric states** with subsections of **intrinsic factors** (sex, age, cause of death), and **extrinsic factors** (PMI, autopsy, plastic body bags, type of clothing, diapers, funerary structure type, insect activity, meteorological variables), and the sections of **artifacts**, and **articulation patterns**.

6.2. **Cadaveric states**

The decomposition process is defined by Rodriguez and Bass and later by Galloway, and can be divided in four basic stages: fresh, bloated, decay, and dry (Rodriguez and Bass, 1983; Galloway, 1997). Previous studies only focused on the first three stages of the decomposition process, and leave the last stage for what it is, as it presents almost no soft tissue. Classification of the different decay stages proposed by Galloway, or Rodriguez and Bass did not fit in the present study because of the time limit of 5 years from inhumation. In order to properly study the cadaveric state of human remains from a cemetery, decomposition stages need to be adapted to the time span of the remains. This means that a corpse could not be exhumed from the niche before 5 years of its burial because of sanitary reasons. In this thesis, decomposition stages were readapted and **five cadaveric states**, within the range of advanced decay, were described. The cadaveric state of all exhumed corpses was described for the entire corpse as well as for different anatomical parts. The existing descriptions concerning the conservation stage of **mummification** (M) and **saponification** (saponification with wet putrid matter, SWPM), and reduction stage of **total skeletonization** (TS) remained the same. Saponification and mummification however, are not the final products of decay. In order to specify these intermediate stages, two new terms were introduced to specify the presence of dry or wet putrid matter over the skeleton: **skeletonization with dry putrid matter and partial desiccation** (DPMD), and state of **skeletonization with wet putrid matter** (WPM). These five states (TS, WPM, DPMD, M, SWPM) are a better representation, in our opinion, to the real cadaveric states after a long time period. Sometimes, a co-existence of different states in one corpse/anatomical part could be observed.

In some occasions during the statistical analysis, **three cadaveric states** were used, because of the sample size and also to facilitate the discussion with other published works. In those cases, **total skeletonization**, **dry cadaveric state** (including skeletonization with dry putrid matter and partial desiccation, and state of mummification), and **wet cadaveric state** (including skeletonization with wet putrid matter, and saponification with wet putrid matter) were taken into account.

The condition of remains on cemeteries can vary considerably due to physical, chemical, and biological factors (Rogers, 2005). For this reason, differences between cemeteries could be observed concerning the presence and frequency of established cadaveric states for the entire corpse. At the Cemetery of Montjuïc all five cadaveric states could be observed, with a predomination of SWPM. The Cemetery of Terrassa presented the highest frequency of M of all cemeteries and a complete absence of SWPM for the overall corpse. The Cemetery of Collserola showed the highest presence of WPM and not one case of TS corpse.

Taking into account only three cadaveric states, the highest frequency of corpses in a dry cadaveric state was observed in the Cemetery of Terrassa, followed by the Cemetery of Montjuïc and finally by the Cemetery of Collserola that presented the highest frequency of corpses in wet cadaveric state among all the cemeteries. Related to the total skeletonization, a higher frequency was observed in the Cemetery of Terrassa compared to the Cemetery of Montjuïc.

During this research it was seen that different cadaver preservation caused different postmortem changes. Corpses in a dry cadaveric state tend to preserve better, with a slightly higher disintegration of the posterior part (the part that is in contact with the surface) of the corpse/anatomical part. This finding is congruent with other studies since more advanced decay can be observed at the pressure points (Berryman et *al*., 1991; Pokines et *al*., 2015). In cases where the corpse was mummified, evidence of insect activity described previously by other authors, could be observed in the form of small holes through the desiccated skin. Additionally, a higher retention of hair, body and facial hair, nails, organs and cloth impressions on the skin was observed as mentioned in literature (Berryman et *al*., 1991; Pokines et *al*., 2015). The wet cadaveric state demonstrated a higher degradation of soft tissue and bone. Skeletal elements that are moister tend to disintegrate easily.

Ferreira and Cunha (2013) also described different cadaveric states for different anatomical parts of 25 exhumed corpses from a Portuguese cemetery. In their study, the biggest part of the anatomical parts were skeletonized or saponified. The difference in the predominate cadaveric state between Ferreira's study and the current study may be mainly because of different funerary rituals and a significantly shorter PMI. Corpses from the Portuguese cemetery were earthed in the ground while in our study they were placed in cement niches above the ground. Soil offers more stable conditions to the corpse due to the restriction from oxygen and insect activity compared to the niche structure. Niches are not completely hermetic and allow a slight air stream that may facilitate the drying process of the remains.

6.2.1 **Intrinsic factors**

One of the focuses of this thesis was to analyse the influence of intrinsic factors, as sex, age, and cause of death, on the observed cadaveric state. During this study the influence of an **individual's sex** was not displayed. Statistically, there was no significant difference between males and females in the observed cadaveric state. However, it is a generally accepted fact that there can be a tendency to some cadaveric state because of an individual's sex. Female bodies have a higher chance to develop adipocere than male bodies due to a higher content of fat as well as a different fat distribution (Pfeiffer et *al*., 1998; Fiedler and Graw, 2003; Bruin, 2010). Furthermore, Ferreira (2012) statistically confirmed in her PhD thesis that saponification of the abdomen is more frequently observed in female individuals. In other studies about corpses from a cemetery context this factor was not discussed. Instead of the individual's sex, the importance of the body composition is sometimes mentioned (Ferreira and Cunha, 2013). It is commented that well-nourished persons, with a high body fat percentage at the time of death, delay the decomposition process because of adipocere formation. Work done by Mann et *al*. (1990) do not agree with this conclusion that indicates that obese corpses tend to lose their body mass due to liquefaction of body fat. Moreover, during his research on decomposition rates based on sex, no differences could be noted between males and females. We had no information to our disposal about the body composition so no analysis could be done.

Results from this thesis indicate that the **individual's age** displayed no association with a concrete cadaveric state. This can be because of a higher representation of adult individuals, concretely the senile group, among the studied samples. The age factor is quite controversial. Some studies (Bruin, 2010) suggest that old individuals tend to form adipocere due to the gelatinous transformation of fat tissue and degenerative old age adiposity that leads to the translocation of fat. Other studies demonstrate that new-borns and infants are prone to adipocere formation because of their high proportion of fat. Also, there are studies that did not observe any relation between age and the observed cadaveric state, as we did during our study (Fiedler and Graw, 2003; Fiedler et *al*., 2009). Ferreira (2012) states that they have found a statistic correlation between age and the cadaveric state of the head and chest. They indicate that individuals older than 80 years old never presented saponification of the head, while saponification or skeletonization of the chest were more common for individuals between 71 and 90 years. Finally, they concluded that sampling might skew these results. As mentioned above in the section of influence of sex, the influence of age on the conditions of cemetery remains was not tested in other studies from cemetery context.

During this thesis, clinical histories/information about the **cause of death** were not always available, so certain analyses of the weight of this factor could not be extensively explored. With the current data, it can be stated that death circumstances did not significantly influence the cadaveric state nor was there an influence of the presence of perimortem lesions on the final cadaveric state. Related to the cause of death, Ferreira and Cunha (2013) mention an increase of the decomposition rate in cases when an individual suffered an infectious cause of death. However, it is possible that the long PMI of our samples covered up the relevance of the cause of death or perimortem lesions.

In summary, the influence of an individual's sex, age, and cause of death (intrinsic factors) was not confirmed in our analysis. Therefore, an influence of these factors has to be considered on the decomposition rate rather than on the final conservation state of remains.

6.2.2 Extrinsic factors

Also the influence of **external factors** such as postmortem interval, manipulation of the corpses (autopsy performance), clothing and wrapping presence, funerary structure, insect activity, and meteorological conditions were tested.

- **PMI**

The remains used in the present study passed at least 5 years inhumed so there was no possibility to observe early stages and active processes of decomposition. This offered a unique possibility to obtain samples with a large **PMI** in the moment of aperture of the funerary structure. In this study, the exhumed remains had a mean PMI of 22,63 years ± 15,97 years. Therefore, the discussion and conclusions made must consider this long PMI.

In both the anatomical parts and the overall corpse, it was observed that TS is the state that is related to the longest inhumation time followed by remains in DPMD. In addition, remains in DPMD state presented a higher PMI than those that are M, followed by remains in WPM and those in SWPM. During our study, some cases of saponification could be observed with different PMIs, so its formation seems to be independent on the elapsed time. This observation is in concordance with other studies (Bruin, 2010; Ubelaker and Zarenko, 2011) that conclude that once adipocere tissue has fully formed and the microenvironment of the corpse maintained its stability the time since death does not affect the conservation of saponified corpses.

When the relation between PMI and cadaveric states was analysed among the different cemeteries, some differences were found. In the Cemetery of Terrassa, M was the cadaveric state that presented the highest PMI, then DPMD, followed by TS and as last ones those in WPM. In contrast to the Cemetery of Montjuïc, where state of TS presented the highest PMI, followed by DPMD, M, and finally very similar PMI presented states of SWPM and WPM. In the Cemetery of Collserola, the PMI is very similar for states of DPMD and those in state of WPM and a slightly shorter PMI was observed for the M state. The last few years, there were relatively many studies published related to the estimation of the PMI, and some formulae were created to facilitate its estimation (Rodriguez and Bass, 1983; Galloway et *al*., 1989; Galloway, 1997; Megyesi et *al*., 2005; Ross and Cunningham, 2011; Vass, 2011). As mentioned before (Discussion paragraph 6.2), methods elaborated for cadaveric state description (Rodriguez and Bass, 1983; Galloway, 1997) and methods for PMI estimation (Accumulated Degree Days- ADD, and Total Body Score- TBS) (Chapter 1) are not suitable for our study because of the elapsed time from an individual's death, and the specific funerary structures. The TBS method has to be applied to cases of human remains found above ground, without adipocere formation and with known daily temperature. The ADD method can be applied for aerobic and anaerobic environments but with a maximum of 1285 accumulated days after an individual's death. So the problem with PMI estimation for skeletal remains, or remains with little tissue preservation remain unsolved using those methods. The comparison with other cemetery studies is quiet complicated because of a significantly shorter PMI in their researches (Berryman et *al*., 1991; Rogers, 2005; Eliopoulos et *al*., 2011; Ferreira and Cunha, 2013; Pokines et *al*., 2016). For example, a study of Ferreira and Cunha (2013) evaluated 25 exhumed corpses from a Portuguese cemetery with PMI between 50-51 months.

When focusing on the passed PMI and observation of TS for different anatomical parts in the moment of the niche aperture, it could be observed that the posterior parts of the corpses skeletonized first, followed by the feet, hands, skulls and mandibles, lower limbs, abdomens, and chest that are the anatomical parts which needed more time to get skeletonized. This observation differs from the one of Ferreira (2012), where the skull was the first one to skeletonize, followed by the upper limbs, lower limbs, chest, and abdomen. The observed differences between our study and the one of Ferreira are probably due to different PMI, and different funerary rituals. The fact that in our results posterior parts of corpses skeletonized first, could be related to the accelerated decomposition in pressure points that also was observed by other authors (Berryman et *al*., 1991; Pokines et *al*., 2015). Furthermore, it could be related to the accumulation of decomposing body fluids on the bottom of the coffin without the possibility of filtration into the soil.

According to some authors, skeletonization with ligaments or tendons conservation may be observed up to 2 years after death and total skeletonization can take up to 5 years (Villanueva Cañadas, 2004). During our study, it could be seen that all remains passed more than 5 years inhumed and a lot of them presented tissue conservation in different amplitudes. This observation confirms that the cadaveric state proved to be too variable and inconsistent to be of any value for determining the postmortem interval when it is deemed in isolation, which is concordant with results from other studies (Ferreira and Cunha, 2012; Hau et *al*., 2014).

- **Autopsy**

Some special situations have been analysed to see the effect on the state of decomposition. Manipulation of corpses by human action is included in these specific situations. As the remains of the present study came from cemeteries some of them underwent **autopsy**. When an autopsy was performed, there was a significant increase of TS and wet cadaveric state (WPM, SWPM), as well as a slight increase of M. On the other hand, when autopsy was not performed, a tendency to some kind of preservation of soft tissues was frequent and DPMD could be observed. The fact that a corpse tend to skeletonize, or presented a wet cadaveric state could be explained by extraction of the brain and other organs during autopsy and its placement to the thorax cavity. Because of the decomposition of the organs and increase of blood and other liquids inside the thorax cavity, the decay is accelerated. On the other hand, the increase of M in autopsied corpses could be explained because of blood loss. We present the possibility that the final cadaveric state when an autopsy was performed can be dependent on the fact if examined vital organs and brain during an autopsy were posteriorly returned to the corpse or not. An increase of the DPMD in not autopsied corpses cannot be explained in straightforward way. At the moment, we did not find other parallels to confront our results. Berryman and colleagues (1991) used some autopsied corpses but they did not discuss the influence that may have on the composition state (Rodriguez and Bass, 1983; Rodriguez and Bass, 1985). Because of the absence of similar studies with autopsied corpses, we introduce in this study the presence of open lesions. Generally, any presence of open lesions (stab wound or gunshot) but also the presence of an autopsy lesions, decompose faster than bodies without wounds because of insect activity. So, at the same time they should inhibit adipocere formation or mummification (Mann et *al*., 1990; Fiedler and Graw, 2003; Bruin, 2010). At the same time, it has to be taken into consideration the fact that the presence of open lesions are closely linked to insect activity because of the increase of moisture. During an autopsy, vital organs are removed and there is a loss of blood. This may cause the corpses to lose their attraction for insects and so the increase of decomposition rate may not be observed. But mainly, the different conditions of the cemeteries and the niches can affect the final cadaveric state and must be taken into consideration. The cases where an influence of open lesions is highlighted on the decomposition, took place above ground, which means direct access for insects to the corpse (Mann et *al*., 1990). In situations where corpses are earthed or protected by a funerary structure (as niche and coffin) it is not demonstrate so clearly (Rodriguez and Bass, 1985). Work done by Simmons and colleagues pointed that variables such as penetrating trauma had no effect on the decomposition rate, however they pointed to further research being required (Simmons et *al*., 2010; Hayman and Oxenham, 2016). A higher number of autopsied corpses and descriptions of their cadaveric state is needed to confirm this hypothesis.

- **Plastic body bags**

In some occasions, corpses may be placed in a **plastic body bag** because of transport, to protect against diseases suffered by the deceased or to avoid fluid leakage. A plastic body bag was one of the external factors that could be observed that could affect the cadaveric state. An increase of wet cadaveric state and a decrease of dry cadaveric state could be observed. This observation is related to the accumulation of moisture and decomposition fluids inside the body bag, without any possibility to be absorbed.

During our study, two possibilities of plastic body bag placement could be observed. Firstly, when a corpse was dressed in cloth, a plastic body bag was placed over the cloth leaving the individual's head uncovered (few cases). Those corpses presented wet conservation of tissues with "rubber appearance". The second possibility concerns corpses wrapped in a funerary sheet where the plastic body bag was placed under the wrapping material. In those cases, an increase of wet cadaveric state of liquid appearance could be observed. Furthermore, it was interesting to see that when a plastic body bag was present, mummification of the head tends to be present. This can be explained because of exclusion of the head from the body bag, that means that head was not covered by body bag in larger amount of cases.

The effect of a plastic bag or plastic wrapping on the corpse decomposition process is of specific forensic interest. Garbage bags are often used as an improvised covering to dispose human remains. Previous studies show that corpses covered with plastic material were able to form adipocere (Bruin, 2010; Ubelaker and Zarenko, 2011). A study performed by Forbes et *al.,* (2005a,c) primarily suggests that the presence of a plastic bag forms a barrier between the corpse and surrounding environment, preventing cation exchange causing the inhibition of the adipocere formation. In the end, Forbes' hypothesis was not confirmed because the tissue they earthed in a plastic bag had liquefied instead of forming adipocere. After their first study, they concluded that this phenomenon was unexpected, so they performed another experiment where first the corpse was wrapped in cloth and then wrapped in a plastic bag and buried. After the second study, adipocere could be observed after the exhumation of the corpses. The authors explain the cause of this phenomenon by the absorption of the clothes, which remove the decomposition by-products (such as glycerol) that inhibits adipocere formation (Forbes et *al.*, 2005a,c; Bruin, 2010). This observation seems to be congruent with the results of this thesis, where an increase of wet cadaveric state (WPM, SWPM) was observed.

- **Type of clothing**

An influence of the **type of clothing** on cadaveric state was examined too. Our results showed that the presence of a funerary sheet displayed higher frequency of wet conservation and lower frequency of dry conservation. Furthermore, there is a clear association between clothes and dry conservation. This fact could be explained because of the higher liquid absorbance by clothes material and their easier drying in contrast to the synthetic tissues or wood from the coffin. Meanwhile as mentioned above, the presence of a body bag could be associated with a funerary sheet presence because it is the easiest way to dress the decedent. During our research, no influence of the number of clothing layers was demonstrated. Different authors agree that clothing/wrapping may help to drain and absorb body fluids and so facilitate the mummification of one or several anatomical parts of the corpse (Cahoon, 1992; Alturalyia and Lukasewycz, 1999, Miller, 2002, Kelly, 2006, Dautartas, 2009, Voss et *al*., 2011).

- **Diapers**

Our results show that diapers demonstrated a tendency to conserve body tissue since state of M and DPMD could be observed. Absorption of liquids at the affected part (abdomen and anterior part) by diapers may explain this observation. The results of this thesis are in contrast to the results obtained in PhD thesis of Ferreira (Ferreira, 2012). She concluded that diapers did not affect the decomposition pattern of abdomen, due to its presence in both, skeletonized as well as saponified corpses. Later in 2013, Ferreira and Cunha in stated their article that the presence of diapers showed a delay in abdominal skeletonization (Ferreira and Cunha, 2013). That conclusion is concordant to our finding. It would be interesting to know the exact composition of diapers in order to discuss the importance of different components on abdominal decay.

- **Place of burial conditions**

The effect of **place of burial conditions** had also been investigated. All corpses presented in this study decomposed within a wooden or conglomerate coffin, because it is not allowed to bury someone without a coffin, in cemetery conditions. The corpse is without any contact with the soil and placed at different heights. This means that fluids from the corpse cannot filtrate into the ground and stay accumulated in the coffin or niche floor. The height of the niche seemed to affect the cadaveric state, especially the highest position of niche. There is a “popular hypothesis” that corpses in the highest niches tend to desiccate/mummificate due to more solar exposure. During our study this theory was not confirmed. In our study, SWPM was related to a higher position of niche rather than DPMD or M. We must take into account that specific characteristics of the type of burial influence the decomposition process and create unique characteristics. There are a lot of studies that compared the decomposition rate between corpses that were earthed and those decomposed above ground. Corpses that were earthed decompose in different and slower rate that those exposed above ground (Rodriguez and Bass, 1985; Mann et *al.,* 1990; Sledzik, 1998; Forbes, 2008). Some authors describe that corpses inhumed in a coffin decompose faster than corpses inhumed directly in the ground (Mant, 1987; Rodriguez and Bass, 1985; Mann et *al*., 1990). Both a coffin and niche, do not represent a constant burial environment and offer initial physical protection from direct contact with outer destructors (Pokines et *al*., 2015). However, the influence of the funerary structure type niche on the corpse decomposition process is not known. Niche structures and coffins cannot be directly compared with earthed inhumation but they may simulate other situations like corpses found within a closed structure because of partial protection from the external factors. As there are no other studies that use corpses from niches, this type of condition can be partially compared to the condition created by other closed structures (houses, garages, *etc*). Galloway (1997) states that corpses hidden in houses or trailers often show slower onset of early decomposition. This information can be applied to our results showing a high number of cases with remains of soft tissues and long PMI.

- **Meteorological variables**

During our study there was an interest to see if meteorological variables have an effect on the final state of the cadaveric state. The cadaveric state seems to be influenced by meteorological variables. Observations from the Cemetery of Montjuïc showed that high values of sunlight affected the SWPM during the first five years of inhumation. In the Cemetery of Collserola, high values of rainfall (during the first six months of the first year), average wind (during the first six months), average relative humidity (during the first year) and sunlight (during the first five years) have an effect on WPM. No effect of meteorological factors was displayed on corpses of the Cemetery of Terrassa. Saponified corpses with wet putrid matter (SWPM) in the Cemetery of Montjuïc, and corpses in WPM in Cemetery of Collserola were those mainly placed in the highest niche.

Analysing all cemeteries together, results showed that corpses in SWPM are those that mark the difference. Saponified corpses with wet putrid matter showed to be affected generally by high values of rainfall (during the first months), minimum relative humidity (during the first six months), average temperature (during five years), minimum temperature (during five years), sunlight (during the first year and during five years), and evapotranspiration (during five years). We suggest the hypothesis that prevailing effect of meteorological variables on corpses in SWPM and WPM states could be related to the highest niche position (see above). It has to be taken into account that during our research, above-mentioned meteorological factors did not affect the corpse directly because of niche structure and coffin presence in all cases. In this sense, meteorological data facilitated from nearest meteorological automatic station serve as approximation but do not display correct and direct data for our study. It would be very interesting to perform the observation about influence of meteorological variables directly in the niche structure. On the other hand, influence of meteorological data is not clear in all cases, so we hypothesize that significant differences between cemeteries were due to direct effect by i.e.: clothing, autopsy, thanatopraxy on the body. These variables display a bigger consequence than the indirect effect of meteorological variability between cemeteries.

Studies related to the importance of meteorological variables on the human decomposition rate were published by different authors (Behrensmeyer, 1978; Rodriguez and Bass, 1983; Galloway et *al*., 1989; Mann et *al*., 1990; Bass, 1997; Galloway, 1997; Sledzik and

Micozzi, 1997; Megyesi et *al*., 2005; Ross and Cunningham, 2011, Schotsmans et *al*., 2011, Vass, 2011; Zhou and Byard, 2011; Cockle and Bell, 2015). The importance of air/soil temperature, humidity/aridity, and rainfall was highlighted and linked with insect action. Mann and colleagues (1990) states that ambient temperature and humidity appears to be correlated with fly and maggot activity, and so affect the decomposition rate of the human body. It was demonstrated that higher temperatures increase the decomposition rate because of the increase of insect activity. Furthermore, humidity affects the decomposition rate in a way that corpses in more arid areas result in mummification or dryness of remains, and a very slow destruction by insects may be observed (Mann et *al*., 1990). In our case and in spite of different locations of cemeteries, the differences in humidity are probably not strong enough to create a variation inside the niche structures. In addition, interesting variables such as salt contribution in air, that could influence the conservation in the Cemetery of Montjuïc, were not possible to analyse.

Results of this thesis showed no influence of **seasonality** on the cadaveric state. This can be explained because of the very long PMI of the exhumed corpses in our study because probably there is higher influence of seasonality on the decomposition rate during the first stages of fresh or early decomposition. Some other studies demonstrated that when death is estimated to have occurred during winter, the decomposition may be retained and a corpse may present a fresh appearance, while under ideal conditions (warm weather during summer) the corpse may become nearly or completely skeletonized within two - four weeks (Mann et *al*., 1990; Galloway, 1997, Hayman and Oxenham, 2016).

Meteorological conditions, accessibility of the corpse and trauma on the body, are factors that are strictly related to **carrion insect activity**. In our study corpses were partially protected from the insect access by the closed structure of the niche and presence of a coffin. These structures are not hermetic and allow some access once closed. Moreover, as the legislation does not allow inhumation of a corpse before 24 hours after death, there had been enough time for an insect invasion. Relation between entomological remains and open lesion was tested but was statistically not significant. Nevertheless, a high quantity of empty *puparia,* some death beetles and spiders were observed in the coffins. Also living insects could be observed on the corpses that took a benefit of the conditions formed by the remains and coffin. Different authors mention an attraction of insects by a decomposing human body. When a corpse is placed on a surface there is free access for the insect to the body.

Temperature or rainfalls can regulate this invasion. Even when temperatures are low it was demonstrated that colonization by insects did not stop but rather reduce in the case of flies, while maggots continue feeding within the corporal cavities. If maggots get exposed to the cold exterior temperature they would die. When corpses are earthed in the soil, a restriction of insect access can be observed (Rodriguez and Bass, 1983; Rodriguez and Bass, 1985; Mann et *al*., 1990; Catts, 1992; Campobasso et *al*., 2001; Simmons et *al*., 2010).

6.3. **Cemetery artifact and origin of the remains**

Artifacts found near and/or on human remains are closely related to the type of cadaveric state and funeral practice. This study aimed to recognize and evaluate cemetery artifacts that can be used to indicate the origin of the remains. The presence and observation of artifacts is significantly conditioned by the preservation and treatment of the corpse before burial, which differs a lot between countries.

In Spain the customary treatment of the body, once death has been ascertained, includes cleaning, clothing, and placing in a coffin. Typically, the lower and upper jaws are tied together so they are not affected by the development of *rigor mortis* (Green and Green, 2006). Embalming of deceased is not performed regularly in Spanish funeral practice, with the exception of the cases when the corpse must be transported to or from another country. However, in Spain it is usual the partial treatment of body, and the aspiration of visceral cavities is needed. After the funeral service, the coffin is taken to the cemetery where it is lifted into the niches.

During our study, four principal types of treatment and related artifacts have been observed. The first one was the results of forensic or clinical **autopsy** practice. After this process, marks on the human body are observed resulting from different procedures performed during autopsy. During autopsy the cranial cavities are opened. An oscillating saw is used for opening the cranium to enable the examination of the brain (Valentin and d´Errico, 1995; Knight, 1996). The placing of absorbent fabric material (cotton or absorbent paper) within the cranial cavity after the procedure is used to prevent slippage of the skullcap from the cranial base during suturing of the head, and reducing the possibility of fluid leakage during the funeral ceremony. Throughout the autopsy, the thorax and abdominal cavity are also opened. The ribs, sternum and clavicles are sectioned by rib shears for the removal of the breastplate to enable the inspection of the thoracic viscera. In addition, incisions in the skin and subcutaneous tissue, and on the ventral surface of the ribs in order that the internal organs along the thoracic wall can be observed (Sheaff and Hopster, 2005). Anthropologists should be aware of the location and nature of these cuts, so they are not confused with those produced in cases of intentional dismemberment or other types of sharp force trauma (Eliopoulos et *al*., 2011). The presence of cut marks in the bone or mummified skin from autopsy practice is indicative that the body has a cemetery origin. In our study, 21 cases of autopsy practice have been observed (CT-11; CBMN-5; CBCLL-5). It was possible to observe both cut marks on the skin and cut marks and/or incisions section on the bone. Also absorbent material within the cranial cavity was found in some cases (CBMN, CBCLL). No absorbent material within the cranial cavity was found in the case of corpses in Cemetery of Terrassa. This absence could be related to the characteristics of the used absorbent fabric material, which breaks down earlier than the rest of tissues.

The second type of artifact highly indicative of cemetery remains is that related to **thanatopraxy treatment**, which results in a large number of traits (artifacts). The most notable are those related to embalming process, which has been noted as a key factor in the identification of cemetery remains. Researchers from the United States, where embalming frequently occurs, have described a number of attributes encountered in embalmed tissues (Berryman et *al*., 1991). According to the funeral industry, embalming involves the injection of chemicals into the vascular system and visceral cavities for disinfection and preservation of a body (Strub and Frederick, 1967; Berryman et *al*., 1991). In Spain, however, embalming is not common, and during our investigation was not observed in any case. Throughout our study, presence of nails, head, facial and body hair was mainly found as a result of natural body conservation. Similarly, dehydrated brain tissue and mummified bodies were found, but the bodies had not been embalmed. Other mummified organs observed during our study were eyes, lungs, heart, diaphragm, entrails and stomach. It may be the result of the warm climate in Catalonia (Spain) and local environmental conditions of the cemeteries, as well as the position of the niche within the block of niches and the location of the block of niches in the cemeteries.

Partial treatment of the decedent sometimes was performed. In those cases, presence of a trocar button in the anterior part of abdomen was found. A plastic trocar button is used to seal the hole left by the trocar during the aspiration of blood, other body fluids and gases from both the abdominal and thoracic cavity, and injection of fluid in order to disinfect and preserve the remains. The plastic trocar button is screwed into the skin, and may resist for years, helping to define the origin of the remains (Berryman et *al*., 1991). One case of trocar button presence during exhumations in the cemetery of Terrassa was observed. The screwed plastic trocar button was placed in the antero-superior part of individual´s mummified abdomen.

Sewing of upper and lower jaw together is another indicative trait of thanatopraxy. Different types of this procedure are known. A few years ago, injector needles with steel pins were used widely. Injector needles are stainless steel pins with attached wire. One is inserted in each gum line and its function is to keep the mouth closed. Small screws have also been used for this purpose (Berryman et *al*., 1991). This type of sewing was used years ago but did not find during these exhumations. A simple sewing was used more often. This procedure is easier, cheaper, more discreet and preserves very well for years. It was possible to observe the rest of thread adhering to the upper or lower jaw in 12 cases (CT-9; CBMN-3). No case of sewing evidence was observed in the Cemetery of Collserola. This absence in the Cemetery of Collserola does not mean absence of procedure but only the absence of preservation of this artifact because of conservation or manipulation of remains during transport.

Cotton packing was the most common artifact observed in all cemeteries, frequently put in the mouth and nostrils to prevent from leakage of fluids. Moreover, this method facilitates the shaping of the lips. Some time ago, a mouth former was used for this function. It is a contoured perforated plastic object to fit the teeth, with a smooth inner surface and spiny outer surface (Berryman et *al*., 1991). A mouth former, compared to cotton packing, is not universal. This was not observed during these exhumations but, conversely, we could observe the presence of cotton packing. Nostril cotton packing (CT-40 cases; CBMN-38 cases; CBCLL-4 cases) was sometimes observed, due to inferior jaw disarticulation, losing the cotton in the oral cavity. In those cases, *buccal* cotton could be observed out of its position. In cases when *buccal* cotton was preserved *in situ* (CT-44 cases; CBMN-52 cases; CBCLL-2 cases), it could occupy all oral cavity and the superior part of trachea. The presence *in situ* of both, *buccal* and nostril cotton, was observed in 70 cases (CT-37; CBMN-30; CBCLL-3).

Other artifacts were observed such as, eye cups. Eye cups are thin, plastic, and transparent disks used to shape the eye and keep the eyelid closed. The disk is molded to produce a smooth, concave surface for direct placement over the ocular globe. The convex surface is spiny to facilitate gripping of the inner surface of the eyelid (Berryman et *al*., 1991). A cotton bead can be placed under the eye cup. Eye cups with cotton beads were observed in just 7 cases during this study (CT-2; CBMN-4; CBCLL-1).

To facilitate dressing of decedent during thanatopraxy, the clothes are often cut in its posterior part (Berryman et *al*., 1991). Such a posterior longitudinal cut was clearly observed during our examinations. It was observed in 114 cases, when the decedent was clothed in clothes and not in a white funeral sheet (CT-64; CBMN-36; CBCLL-14). Due to advanced disintegration of cloth tissue, it was not possible to observe either the type of cloth or the posterior longitudinal cut in many cases.

Another characteristic of thanatopraxy or clinical practice is the presence of diapers. Their function is to reduce the possibility of fluid leakage during the funeral ceremony. Diapers resist decomposition and they are frequently observed in remains from cemeteries. During our observational study, 82 (CT-37; CBMN-40; CBCLL-5) cases of diapers presence could be observed. In some cases it was not possible to identify whether the decedent wore the diapers due to postmortem rake out of the remains.

In cases of disfiguring trauma, wax is commonly used for cosmetic restoration of the face, and is resistant to decomposition (Berryman et *al*., 1991). During this study, any trace of cosmetic restoration or remains of cosmetic wax has not been observed. In 7 cases there could be observed presence of perimortem traumatism from skeletal elements or soft tissue. No cosmetic wax remains were preserved in any case. In one case in Cemetery of Terrassa (CT12) where perimortem polytraumatism was observed, the way in which the decedent was wrapped indicates that the corpse was probably not exposed during the funeral ceremony.

In some cases, an enzyme and microorganisms pack (HYGECO, BIOACTRYN®SACOPACK) is deposited into coffin. This biological powder product is a decomposition accelerant that promotes liquefaction and digestion of fats, proteins, starch, and cellulose. Usually, the product is placed into the coffin between thighs, near to pelvis. The powder is packed in a plastic bag, so the perforation is required for the activation of the product by water or body fluids. When this does not occur, content of the bag changes from a powder to gel structure. The product does not fulfil its function and may be found later during exhumation process, being indicative of cemetery origin. In this study, six inactive products could be observed (CT-2; CBMN-4). It is known that the application of those products started in 2004 in Terrassa, but there was not a list of cases where this product was used in the inhumation, so the evaluation of its efficiency is not possible. No information about an initiation of use of decomposition accelerate product is known in Cemetery of Montjuïc and Collserola. Studies on exhumations performed in North America and Greece (Berryman et *al*., 1991; Rogers, 2005; Eliopoulos et *al*., 2011) did not mention the use of similar products.

The third type of treatment of the dead body is **funeral practice**. Coffin wear, fungal growth, sawdust from coffin adhering to remains, unpigmented fauna, and circular hair lost in the posterior part of skull, could be included in this category. This group of traits may be a guide to the origin of remains but they are not indicative, at least in the first two groups.

In the study of Eliopoulos et *al*. (2011) the most notable factor was the so-called coffin wear, which has been described in other studies, too (Ubelaker, 1989; Berryman et *al*., 1991). Coffin wear refers to the erosion of the bone of pressure points in the supine skeleton, often observed on the occipital bone, scapular spines, humeral heads, spinous processes of the vertebrae, sacrum, innominates, and femora. Moisture or water may be retained in the coffin and accelerate the decay of submerged portions of the body. This decay/erosion may be slight and only affect the superficial layers of the cortical bone, or in some cases, it may extend to the underlying trabecular bone. Differential erosion of bone in contact with the bottom of the coffin may come from electrochemical action of the bone under local effects of temperature and moisture (Berryman et *al*., 1991; Eliopoulos et *al*., 2011). In this study, 54 cases (CT-23; CBMN-29; CBCLL-2) of this kind of wear were observed. Higher presence of this wear in the case of Cemetery of Montjuïc could be due to higher moisture or water presence in niches.

Whitish fungal growth over the face and hands was found in 42 cases (CT-12; CBMN-24; CBCLL-6). Its presence is associated with cosmetic makeup used during the preparation of the body for viewing. Mold or other fungal spores may already be present in the makeup, which provides a medium conductive for growth. The presence of mold on the face and hands is consistent with cemetery remains (Berryman et *al*., 1991; Perper, 1993). Moreover, in two cases (CT) the presence of fungal growth may be observed over the whole body, which could be associated with higher humidity in the niche.

Sawdust from coffin adhering to body could occasionally be seen. Eliopoulos et *al.* (2011) have described that in Greece all coffins had a layer of sawdust in the bottom to absorb decomposition fluids. Thus, in these cases, it is not uncommon to find sawdust adhering to the posterior surface of the bones. In Catalonia, this is not a common practice. The presence of sawdust adhering to bones was observed in those cases when the pillow filled with sawdust was deposited under the head of the decedent (CT-7 cases; CBMN-9 cases; CBCLL-2 cases). The sawdust was released and adhered to the bones due to tearing of the pillow.

Also unpigmented fauna (spiders, moths, mealy bugs) was found in 27 coffins (CT-4; CBMN-19; CBCLL-4). Due to the lack of similar studies, there is no more information about the presence of this kind of fauna. All the studies mentioned above (Rodriguez et *al*., 1985; Rogers, 2005; Eliopoulos et *al*., 2011; Ferreira and Cunha, 2013) were performed in the burials in the ground. During this study just cement vertical structures- niches that were not underground, were exhumed. They are not hermetic for insects, as are the burials in the ground, where the absence of oxygen makes the presence of insects sporadic and rare

(Ferreira and Cunha, 2013). Unpigmented fauna in coffins is good indicator of the absence of sunlight and their presence is a trait to suggest that the body may have a cemetery origin.

Another artifact that can be suggestive of a cemetery origin of the remains is the circular hair loss in the posterior part of skull. This is observed due to the hair being pasted to the pillow. When the skull is removed, this type of defect may be observed. It is important not to confuse this artifact with the loss of natural hair in this part, or some type of *alopecia areata*. In the cases where it could be observe this circular hair lost (CT-20; CBMN-5; CBCLL-2), it was possible due to the paste of lost hair in the pillow.

The last types of artifacts are **the forgotten objects** and **items associated with the funerary** and **autopsy practice,** or **thanatopraxy** (CT-4; CBMN-2; CBCLL-1). The most common artifacts are objects placed in the coffin as part of the burial process, and include parts of plaques, statues, flowers, photos, jars, toys, *etc*. Sometimes, the presence of surgical gloves, injections, injector needle, and probes used for body preparation and/or during clinical care are observed.

Not always all the types of artifacts were observed. Sometimes combination of artifacts, or just some of them were found. It must be taken into account that not all kinds of artifacts have the same value in the determination of a cemetery origin. Berryman et *al*. (1991) describe three types of artifacts as predictors of cemetery origin: the physical characteristics of the remains, coffin/caskets or embalming artifacts recovered in association with the remains, and the presence of embalming tissue. They distinguish between those indicative, and those consistent with, cemetery burial. The results from the study presented here are in agreement with the Berryman classification. Moreover, other variables that have to be taken into account are introduced from our study. Classification of artifacts into four types, and placing them into two groups by their weight/value in relation to their origin was done. Artifacts from autopsy practice, thanatopraxy are considered *highly indicative of cemetery origin* (Table 2). The artifacts of funerary practice and forgotten objects associated with autopsy, funeral treatment, and thanatopraxy are concluded to be *suggestive of a cemetery origin*, but they may not exclude human remains of forensic interest (Table 2). However, to identify the correct origin of the remains, a combination of these artifacts is needed.

In summary, the conditions of corpses exhumed in the Cemetery of Terrassa, Cemetery of Montjuïc, Cemetery of Collserola and the artifacts indicating a cemetery origin were described to help to differentiate them from those of remains of unknown origin. The current study was prompted by similar works based on observations carried out in Greece and United States, where burial customs are very different. The burial customs of Catalonian cemeteries are more similar to those from Greece, where embalming is not widely practiced, but differs in the type of burial. Embalming artifacts are rarely found, because this treatment is not widespread in Catalonia, while it is commonly practiced in the United States. Even so, dry conservation and good preservation of unclaimed human remains was observed. In our study, artifacts highly indicative and suggestive of cemetery context were found. Forensic anthropologists must be familiar with all of them in order to be able to recognize remains that could pertain to a cemetery context.

6.4 **Articulation pattern**

The joint articulation pattern can contribute to the recognition of human behaviour of mortuary gesture in archaeological and forensic contexts. In our study we wanted to know if some characteristics of the joint pattern could be helpful in the interpretation of changes related with postmortem environmental or human intervention (mortuary practice, manipulation of corpse/skeleton, original position).

As this research took place in cemetery conditions, there was a characteristic pattern of corpse deposition. All corpses were placed in a coffin in a concrete way. They were all lying on their backs or slightly lateralized. The inhumation of corpses in a coffin simulates empty space burials with some limits presented by the coffin walls and clothes on the corpse. These characteristics allow the examination of the disassociation pattern of articulations. Three possible patterns were described: articulated, disarticulated and displaced pattern. The determination of one of these patterns in joint structures indicates amplitude of movements that occurred inside the space created by the coffin, clothing or corpse itself. There can be more than one pattern observed within one corpse/skeleton. Most of the corpses/joint structures were held in an articulated pattern, but that does not mean that there was an identical degree of articulated pattern for all joints. For this reason, subgroups were defined within the articulated pattern. It has to be taken into account that many classifications of joint patterns do not consider these slight variations (Duday et *al*., 1990; Roksandic, 2002; Duday and Guillon, 2006; Duday, 2009). Therefore, new subgroups - strict and lax pattern - were created.

An elaborated manual offers the possibility to an easy and clear examination of the skeleton/skeletal elements disassociation based on minimum unidirectional movements. The inter-observer analysis showed that experience of the examiner is essential for the use of this manual. Not just experience and knowledge of the human articulation system but also the experience in the field. It is important to use the elaborated manual directly during fieldwork.

It was shown that the interpretation of the articulation is prone to a higher error rate when only photo-documentation was used.

All observations of the articulation pattern were made from adult individuals. In the case of subadult individuals this method could be limited because of lack of bone fusion. In such cases, the evaluation has to be realized between secondary ossification centres.

It was observed that elbows, hips, shoulders and knees presented a strict articulation pattern more often, while articulation in the *temporo-mandibular* joint, and articulation of the pubic symphysis presented a lax pattern which is more often than expected. The strict pattern of articulations of elbows, shoulders and knees is probably due to geometry of the joint structure and due to direct support with the coffin bottom or cloth. The lax pattern of the *temporo-mandibular* joint and pubic symphysis can also be explained by the geometry of their joint structure, as well as in the case of pubic symphysis because of lateralization of both *coxae* bones when soft tissue faded and in the absence of cartilage. In some cases, hands, *temporo-mandibular*, and wrist joints were disarticulated. Disarticulation of the *temporo-mandibular* joint could be explained by the presence of a pillow in a coffin and rotation of the head to one side in some cases. In the case of wrist and hands disarticulation, it may be caused due to the collapse of the abdominal cavity when hands were placed on the abdomen. It can also be because of the position of the hands itself or for post-depositional movement during transport of the coffin when superior extremities were placed along of the body. There were a few cases of a displaced pattern presented by the articulation of the skull of the first cervical vertebra or between the first and second cervical vertebrae. This displacement is also associated with pillow presence and posterior or lateral rotation of the skull with C1 articulated and sometimes of the mandible, leaving the second cervical vertebra in it its correct position.

However, in most of cases, the corpses exhumed during this study maintained a strict pattern of articulation. This is linked to the presence of clothing that may help to keep the articulation in place, even in the empty space.

Additionally, it was confirmed that it is not that easy to disarticulate joints by movement of the coffin. The disarticulation and displacement occurred mostly when the corpse was moved into the body bag due to a lack of hard support. Other authors mentioned that some articulations persist longer than others process of decomposition rates and tissue loss. Duday et *al*. (1990) and other authors highlighted the importance of the type of burial, noted that burials in soil maintained better the articulation than a burial in a void. Empty space around a decomposing corpse provides more freedom of movement for the skeletal elements than decomposition in soil where faded tissue gets replaced by soil little by little (Duday et *al*., 1990; Roksandic, 2002; Duday and Guillon, 2006; Duday, 2009).

6.5 **Future perspectives**

There are few of research projects related to human decomposition in Europe while in America they started already a long time ago with funding anthropological research facilities. In spite of the difficulties to analyse human remains, some proxy must be found to get a better understanding of the process of decomposition in other specific circumstances; one of them could come from the study of corpses from a cemetery context. Our research is pioneer in Spain and in its completeness also in Europe. Many obtained results from this study are not quantifiable but rely on qualitative observations and experience on behalf of the researcher. Nevertheless, it is a first step in this field and needs to be enriched by new works and experience. Furthermore, comparisons with other cemeteries and different meteorological stations are necessary. With future work in the form of articles, and refinement, the application of this kind of studies in a forensic setting could achieve the requirements for any expert testimony, for example the Daubert law of evidence used in America. The Daubert law declares that the used method of the analysis should be tested, peer reviewed and published, with known or potential error rates and be accepted by the scientific community (Grivas and Komar, 2008; Rogers, 2010).

This research was performed as a Cross-sectional study (transversal study) that involved the analysis of data collected from three different cemeteries. Each research that allows answer to some of the determined questions generates other questions that have to be answered. As could be seen throughout this study, in some specific cases (autopsy presence, meteorological variables, *etc*.) sampling might skew our results. Once the general study of remains from the cemetery is done, we are interested to perform a Cohort study that allows us to focus on some of the unsolved questions that arose from this study.

It could be very interesting to observe a direct effect of meteorological factors on the corpse inside a niche. This way we may analyse how the “relation” between meteorological factors and niche affect the corpse inside in order to determine and solve the difference between meteorological values facilitated by *meteocat* and “true” values observed inside of niche.

Our hypothesis about the cadaveric state and its evolution in autopsied corpses could be another objective of future studies. In order to be able to confirm or reject it, a larger amount of corpses that underwent autopsy are needed and a clear record about the destiny of the inner organs during that autopsy practice should be available.

The joint structure disassociation pattern should be applied on a larger sample size and an evaluation of the relation between observed patterns (strict, lax, disarticulation, displacement) and known PMI could be performed. It should be interesting to observe if the sequence of joint disassociation inside an articulated pattern (strict/lax) could be correlated with longer or shorter PMI. Also, the application of the elaborate manual to an ancient context must be considered.

Chapter 7 **CONCLUSIONS**

"Science, in the very act of solving problems, creates more of them".

Abraham Flexner, 1930.

I. Five different cadaveric states have been described in cemetery remains: total skeletonization, skeletonization with wet putrid matter, skeletonization with dry putrid matter and partial desiccation, mummification, and saponification with wet putrid matter. Analysing all cemeteries together, total skeletonized corpses presented the longest PMI, followed by skeletonization with dry putrid matter and partial desiccation, mummification, skeletonization with wet putrid matter, and saponification with wet putrid matter.
However, the analysis of each cemetery separately displays different PMIs for some cadaveric states. In Cemetery of Terrassa mummification displayed the longest PMI while in Cemetery of Montjuïc total skeletonization did. In Cemetery of Collserola the relationship between the observed cadaveric state and PMI was not statistically confirmed, probably due to sample size.

II. The location of each cemetery offers a uniqueness of ambient conditions that affects the observed cadaveric state. Cemetery of Montjuïc presents all five cadaveric states, with the highest frequency of saponification with wet putrid matter of all cemeteries. Cemetery of Terrassa presents absence of saponification with wet putrid matter and the highest frequency of mummification of all cemeteries. Cemetery of Collserola presents absence of total skeletonization and the highest frequency of skeletonization with wet putrid matter of all cemeteries.

III. Age, sex and cause of death did not have any effect on the observed final cadaveric state.

IV. The funerary practice also has an effect on the final cadaveric state. Presence of plastic body bags and diapers, type of clothing, place of burial and time since death affect the final cadaveric state. Prevalence of just one factor cannot be identified in cemetery conditions due to the interactions among all the factors. Presence of plastic body bags, wrapping in funerary sheet and a higher position in the niche tend to lead to wet cadaveric state and saponification with wet putrid matter. Clothes and diapers presence facilitate the dryness of soft tissue and delay its destruction. Autopsied corpses did not present a clear prevalence of a specific cadaveric state. The influence of the season when individual died was not statistically confirmed.

V. The cadaveric state is influenced by meteorological variables. In Cemetery of Montjuïc saponified corpses with wet putrid matter tend to have been exposed to high values of sunlight. In Cemetery of Collserola skeletonized corpses with wet putrid matter tend to have been exposed to high values of rainfall, average wind speed, average relative humidity and sunlight. When all cemeteries were analysed together, saponified corpses with wet putrid matter were confirmed to have been exposed by high values of rainfall, minimum relative humidity, average temperature, minimum temperature, sunlight, and evapotranspiration.

VI. Personal characteristics, such as bone prostheses, antemortem lesions/treatments, degenerative changes and discrete traits are useful for differentiating individuals in the cemetery verification process. They can be helpful in the identification of individuals if the antemortem record is available. In absence of antemortem record, the description and record of personal characteristics of the corpse/skeleton is useful to delineate the biological profile of an individual.

VII. The artifacts indicating a cemetery origin were described to differentiate them from those of remains from unknown origin. The observed artifacts were classified into two groups: highly indicative and suggestive of the cemetery origin. In total, 14 different types of artifacts related to remains from cemetery context were described. Observations related to medical practice or thanatopraxy were considered as highly indicative of cemetery context, whereas artifacts of mortuary aesthetics, funeral practice, were considered as just suggestive of cemetery origin.

VIII. A new unbiased method to evaluate the pattern of joint disassociation based on minimum unidirectional movements was elaborated. The pattern of joint disassociation can be described as strict, lax, disarticulated and displaced. The method enables the interpretation of changes related with postmortem environmental or human intervention. The empty space of coffins did not seem to trigger a higher frequency of a lax patter of articulation.

Chapter 8 **REFERENCES**

Armentano N, Nociarová D, Torres M, Pedro M, Subirana M and Malgosa A. 2014. Taphos-m: Taphonomical and Anthropological Project. Human osteo-biography using Sus scrofa domestica model. XVIII Congreso Sociedad Española de Antropología Física "Una mirada al futuro". País Vasco. pp. 55-72.

Armentano N, Esteve X, Nociarová D and Malgosa A. 2012. Taphonomical study of the anthropological remains from Cova Des Pas (Minorca). Quaternary International 275:112–119.

Aturaliya S and Lukasewycz A. 1999. Experimental forensic and bioanthropological aspects of soft tissue taphonomy. Factors influencing postmortem tissue dessication rate. Journal of Forensic Sciences 44:893-896.

Bass WM. 1997. Outdoor decomposition rate in Tennessee. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp.193–199.

Bass WM. 1984. Time interval since death. In: Rathbun R & Buikstra JE, editors. Case Studies in Forensic Anthropology. Springfiled, Ilinois: Charles C. Thomas. pp. 136–147.

Behrensmeyer AK. 1978. Taphonomic and ecologic information from bone weathering. Paleobiology 4:150-162.

Berryman HE, Bass WM, Symes SA, Smith OC. 1991. Recognition of cemetery remains in the forensic setting. Journal of Forensic Sciences 36:230-237.

BOP 240 DE 6/10/2000 Reglament del Servei de cementiris municipal de Terrassa (Catalunya).

Bouquin D, Beauthier JP, Depierre G. 2013. The dead do not dress: contribution of forensic anthropology experiments to burial practices analysis. International Conference on Cultural Heritage and New Technologies, Vienna. http://www.chnt.at/proceedings-chnt-17/.

Breitmeier D, Graefe-Kirci U, Albrecht K, Weber M, Tröger HD, Kleemann WJ. 2005. Evaluation of the correlation between time corpse spent in in-ground graves and findings at exhumation. Forensic Science International 154:218-223.

Brothwell DR. 1987. Desenterrando Huesos. Fondo de cultura económica. Mexico.

Bruin RA. 2010. What are the contributing factors for the formation of adipocere in soil, and how are they relevant in forensic context? PhD Dissertaition, University of Amsterdam.

Cahoon SE. 1992. Effects of clothing on human decomposition and deterioration of associated yarns. Master Dissertation, University of Tennessee.

Campobasso PC, Di Vella G and Introna F. 2001. Factors affecting decomposition and Diptera colonization. Forensic Science International 120:18–27.

Cardoso HFV, Santos A, Dias R, Garcia C, Pinto M, Sérgio C and Magalhães T. 2010. Establishing a minimum postmortem interval of human remains in an advanced state of skeletonization using the growth rate of bryophytes and plant roots. International Journal of Legal Medicine 124:451–456.

Carter DO, Tibbett M. 2008. Cadaver decomposition and soil: processes. In: Tibbett M & Carter DO, editors. Soil analysis in forensic Taphonomy. Chemical and biological effects of buried human remains. Boca Raton, Florida: CRC Press. pp. 29-52.

Catts EP. 1992. Problems in estimating the postmortem interval in death investigations. Journal of Agricultural Entomology 9:245-255.

Christensen AM, Passalacqua NV and Bartelink EJ. 2014. Forensic Anthropology: Current Methods and Practice. San Diego, United States: Elsevier Inc. pp. 1-16.

Clark MA, Worrell MB, Pless JE. 1997. Postmortem changes in soft tissues. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp. 151-164.

Cockle DL and Bell SL. 2015. Human decomposition and the reliability of a "Universal" model for post mortem interval estimations. Forensic Science International 253:136.e1-136.e9.

Crétot M. 1978. L'arcade dentaire humanine (Morphologie). París: Julien Prélat Edition.

Cunha E. 2006. Pathology as a factor of personal identity in forensic anthropology. In: Schmitt A, Cunha E, & Pinheiro J, editors. Forensic Anthropology and Medecine: Complementary

Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc. pp. 333-358.

Damann FE and Carter DO. 2014. Human decomposition ecology and postmortem microbiology. In: Pokines J & Symes SA, editors. Manual of Forensic Taphonomy. Boca Raton, Florida: CRC Press. pp. 37–51.

Dautartas AM. 2009. The effect of various coverings on the rate on human decomposition, Master's Thesis, University of Tennessee.

DOGC 2528-28.11.1997. Decret 297/1997 Presidència de la Generalitat. Reglament de policia sanitaria monrtuòria.

Dent BB, Forbes SL, Stuart BH. 2004. Review of human decomposition processes in soil. Environmental Geology 45:576–585.

Di Maio VJ and Di Maio D. 2001. Forensic Pathology (second edition). Boca Raton, Florida: CRC Press.

Dix J and Graham M. 2000. Time of Death, Decomposition and Identification. An atlas. Boca Raton, Florida: CRC Press.

Duday H. 2009. The Archaeology of the Death. Lectures in Archaeothanatology. Oxford, United Kingdom: Oxbow Books.

Duday H and Guillon M. 2006. Understanding the circumstances of decomposition when the body is skeletonized. In: Schmitt A, Cunha E, & Pinheiro J, editors. Forensic Anthropology and Medicine: Complementary Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc. pp. 117-157.

Duday H, Courtaud P, Crubezy E, Sellier P, Tillier AM. 1990. L'anthropologie de "terrain": reconnaissance et interpretation des gestes funeraires, Bulletins et Memoires de la Societe d'Anthropologie de Paris, 2:26–49.

Efermov IA. 1940. Taphonomy: New branch of paleontology. Pan-American Geologist 74:81–93.

Eliopoulos C, Moraitis K, Reyes F, Spiliopoulou Ch and Manolis S. 2011. Guidelines for the recognition of cemetery remains in Greece. American Journal of Forensic Medicine and Pathology 32:153-156.

Ferembach D, Schwidetzky I, Stloukal M. 1980. Recommendations for Age and Sex Diagnoses of Skeletons. Journal of Human Evolution 9: 517-549.

Ferreira MT and Cunha E. 2013. Can we infer post mortem interval on the basis of decomposition rate? A case from a Portuguese cemetery, Forensic Science International 226:298.e1-298.e2.

Ferreira MT and Cunha E. 2012. Será credível estimar o PMI em restos cadavéricos em advançado estado de decomposiçao? Cadernos de GEEvH1 2:7-20.

Ferreira MT. 2012. Para lá da morte: Estudo tafonómico da decomposição cadavérica e da degradação óssea e implicações na estimativa do intervalo pós-morte , PhD Dissertation, Universidade de Coimbra.

Fiedler S, Buegger F, Klaubert B, Zipp K, Dohrmann R, Witteyer M, Zarei M, Graw M. 2009. Adipocere withstands 1600 years of fluctuating groundwater levels in soil. Journal of Archaeological Science 36: 1328-1333.

Fiedler S and Graw M. 2003. Decomposition of buried corpses, with special reference to the formation of adipocere. Journal of Forensic Sciences 90:44-52.

Fitzgerald CM and Oxenham M. 2009. Modelling time-since-death in Australian temperate conditions. Australian Journal of Forensic Sciences 41:27-41.

Forbes SL. 2008 Potential determinants of postmortem and postburial interval of buried remains. In Tibbett M & Carter DO, editors. Soil Analysis in Forensic Taphonomy: Chemical and biological effects of Buried Human Remains. Boca Raton, Florida: CRC Press. pp. 225–246.

Forbes SL, Stuart BH, Dent BB. 2005a. The effect of the burial environment on adipocere formation. Forensic Science International 154:24–34.

Forbes SL, Stuart BH, Dent BB. 2005c. The effect of the method of burial on adipocere formation. Forensic Science International 154:44–52.

Forbes SL, Stuart BH, Dent BB. 2002. The identification of adipocere in grave soils. Forensic Science International 127:225–230.

Galloway A. 1997. The process of decomposition: a model from the Arizona-Sonoran desert. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp. 139-150.

Galloway A, Birkby WH, Jones AM, Henry TE, Parks BO. 1989. Decay rates of human remains in an arid environment. Journal of Forensic Science 34:607-616.

Garamendi González PM and López Alcaraz M. 2011. Autopsia médico-legal (I.). Aspecton generales. En: Delgado Bueno S, director . *Tratado de medicina* legal y ciencias forenses. Tomo III. Patología y Biología forense. BOSH, Barcelona. pp. 481-502.

Gennard DE. 2007. Forensic Entomology: An Introduction. United Kingdome: Wiley.

Gonzalez-Fernádez J, Giner Blasco J, Patitó JA. 2011. Fenómenos destructores del cadáver: autolisis y putrefaction. Fenómenos conservadores: saponificación, momificación y otros. En: Delgado Bueno S, director. Tratado de medicina legal y ciencias forenses. Tomo III. Patología y Biología forense. BOSH, Barcelona. pp. 21-40.

Green J and Green M. 2006. Dealing with Death: A Handbook of Practices, Procedures and Law (second edition). London, United Kingdom: Jessica Knigsley Publisher.

Grenčík M. 2011. Forenzné aspekty exhumácie. PhD Dissertation, Univerzita Komenského v Bratislave, Jesseniova Lekárska Fakulta v Martine.

Grivas CR and Komar DA. 2008. Kumho, Daubert, and the nature of scientific inquiry: implications for forensic anthropology. Journal of Forensic Science 53:771–776.

Gutiérrez A, Nociarová D, Malgosa A and Armentano N. 2016. Comparación de los efectos tafonómicos observados en dos estructuras funerarias de espacio vacío. Revista Española de Medicina Legal. In Press.

Haglund WD and Sorg MH. 1997. Method and theory of forensic taphonomy Research. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp. 27–40.

Hau TC, Hamzah NH, Lian HH and Hamzah SPAA. 2014. Decomposition process and post mortem changes: Review, Sains Malaysiana 43:1873–1882.

Hayman J and Oxenham M. 2016. Recent research and current trends. In: Hayman J & Oxenham M, editors. Human body decomposition. Oxford, United Kingdome: Elsevier Inc. pp. 127-151.

Janjua MA and Rogers TL. 2008. Bone weathering patterns of metatarsal versus femur and the postmortem interval in southern Ontario. Forensic Science International 178:16-23.

Kelly JA. 2006. The influence of clothing, wrapping and physical trauma on carcass decomposition and arthropod succession in central South Africa, PhD dissertation, University of the free State of South Africa.

Klepinger LL 2006. Fundamentals of forensic anthropology. United States: John Wiley & Sons, Inc. pp. 117–130.

Knight B and Saukko P. 2004. Knight's Forensic Pathology (third edition). London: Hodder Arnold.

Knight B. 1996. Forensic Pathology (second edition). London: Arnold

Krogman WM and Iscan YM. 1986. The Human Skeleton in Forensic Medicine. Springfield, Illinois: Charles C. Thomas.

Lovejoy CO, Meindl RS, Pryzbeck TR and Mensforth RP. 1985. Chronological metamorphosis of the auricular surface or the ilium: a new method for the determination of adult skeletal age at death. American Journal of Physical Anthropology 68:15-28.

Mann RW, Bass WM, Meadows L. 1990. Time since death and decomposition of the human body: variables and observations in case and experimental field studies. Journal of Forensic Sciences 35:103-111.

Mant AK. 1987. Knowledge acquired from pos-War exhumations. In Boddington A, Garland AN, Janaway RC, editors. Death, decay and reconstruction: approaches to archaeology and forensic science. Manchester, Manchester University Press. pp. 65-78.

Martin R and Saller K. 1975. Lehrbuch der anthropologie. Sttutgart: Ed. G. Fischer.

Masset C. 1982. Estimation de l'âge au décés par les sutures craniennes. Thèse. Université París.

Megyesi MS, Nawrocki SP, Haskell NH. 2005. Using accumulated degree-days to estimate the postmortem interval from decomposed human remains. Journal of Forensic Sciences 50:618-626.

Miller RA. 2002. The effects of clothing on human decomposition: implications for estimating time since death. Master's Thesis, Knoxville, University of Tennessee.

Nawrocki SP. 1995. Taphonomic processes in historic cemeteries. In: Grauer A, editor. Bodies of Evidence: Reconstructing History Through Skeletal, New York: Wiley-Liss. pp. 49-66.

Nociarová D, Adserias MJ, Malgosa A, Galtés I. 2014a. Where do those remains come from? Forensic Science International 245:18-24

Nociarová D, Adserias MJ, Armentano N, Galtés I and Malgosa A. 2014b. Exhumaciones de los Restos Humanos no Reclamados Como Modelo Tafonómico. Revista Española de Medicina Legal 2:1-5.

Ordenanza de Cementerios. 2007 Cementiris de Barcelona.

Parks CL. 2011. A study of the human decomposition sequence in Central Texas. Journal of Forensic Sciences 56:19-22.

Payne JA. 1965. A summer carrion study of the baby pig Sus scrofa Linnaeus. Ecology 46:592–602.

Perper JA. 1993. Time of death and changes after death: Part 1: anatomical considerations. In: Spitz WU, editor. Spitz and Fisher´s Medicolegal investigation of Death (third edition). Springfield, Illinois: Charles C. Thomas. pp: 14-50.

Pfeiffer S, Milne S and Stevenson RM. 1998. The natural decomposition of adipocere. Journal of Forensic Sciences 34:368-370.

Pinheiro J. 2006a. Decay process of a cadaver. In: Schmitt A, Cunha E, & Pinheiro J, editors. Forensic anthropology and medicine: Complementary Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc. pp. 85-116.

Pinheiro J. 2006b. Introduction to forensic medicine and pathology. In: Schmitt A, Cunha E, & Pinheiro J, editors. Forensic anthropology and medicine: Complementary Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc. pp. 13-37.

Pokines JT. 2016. Taphonomic alterations to terrestrial surface-deposited human osseous remains in a New England environment. Journal of Forensic Identification 66:59-78.

Pokines JT. 2015. Taphonomic patterning of cemetery remains received at the Office of the chief medical examiner, Boston, Massachusetts. Journal of Forensic Sciences 61:71-81.

Pokines JT. 2014. Introduction. Collection of macroscopic osseous taphonomic data and the recognition of taphonomic suites of characteristic. In: Pokines JT, Symes SA, editors. Manual of Forensic Taphonomy. Boca Raton, Florida: Boca Raton. pp. 1-17.

Pomara C, Karch SB, Fineschi V. 2010. Forensic Autopsy: A Handbook and Atlas. Boca Raton, Florida: CRC Press.

Reed HB. 1958. A study of dog carcass communities in Tennessee with special reference to the insects. American Midland Naturalist 59:213–245.

Reverte Coma JM. 1999. Antropologia Forense (segunda edición). Ministerio de Justicia, Madrid. pp. 807-838.

Roberts LG and Dabbs GR. 2015. A taphonomic study exploring the differences in decomposition rate and manner between frozen and never frozen domestic pigs (*Sus scrofa*). Journal of Forensic Sciences 60:588-594.

Rodriguez WC and Bass WM. 1983. Insect activity and its relationship to decay rates of human cadavers in east Tennessee. Journal of Forensic Sciences 28:423-432.

Rodriguez WC and Bass WM. 1985. Decomposition of burried bodies and methods that may aid in their location. Journal of Forensic Sciences 30:836-852.

Rogers CJ. 2010. Dating death : forensic taphonomy and the postmortem interval. PhD Dissertation, University of Wolverhampton.

Rogers CJ. 2006. An investigation into the effects of decomposition of wrapped and unwrapped bodies an application of macroscopic and microscopic techniques in forensic anthropology to develop a new taphonomic model. BSc Dissertation, University of Wolverhampton.

Rogers TL. 2005. Recognition of cemetery remains in a forensic context. Journal of Forensic Sciences 50:5-11.

Roksandic M. 2002. Position of skeletal remains as a key to understanding mortuary behaviour. In: Haglund WD & Sorg MH, editors. Advance in Forensic Taphonomy, Boca Raton, Florida: CRC Press. pp. 122-140.

Ross AH and Cunningham SL. 2011. Time-since-death and bone weathering in a tropical environment. Forensic Science International 204:126-133.

Scheuer L and Black S. 2000. Developmental Juvenile Osteology. San Diego, United States: Elsevier Academic Press.

Schmitt A, Cunha E, and Pinheiro J. 2006. Forensic Anthropology and Medicine: Complementary Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc.

Schotsmans EMJ, Van de Voorde W, De Winne J and Wilson AS. 2011. The impact of shallow burial on differential decomposition to the body: A temperate case study. Forensic Science International 206:e43-e48.

Scientific Working Group for Forensic Anthropology (SWGANTH). 2010. http://swganth.org/products--drafts.html.

Sheaff MT and Hopster DJ. 2005. Post Mortem Technique Handbook (second edition). London United Kingdome: Springer.

Simmons T, Adlam RE, Moffat C. 2010. Debugging decomposition data – comparative taphonomic studies and the influence of insect and carcass size on the decomposition rate. Journal of Forensic Sciences 55:8-13.

Sledzik P. 1998. Forensic taphonomy: postmortem decomposition and decay. In: Reichs K, editor. Forensic Osteology: Advances in the Identificationof Human Remains. Springfiled, Ilinois: Charles C. Thomas. pp. 109–119.

Sledzik PS and Micozzi MC. 1997. Autopsied, embalmed, and preserved human remains: distinguishing features in forensic and historic contexts. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp. 483-495.

Strub CG and Frederick LG. 1967. The Principles and Practice of Embalming (fourth edition. Dallas: Frederick.

Tersigni-Tarrant MTA and Shirley NR. 2013. Brief history of forensic anthropology. In: Tersigni-Tarrant MTA & Shirley NR , editors. Forensic Anthropology: An Introduction. Boca Raton, Florida: CRC Press. pp. 1-16.

Ubelaker DH and Zarenko K. 2011. Adipocere: What is known after over two centuries of research. Forensic Science International 208:167-172.

Ubelaker DH. 2006. Introduction to the forensic anthropology. In: Schmitt A, Cunha E, & Pinheiro J, editors. Forensic Anthropology and Medicine: Complementary Sciences From Recovery to Cause of Death. Totowa, New Jersey: Humana Press Inc. pp. 3-12.

Ubelaker DH. 1997. Taphonomic application in forensic anthropology. In: Haglund WD & Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Boca Raton, Florida: CRC Press. pp. 77–90.

Ubelaker DH. 1989. Human Skeletal Remains. Excavation, Analysis, Interpretation (second edition). Washington D.C.: Taraxacum.

Valentin F and d´Errico F. 1995. Brief communication: Skeletal evidence of operations on cadavers from Sens (Yonne, France) at the end of the XVth century. American Journal of Physical Anthropology 98:375-390.

Vass AA. 2011. The elusive universal postmortem interval formulae. Forensic Science International 204:34-40.

Vass AA, Barshick SA, Sega G, Caton J, Skeen JT, Love JC, Synstelien JA. 2002 Decomposition chemistry of human remains: a new methodology for determining the postmortem interval. Journal of Forensic Sciences 47:542–553.

Vass AA. 2001. Beyond the grave-understanding human decomposition. Microbiology Today 28:190-192.

Vass AA, Bass WM, Wolt JD, Foss JE, Ammons JT. 1992 Time since death determination of human cadavers using soil solution. Journal of Forensic Sciences 37:1236–1253.

Villanueva Cañadas E. 2004. Data de la muerte y otros problemas tanatológicos medico-legales. In: Gisbert Calabuig & Villanueva Cañadas, editors. Medicina Legal y Toxicología (sexta edición). Barcelona: Masson. pp. 242-252.

Voss SC, Cook DF, Dadour IR. 2011. Decomposition and insect succession of clothed and unclothed carcasses in Western Australia. Forensic Science International 211:67-75.

Wiley P and Heilman A. 1987. Estimating time since death using plant root and stems. Journal of Forensic Sciences 32:1264–1270.

Wilson-Taylor RJ. 2013. Time since death estimation and bone weathering. In: Tersigni-Tarrant MTA, Shirley NR, editors. Forensic anthropology: An Introduction. Boca Raton, Florida: CRC Press. pp. 339-380.

Williams A. 2015. Australian Human Taphonomy Facility. http://www.forensicanna.com/2015/01/australian-human-taphonomy-facility.html.

Zhou C and Byard R. 2011. Factors and processes causing accelerated decomposition in human cadavers – an overview. Journal of Forensic and Legal Medicine 18:6-9.

Chapter 9 **ANNEX**

Universitat Autònoma de Barcelona

ESTUDI DE LES VARIABLES QUE INTERVENEN EN EL PROCÉS DE DESCOMPOSICIÓ DINS D'UN CEMENTIRI.

FITXA EXHUMACIÓ.

DATA: Nº D' EXHUMACIÓ: INVESTIGADORS:

Dades de l'enterrament:

Data de la mort:

Temps transcorregut des de l'enterrament fins a l'obertura:

Situació en el cementiri (bloc/via):

Enterrament: Posició del nínxol (fila): de

Posició del nínxol (columna): lateral /central

Orientació del nínxol:

Tipus de caixa:

Caixa:

cap	peus	longitud	profunditat

Persona:

edat	sexe	patologies/anomalies

FORRO	
0	No observable
1	part superior
2	part inferior
3	total (Y)
4	lateral

PLÀSTIC	
0	No observable
1	part superior
2	total (Y)
3	total
4	part inferior
5	Sota del cadàver

Descripció externa del cadàver:

Cadàver: Posició de l'individu/ Posició en relació a la caixa:

	Extensió	Abducció	Adducció	
Braç D				
Braç E				
	Extensió	Semiflexió	Flexió/	Flexió forçada
Avantbraç D				
Avantbraç E				
	Sobre el pit	Sobre el ventre	Als costats	Altre
Posició mans				
	Dorsal	Palmar	Altre	
Visió mà dreta				
Visió mà esq				
	Extensió	Semiflexió	Flexió	Flexió forçada
Posició cama D				
Posició cama E				

Roba: No/ Sí Descripció:

V		S
	capes	**capes**
Part superior		
Part maluc		
Part inferior		
Estat de la roba	B/ R/ P	B/ R/ P

Objectes associats:

	braçalet hospital	A	BD	BE
	coixí:	A	P	
	bolquers:	A	P	
Tap	nas:	A	P	
	boca:	A	P	

Altres:

Fauna cadavèrica: P / A

Si P -> Tipus

Descripció:

Cadàver nuu/estat preservació:

TIPUS PRESERVACIÓ	
1	Esqueletització total
2	Esqueletització amb putrílag humid
3	Esqueletització amb putrílag sec
4	Desecació/Momificació
5	Saponificació
6	Corificació

ESTAT I TIPUS DE DESCOMPOSICIÓ						
Cr+Md	TH	EESS	M	EEII	P	ABD

Estat dels cabells i altres annexes cutanis:

Cabells: P/ R/ B

Pèl (tipus): P/ R/ B

Ungles: P/ R/ B

Descripció interna:

Òrgans (quins/estat):

Mostres:

Altres observacions:

Informació tafonòmica/ARTICULACIONS

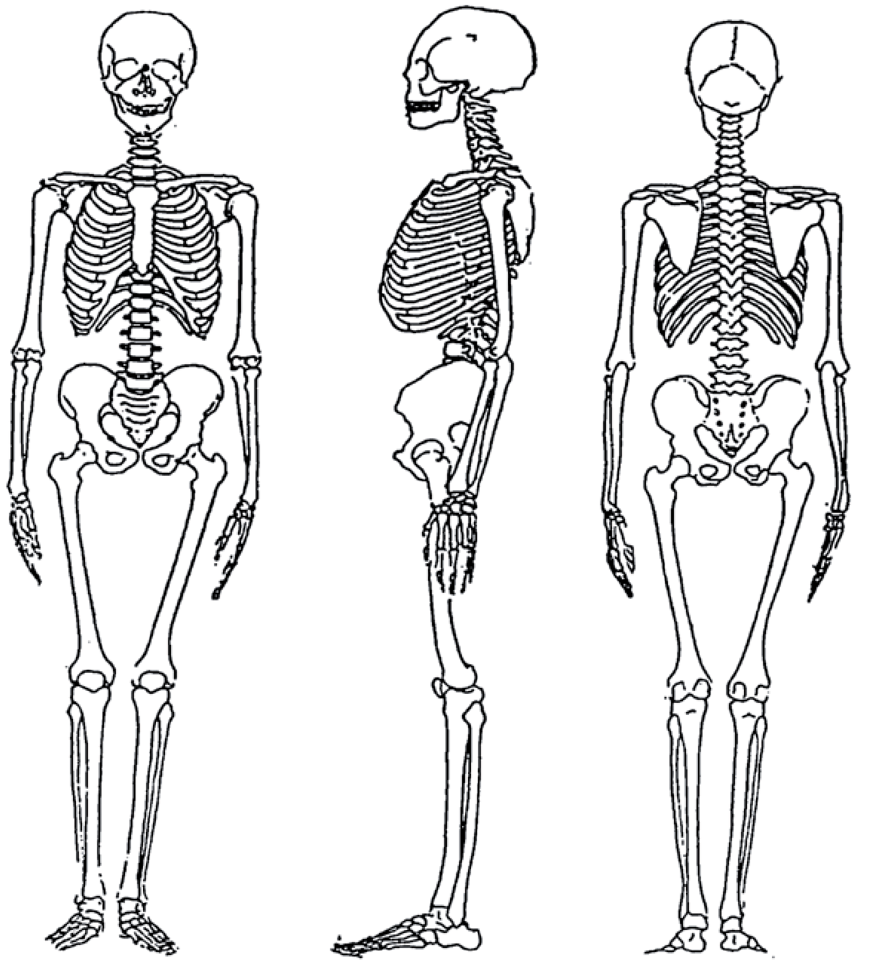
(E-ESTRICTE, L-LAXO, DS-DESARTICULADO, DZ-DESPLAZADO)

ATMD:	ATME:
AATLAOCCIP:	
AHD:	AHE:
ACLESTD:	ACLESTE:
ACLACROD:	ACLACROE:
ACD:	ACE:
ARCDistD:	ARCDistE:
AMD:	AME:
AMÀ D:	AMÀ E:
ASP:	
ASID:	ASIE:
AFAD:	AFAE:
ARD:	ARE:
ATPProxD:	ATPProxE:
ATPDistD:	ATPDistE:
ATOBD:	ATOBE:
APEUD:	APEUE:
ACV:	ACOSTOESTERNAL:

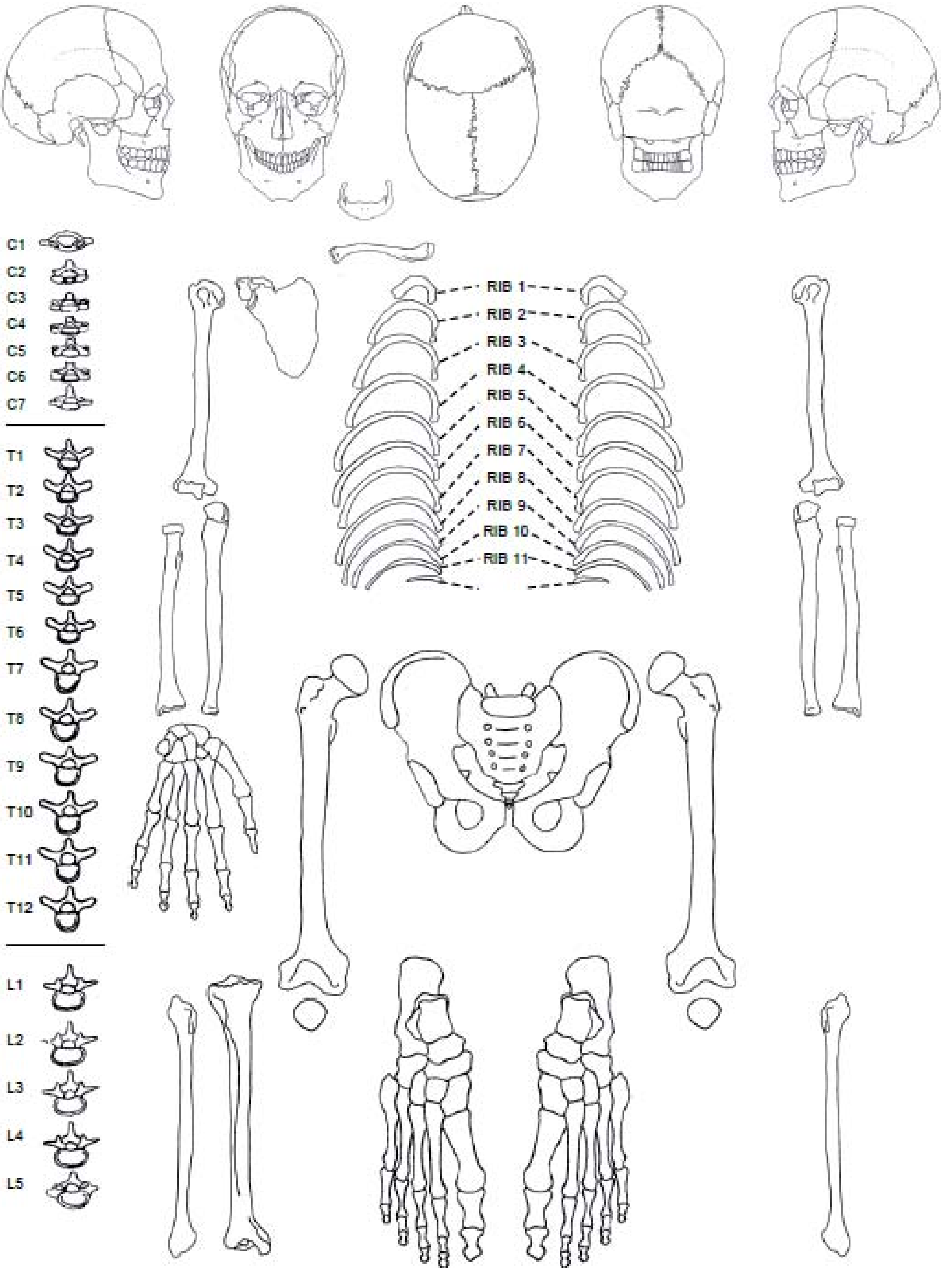
ACOSTOVERTEBRAL:

Descripció/Comentaris articulacions:

Esquemes:



Patologia observada:


C1
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RIB 6
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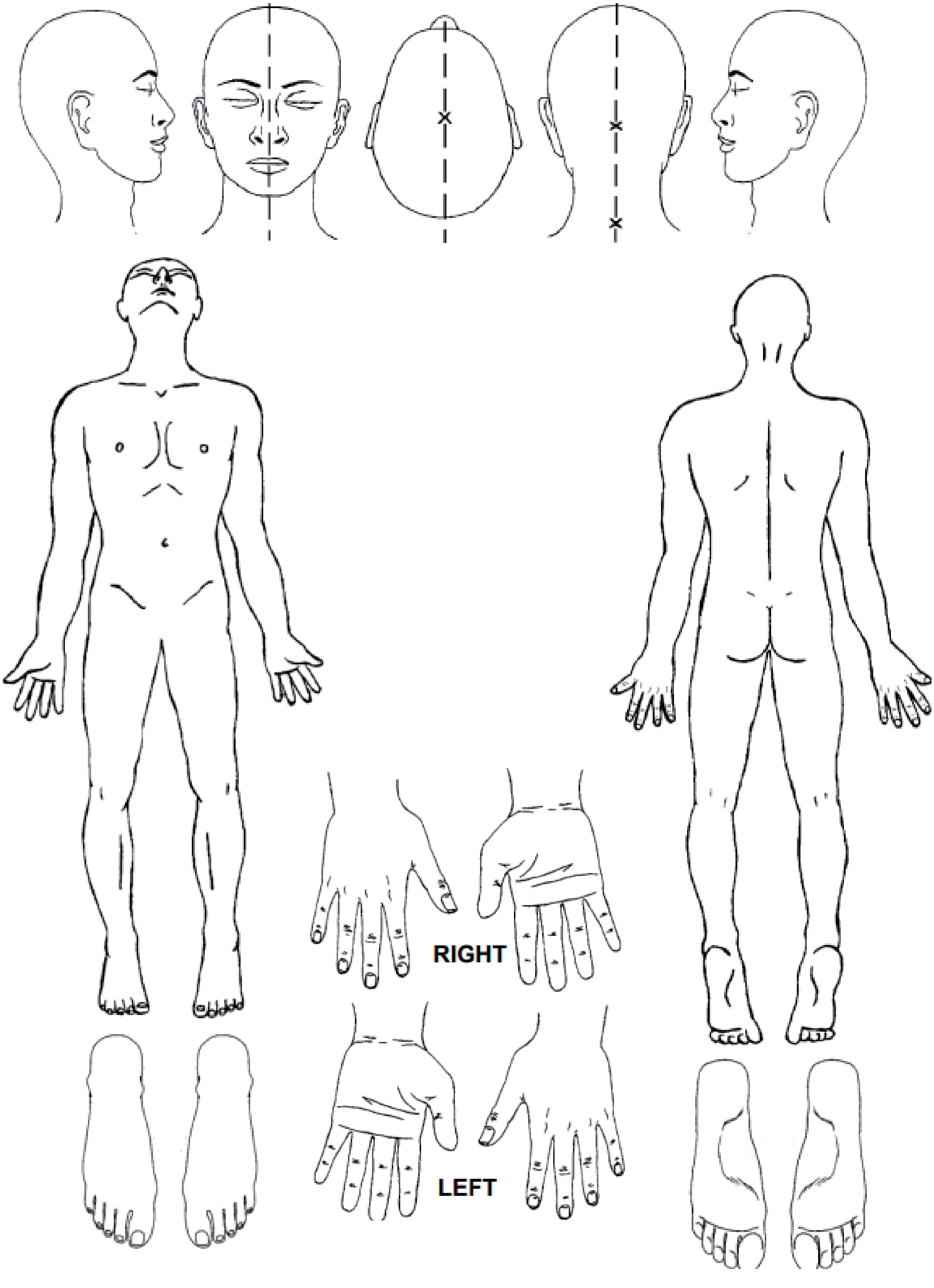
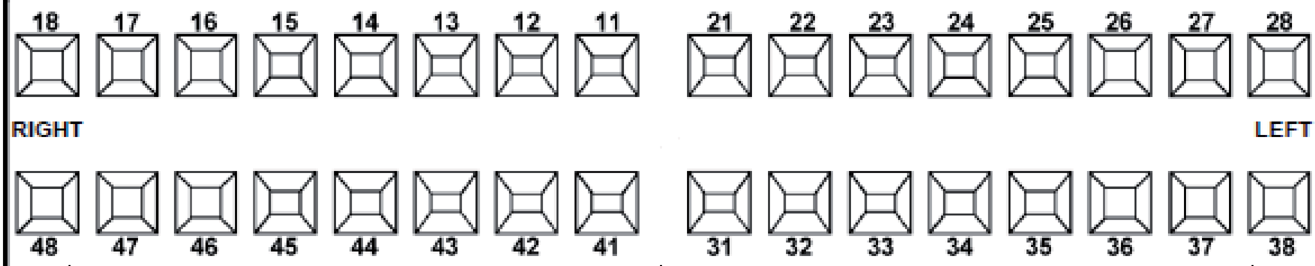
RIB 8
RIB 9
RIB 10
RIB 11


RIGHT
LEFT

ODONTOGRAMA *POST-MORTEM.*

86	DENTAL FINDINGS for permanent teeth (Note primary teeth specifically)		
11			21
12			22
13			23
14			24
15			25
16			26
17			27
18			28



48			38
47			37
46			36
45			35
44			34
43			33
42			32
41			31
87	**Specific description of** Crowns, bridges, dentures and implants		
88	**Further findings** Occlusion, attrition, anomalies, smoker, periodontal status, supernumeraries, etc.		