AM-PM facial image comparison for forensic human identification

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Abstract

The uniqueness of the face has been studied concerning its application for human identification. In particular, morphological facial comparison has been used to verify the identities of living individuals in forensic investigations and has received considerable attention, including validation studies and the development of international guidelines (FISWG, 2019a; Bacci et al., 2021b). At the same time, the application of morphological comparison in post-mortem identification has been recognised (Olivieri et al., 2018; Cappella et al., 2021), but remains understudied and require further validation. In light of this, this study investigates the reliability of morphological facial comparison using an unconstrained sample of ante-mortem (AM) and post-mortem (PM) images of recent deceased (N=29), and aims to develop a methodological protocol combining the structure of the living individual's guidelines and accounts for the early post-mortem changes that affect the face. The reliability of the morphological method for PM identification is investigated by performing the comparisons and documenting the process using the protocol, and by testing it with three observers on selected AM-PM pairs (N=15).

The key findings suggest that AM-PM photographic comparison using the proposed protocol could help to narrow down the potential matches of a PM subject. Moreover, in some cases, it is also possible to provide a single correct AM target for a PM subject with a high level of confidence. While the validity of the protocol requires further investigation beyond this study, its design, which includes the addition of a stage for analysis of the decomposition changes affecting the PM subjects and a holistic preliminary analysis of AM-PM pairs to exclude the obvious non-matches, seems advantageous. The interobserver study results indicate that both absolute agreement (ICC=0.813) and agreement on the level of support (Kendal's K=0.885) are satisfactory. Overall, the limitation of the study includes the small interobserver random sample (15 pairs), the absence of non-matching AM subjects in the sample pool tasks, and presence of a very limited number of PM subjects showing signs of post-mortem changes (e.g. facial bloating).

This study could benefit forensic casework, in particular in the Disaster Victim identification (DVI) procedures, when other AM primary identifiers are scarce. Future studies should investigate the application of PM photographic facial comparison using a larger database simulating an open disaster scenario, while also further validating and testing the applicability of the developed method with different observers.

Declaration

I declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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1. LITERATURE REVIEW

1.1 Personal Identification

The term human identification refers to the process of determining a person's identity. Identity is a difficult concept to define, and its meaning has been extensively researched in the philosophical, psychological, legal, biological, and scientific disciplines. The concept of identity has been widely explored in philosophy since antiquity and the origin of the word "identity" derives from the Latin "idem" which means "the same" (Glare, 1982) implying that an entity's overall identity features remain consistent in different situations. However, some argue that identity is a continuous and dynamic process since organisms are naturally - and biologically- in a perennial change as they are subjected to external and internal stimuli (Coulmas, 2019).

From a scientific perspective, the identity of a person may be classified into two major categories (Zeiler, 2007):

- biological identity
- physical identity

The biological identity is the inherited genetic sequence, known as DNA sequence. Since its discovery, DNA has been defined as the "blueprint of life" that dictates all the biological functions, and structure as well as some of the phenotypical expressions (Goodwin, 2010). DNA profiling has obtained a central role in medicolegal and forensic investigations due to its uniqueness, sensitivity, and evidential power and it is usually performed by extracting the genetic material from samples of bodily fluids such as saliva and blood (Jobling and Gill, 2004).

The physical identity refers to the visible body characteristics and features genetically dictated and acquired after birth (Thompson and Black, 2006). The number of physical characteristics that define our appearance can differ as a result of the natural age-related changes that occur from childhood to senility and that are influenced by nutrition, habits, and geographical location. Other modification of the physical appearance includes tattoos, trauma and dental modifications (Thompson and Black, 2006).

1.2 Forensic Human Identification

Personal identification assumes a particularly relevant role in forensic practice, and establishing someone's identity beyond a reasonable doubt is one of the goals of forensic investigation that involves unknown individuals (Cattaneo, Angelis and Grandi, 2006).

The requirement for positive identification is essential in various scenarios involving unknown bodies or human remains (Thompson and Black, 2006):

- Criminal investigations following an unnatural death, homicide, or suicide.
- Large-scale disasters brought on by natural forces or purposeful human action.
- War crimes and genocides.

The process of identification in the medico-legal context compares ante-mortem (AM) information gathered with the help of relatives of the deceased, as well as professionals such as doctors or dentists, with post mortem (PM) data, personal information gathered by examining the unidentified human remains (Thompson and Black, 2006). The PM data can include genetic material, fingerprints, and dental records, the information is usually gathered and interpreted with the help of forensic experts such as forensic pathologists, anthropologists, odontologists, and biologists (Blau et al., 2021).

The process of identifying an individual or multiple individuals can be a very complex task and is predominantly influenced by the individual's preservation, the extent of PM changes and the amount of AM data (Cattaneo, Angelis and Grandi, 2006).

1.2.1 Decomposition

Among the elements that can influence the preservation of the body and ultimately influence the identification process, the decomposition changes are particularly relevant.

The decomposition is a natural process that affects an individual after death and gradually leads to the destruction of the tissues (Dix and Graham, 1999). Generally, the decomposition of a body follows a 5 stages progression: fresh, bloat, active decay, advanced decay, and skeletonization (Statheropoulos et al., 2011). However, these stages are heavily influenced by many intrinsic and extrinsic factors. Intrinsic factors include weight and size of the body, posture of the body at death, and clothing. Extrinsic factors include the environment, temperature, weather, humidity, type of burial, level of insect, and other animal activity (Vass, 2001; Hau et al., 2014; Payne-James and Jones, 2019).

Detailed knowledge of the various phases of decomposition and the influence of various factors is particularly relevant for forensic investigations as it helps to calculate how much time has passed since death, also called post-mortem interval (PMI). Calculating the PMI is a challenging task but it has received great attention from researchers that have investigated various formulas and approaches including visual scoring for terrestrial decomposition (Megyesi, Nawrocki and Haskell, 2005) region and environmental related formulas for different types of climate, such as for temperate climates (Fitzgerald and Oxenham, 2009), warm humid regions (Clark, Worrell and

Pless, 1997), as well as for aquatic environments (Mateus and Vieira, 2014; van Daalen et al., 2017).

PM changes are generally divided into early PM changes that appear within 2 hours from death, and are characterised by biomolecular changes, visible skin pallor due to cessation in blood circulation, as well as the purging of stomach material and general flaccidity (Dix and Graham, 1999)

Following this first early stage, the phases are described as algor mortis, rigor mortis and livor mortis. Algor mortis refers to the general cooling of the body and at this stage, the tissues are sensitive to external pressure so they will retain certain shapes if external pressure is applied (Dix and Graham, 1999). Rigor mortis is the temporary rigidity of the body's muscles caused by chemical reactions in muscular cells, it is followed by flaccidity and livor mortis with discolouration of the skin observed due to gravitational movement of blood. the discolouration is particularly relevant for investigations, as it can suggest if the body has been moved after death (Clark, Worrell and Pless, 1997).

These stages are followed by autolysis and putrefaction, where the autolytic enzymes start to be released on a cytoplasmatic level, ultimately causing skin slippage due to the separation of dermal and epidermal layers, marbling appearance of the skin, together with loosening of hairs and nails (Dix and Graham, 1999). This stage is soon followed by putrefaction that can last days or weeks after death, where microorganisms reproduce causing bloating and severe discolouration of the tissues. These stages are also accompanied by the presence of insects that colonise the body and can accelerate the overall destruction of the tissue (Clark, Worrell and Pless, 1997).

As mentioned before, the onset of the various stages is determined by intrinsic and extrinsic factors and in certain environmental conditions the PM changes deviate from the presented stages.

For example, excessively dry conditions with high temperatures and little humidity can cause severe dehydration in the body, which results in the preservation of the tissue through a process known as mummification (Gennard, 2012).

The implications of studying how the decomposition changes affect the body in different environmental conditions can benefit human identification, however, there currently is not much study on how PM changes modify facial appearance, despite facial appearance being commonly utilised for identification in medicolegal investigations (Wilkinson and Tillotson, 2012).

1.3 Disaster Victim Identification (DVI)

In forensic science, the identification of unknown deceased individuals is a challenging task that carries immense significance in both crime scene investigations and mass disasters (Cattaneo, Angelis and Grandi, 2006). The latter, in particular, represents one of the most challenging scenarios for forensic experts due to the scale of destruction and the complexities involved in identifying victims. Disasters, as defined by the World Health Organization, involve extensive damage, ecological disruption, loss of human life, and a deterioration of health and health services that necessitate a response beyond the capabilities of the affected community (WHO). Generally, when a disaster involves several fatalities that are greater than local resources can manage, they are referred to as mass disaster or mass fatality incidents (College of Policing, 2022). Mass disasters are generally classified according to the nature of the disaster and what has generated it (Interpol, 2018):

- Natural: tsunamis, earthquakes, hurricanes, pandemic
- Accidental or human-made: plane crashes, building collapse, fire, ship sinking, terrorist attacks

Independently of the nature of the disaster, the priority of the authorities is to recover the human remains and positively identify the victims, since the processes of identification of human remains can become more challenging as time passes (Acharya et al., 2017; de Boer et al., 2020). Because of the complexities of recovery management and identification in mass disaster, an internationally accepted set of protocols and guidelines for the identification of the victims was introduced for the first time in 1984, by the International Criminal Police Organization (Interpol), which plays an important role in a variety of criminal and missing persons investigations that transcend international borders (Sweet, 2010).

The international protocol takes the name of Disaster Victim Identification (DVI) and is a comprehensive and adaptable manual that is constantly re-examined to provide the best disaster management handling procedures and scientific advancement to maximise the identification of the victims. Also, since the concept behind the DVI manual is to provide guidelines and best practices, it that can be adapted to disaster victim identification procedures for various entities and in various locations of the world, as well as to diverse country-specific legislations and policies (Interpol, 2018).

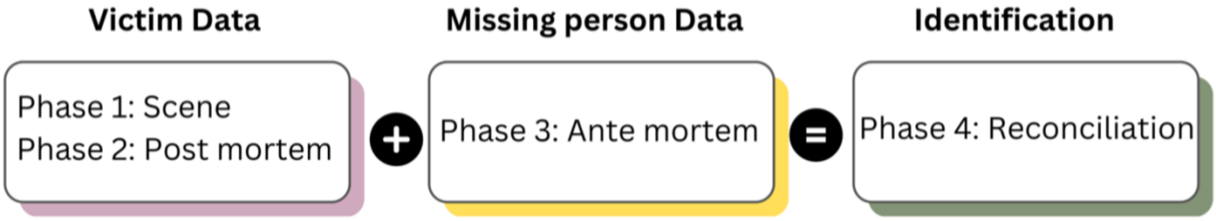
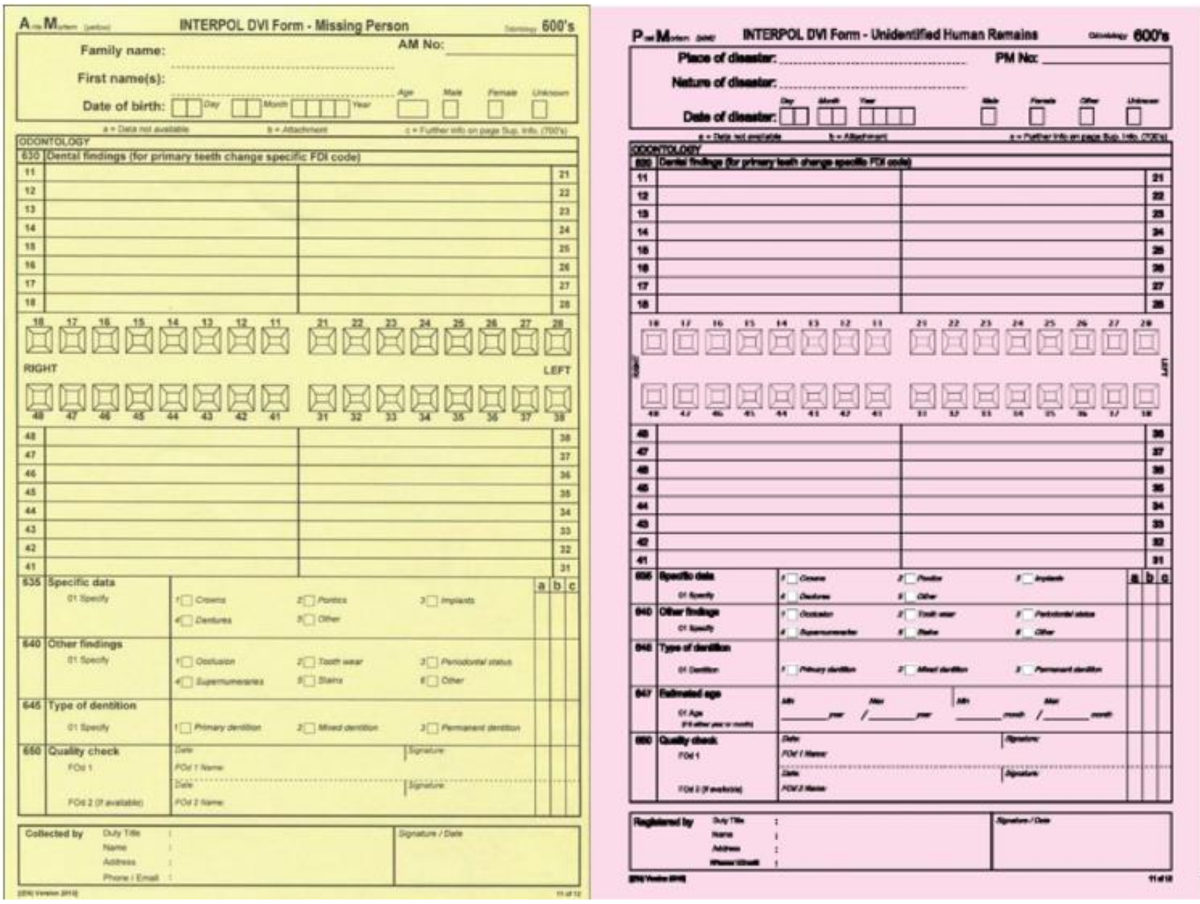


Figure 1. The DVI phases. This process aims to positively identify the victims (Interpol, 2018)

The response and the identification strategy adopted during DVI operations are significantly affected and influenced by the type of mass fatality, distinguished into *open* and *closed* disasters (Interpol, 2018). A *closed* disaster describes an accident involving an identifiable group of victims in a defined space and time. For instance, aircraft crashes are a good example of closed fatalities where a detailed passenger list is usually available which means that personal information and victims' family contacts are easier to obtain (Laczko, 2016). On the contrary, an *open* disaster indicates an incident where the number and identity of the victims involved is unknown, requiring more time and resources to gather initial information about the alleged missing people (Interpol, 2018). An example of an open disaster is a terroristic attack in a public space or an earthquake where, contrary to a plane crash, prior records or detailed lists of the victim are not available.
From a forensic medico-legal point of view, any mass disaster victim identification operation requires the same investigation phases that are usually employed in a PM examination in case of suspicious or unnatural death (Cattaneo, Angelis and Grandi, 2006). However, while in "routine" deaths, the identity is easily achieved and more attention is given to the cause of death and evidence of how the crime was committed, the main goal of DVI operations is to provide a positive identification. In order to do that, various forensic specialists are involved in the AM and PM data collection phases carried out following the standard procedures set out by the DVI protocol which requires using the DVI standardised record system (Blau and Rowbotham, 2022). An example of documentation used for AM and PM data can be seen in Figure 2.


INTERPOL DVI Form - Missing Person
600's
Family name:
AM No:
First name(s):
Date of birth:
ODONTOLOGY
630 Dental findings (for primary teeth change specific FDI code)
RIGHT
LEFT
635 Specific data
640 Other findings
645 Type of dentition
650 Quality check
Collected by

INTERPOL DVI Form - Unidentified Human Remains
600's
Place of disaster:
PM No:
Nature of disaster:
Date of disaster:
ODONTOLOGY
Registered by

Figure 2. Examples of the Interpol DVI forms. The yellow form (on the right) is used to collect AM data on the missing persons. The pink form (on the left) is used to gather PM information on the human remains (Interpol, 2018).

The AM data is collected by contacting missing people family members, friends, doctors, and dentists. The data collected usually includes descriptions, images, circumstances of disappearance, biological samples such as hair or DNA samples from close relatives, clinical records, and dental information. The AM data collection phase is a crucial phase of DVI procedures and often the amount and quality of AM data collected is significantly influenced by the type of disasters, with open disasters such as migration since often relatives are difficult to contact (Black et al., 2010; Olivieri et al., 2018; Cattaneo et al., 2020; Cappella et al., 2021).

Together with the AM data, various forensic specialists collect PM data, that is the evidence collected by forensic personnel during the PM examination (autopsy) of the unknown remains. As reported in Figure 3, they can include physical examination of the victims' bodies, biological samples of DNA, fingerprints and dental information.

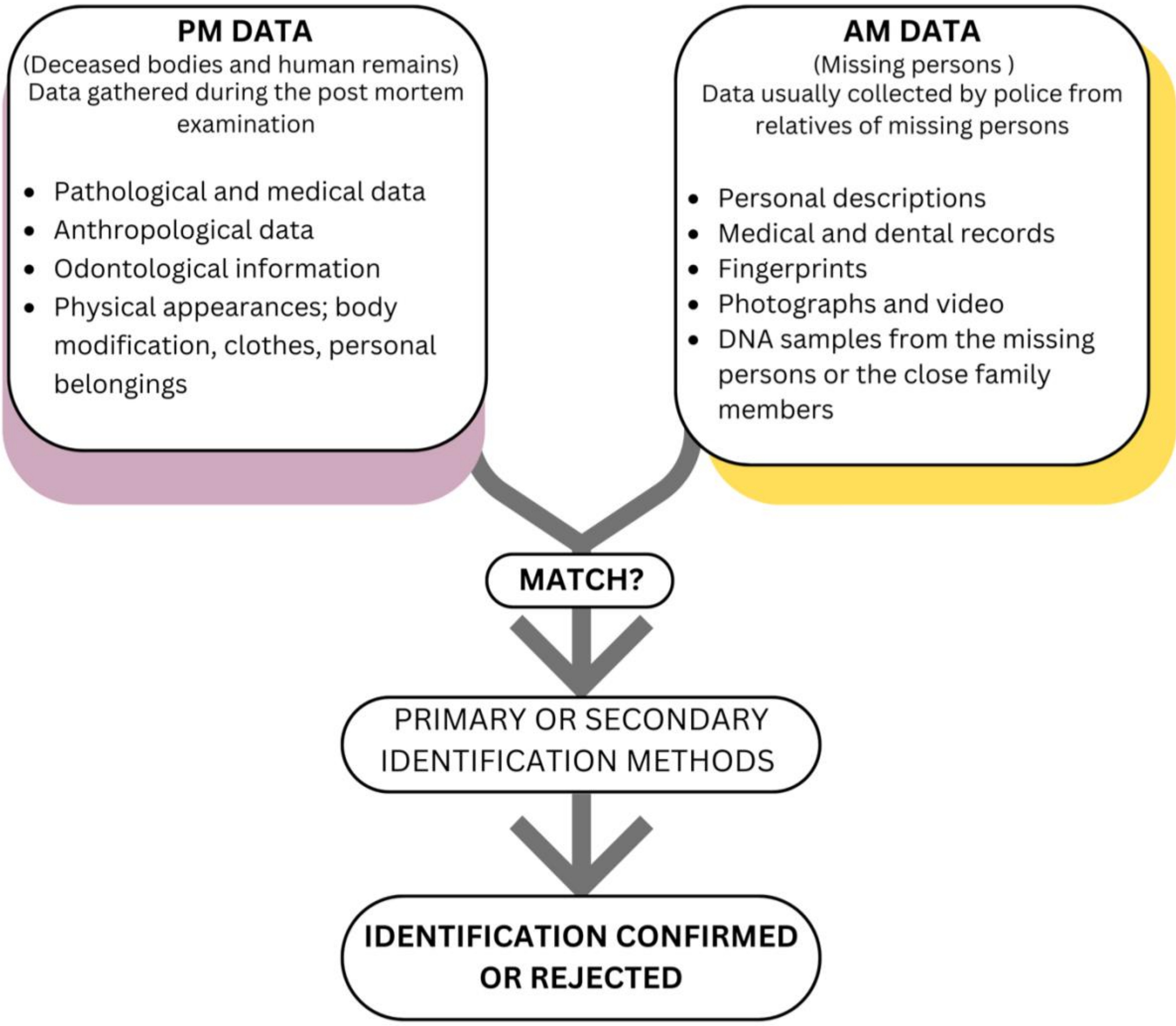


Figure 3. Flowchart showing the different phases to reach an identification (Interpol, 2018; Cattaneo et al., 2020)

The crossmatch between AM and PM data to confirm a person's identity is carried out by comparison of the results of DNA analysis, odontological analysis, x-ray examinations or fingerprint matching. The human remains decomposition state and the available AM data usually inform the methods that are available to use.

Not all the identification methods have the same identification power, reliability or uniqueness of the characteristics used, traditionally the Interpol DVI guidelines distinguish between primary and secondary methods of identification (Dix and Graham, 1999; Interpol, 2018). Recently, the division between primary and secondary identification identifiers has been under discussion (de Boer et al., 2020). In a statement published by members of the Forensic Anthropology Society of Europe (FASE), it is argued that the preferred primary identifier cannot always be used to support identification and often traditionally "secondary identifiers" provide sufficient evidentiary value for a conclusive identification with the use of a reliable methodology (de Boer et al., 2020). In light of this, the division between primary and secondary identifiers seems inappropriate since the usefulness of any identifier has been proven to be context-dependent (Berger, van Wijk and de

Boer, 2020; Blau et al., 2023). Nevertheless, to provide a clear organisation of the literature review chapters, the identifiers will continue to be referred to as "Primary" and "Secondary" throughout this thesis.

1.3.1 Traditional Primary methods of identification

The most tested and reliable methods are called primary methods and include (Interpol, 2018):

- genetic analysis using DNA samples
- fingerprints matching
- odontological analysis
- medical data or pathological conditions detected via CT scans or X-rays.

In the DVI procedure, DNA analysis has the great potential to provide high-reliability matching and is considered the most efficient way to identify human remains (Jobling and Gill, 2004). The profiling is based on the use of autosomal short tandem repeat (STR) strand or mtDNA sequence and it is necessary to have a DNA sample from the victim and the missing people involved in the accident or relatives (Jobling and Gill, 2004).

The suitability of DNA for identification is particularly relevant in DVI for a variety of reasons. Firstly, DNA can be recovered from almost any body part and generally preserves well in almost all decomposition conditions. Also, if the direct comparison between the PM DNA and the AM DNA of the missing person is not possible, immediate relatives' DNA can be used with a high degree of reliability (de Boer et al., 2018). In this regard, the Interpol DVI guidelines suggest that the AM DNA should always be sourced from first-degree relatives, together with biological samples and personal objects of the potential victims (Interpol, 2018).

Challenges in DVI scenarios often make DNA sampling and analysis a complicated task. For example, the number of individuals involved, and the presence of commingled remains can produce a genetic cross-contamination (Interpol, 2018). Furthermore, the presence of relatives can pose challenges in identification processes, particularly when siblings and parents share a significant number of DNA sequences. While DNA analysis can establish familial relationships, it may not be able to differentiate between individuals within the same family (Montelius and Lindblom, 2012). This issue was evident in the aftermath of the landslide disaster in Taiwan, where many victims were related. In such instances, it became possible to assign individuals to their respective families based on genetic relatedness, but it was difficult to achieve specific identification for those individuals (Lin et al., 2011). Furthermore, the cost of DNA analysis can be a significant barrier when many individuals are involved, particularly in cases where the victims come from low-income countries or are asylum seekers and migrants who have lost their lives on migration routes. Usually, DNA matching is carried out by DVI teams of the individual countries, that travel to the site of the disaster and look for their citizens. In such situations, some governments might not be able to cover the expenses associated with the DNA matching processes. An example was the Bali bombing, where the Australian government had offered their help to the Indonesian government to cover the cost of some DNA identifications (Lain, Griffiths and Hilton, 2003)

Another method that is well known to be reliable and low-cost is the dental analysis carried out by forensic odontologists. This method is routinely used when AM dental data is available and it can be applied to identify fresh deceased, mutilated, skeletonised, or highly decomposed human remains since teeth and dental treatments can even resist when the body is exposed to heat sources (Silva et al., 2008; Sweet, 2010). An example of the effectiveness of forensic odty is the complex identification procedures that took place during the Australian bushfires in Victoria state in 2009 where 60% of the identifications carried out had dental data available, and 40% were based on dentistry alone (Hinchliffe, 2011). Another example is the closed Linate aircraft disaster in 2001, where dental analysis was used as a stand-alone method or in combination with DNA or visual methods to successfully identify more than three-quarters of the 188 victims (Lain, Griffiths and Hilton, 2003; Cattaneo, Angelis and Grandi, 2006).

The use of forensic dentistry and its success in the identification procedures is directly dependent on the availability of dental documentation gathered during the victim’s life (Petju et al., 2007). In light of this, in some developing countries is not uncommon for people not to receive dental treatments (Petju et al., 2007; Forrest, 2019), or have poor dental records (Avon, 2004) due to the absence of appropriate legislation on dental record-keeping procedures (Soomer, Ranta and Penttilä, 2001), that ultimately make dental identification not possible. Even in case of unavailable dental data, the presence of smile images gathered during the AM collection phase might be useful, particularly if there are dental anomalies or variations in shape and position (Tinoco et al., 2010). These images can then be compared to PM images of the individual's dentition (Tinoco et al., 2010). An example of the use of smile images for identification in mass disasters was the Christchurch earthquake disaster in New Zealand 181 victims were involved. Odontological analysis was employed in 33% of the identifications, and in some instances, the use of smile photographs collected during the AM data collection process played a significant role in the identification process (Trengrove, 2011).

Similarly, to dental analysis, medical imaging such as radiographs, CT and MRI scans of implants, healed injuries, and fractures can also provide support for identification in mass disasters (O'Donnell et al., 2011).

1.3.2 Traditional Secondary methods in DVI

When the circumstances of the disaster limit the use of primary methods, the Interpol guidelines suggest that there are secondary identifiers that can be used to support the identification of the victims (Interpol, 2018)**.** Secondary identifiers are circumstantial personal belongings associated with the bodies such as clothes, wallets, ID cards, descriptions from relatives, and morphological traits such as tattoos and moles (Interpol, 2018). Tattoos in particular have an exceptional identification power (Caplova et al., 2018b), and tend to remain stable throughout a number of decomposition stages such as skin slippage or in the case of burnt bodies, since the tattoo pigments are embedded at a deep skin level. Research on the stability and the morphological changes of tattoos due to decomposition in uncontrolled environments suggested that tattoo visibility is influenced by body composition, the quality of the tattoos and the environment (Probert et al., 2022). In a recent study, Probert et al. (2022) found that tattoos change morphology during the bloat and active decay stages but that tattoo comparison between AM and PM images is still possible. They also stated that that the lack of visibility is not due to the change of morphology but rather from a discolouration of the skin, which is generally consistent with another previous study conducted by Bennett and Rockhold (1999). In case the tattoos are difficult to visualise on the deceased individual, infrared photography seemed to be a useful alternative to enhance their visibility since some colour pigments are responsive to infrared light wavelengths (Starkie et al., 2011).

The importance of tattoos for identification has been seen in the identification of deceased migrants drawn in the Evros River in Greece in 2020 (Pavlidis and Karakasi, 2020) and in supporting identification procedures of the 11 victims of the 2015 Shoreham Air show crash in England where they provide crucial clues during initial identification procedure of the 1200 body parts recovered (Blau et al., 2023). Similarly, in 2% of the cases, the victims of the aeroplane disaster in Linate, Milan, 2001, scars and tattoos were accepted as the sole means of identification (Cattaneo, Angelis and Grandi, 2006). As reported in the previous case skin marks such as moles, birthmarks and scars can be powerful morphological elements that provide an important support for identification (Blau et al., 2023). They are usually recorded during the PM analysis of the victims, however, their stability can be influenced by the decomposition process, which is something that still needs more research (Caplova, 2017). Their role in identification, particularly in relation to their presence on the face will be discussed later in this review of the literature.

Additionally, personal belongings can provide an important indication regarding the victims' identities (Blau et al., 2023), but they should never be used as sole identifiers (Pavlidis and Karakasi, 2020; Cappella et al., 2021). An interesting illustration of the support that personal belongings can have in identification procedures is the DVI procedures on the victims of human rights violations in Kosovo in the early 2000s. The identification of the 116 cases involved clothing and artefact exhibition for relatives of the victims, which led to recognition in 72% of the cases, with most of them subsequently confirmed by DNA analysis (Baraybar, 2008).

Although the aforementioned identifiers can play an important role in identifying victims of open and closed disasters, they always need to be used in conjunction with primary identifiers (De Angelis, Cattaneo and Grandi, 2007; Baraybar, 2008; Caplova, 2017; Caplova et al., 2018b; Blau et al., 2021). This is in accordance with the DVI Interpol guidelines, which typically discourage their use as the only method of identification.

(Interpol, 2018), since often these "secondary" identifiers lack quantification regarding the frequency and uniqueness of specific traits (Blau et al., 2023). However, there is an argument that instead of determining whether a particular trait is unique, experts should focus on establishing the number of people exhibiting that specific trait within the context of the disaster (Blau et al., 2023). Also, not all secondary identifiers have the same identification power, and the reliability and strength of an identifier should be based on the robustness of the method used (Robertson, Vignaux and Berger, 2016; Berger, van Wijk and de Boer, 2020; de Boer et al., 2020). For this reason, the Forensic Anthropology Society of Europe (FASE) support the shifting in perspective that "secondary" identifiers are not the "last resource" and argues that the distinction between "primary" and "secondary" identifiers appears to be misleading.

This position is also reflected in the identification procedures of the terroristic attacks in Paris between 2015 and 2016, as described by Arrighi and Charlot (2020), who report how the early stages of identification were sped up by using strong secondary identifiers, such as tattoos and scars. This avoided the need to wait for the DNA or dental records to be processed, as they were used in a later stage to confirm the presumed identities (Arrighi and Charlot, 2020). A similar approach has been utilised in complex migrant identifications in Greece, where the initial recognition of personal belongings through photographs from relatives abroad, served as indicative identification that was later established in genetic kinship (Pavlidis and Karakasi, 2020). Also, Gunawardena et al. (2019) reviewed how DVI procedures are used in low-resource countries, emphasising how magistrates and legislators should be willing to accept a combination of strong secondary identifiers, such as tattoos and moles, particularly in situations where primary methods cannot be used (Gunawardena et al., 2019).

1.3.3 Identification challenges in DVI

Since DVI management poses significant challenges for forensic experts (Gunawardena et al., 2019), DVI guidelines were created to assist experts in successfully recovering and identifying the victims involved (Interpol, 2018). The guidelines are designed to be applicable across various disasters and countries and are constantly updated to reflect the advancement of scientific and management practices.

The initial challenges during the DVI procedure are the recovery procedures, coordination of medical staff and other stakeholders (Cattaneo, Angelis and Grandi, 2006), local legislation, government resources and type of disasters (Byard and Winskog, 2010; Winskog and Byard, 2016). One crucial aspect that influences the success of DVI operations is setting up appropriate space to carry out PM analysis and correctly store the bodies (Sweet, 2010; Winskog and Byard, 2016), especially in hot and humid environment where putrefaction is accelerated (Dix and Graham, 1999). A case where already existing mortuary facilities were destroyed and were unsuitable for the number of victims was the Indian Ocean tsunami that hit Thailand's coasts in 2004, where there was a lack of means to refrigerate and store bodies to slow down the decomposition (Tsokos et al., 2006). Staff and local authorities attempted to cool down the bodies using dry ice, but it was ineffective due to the weather and only when the mobile PM facilities were set up the bodies could be stored appropriately (Tsokos et al., 2006).

Also, identification procedures in national and international disasters are often poorly regulated from a legislative perspective. Cattaneo et al. (2022) highlight how the identification procedures of the migrants perished near the Italian coasts has highlighted a national, and international problem, where the identification of these dead appears not to be mandatory. The authors provided two examples of disasters in Italy that involved migrants. In the first case of 2013, the prosecutors of Agrigento requested examination and DNA analysis on the victims, while in the second case in 2015 for the 1000 no identification or PM analysis was deployed as the prosecutors of Catania declared that since the traffickers were arrested there was no juridical need of identify the bodies and there were no resources for such operation. Similarly, Wilkinson and Castaneyra-Ruiz (2021) reported no attempts to identify deceased migrants in the Canary Islands and the time-consuming bureaucratic process to access records, which are often inaccurate or missing, about buried unidentified migrants.

Lack of government resources is another element that can have a significant effect of identification procedures (Cattaneo, Angelis and Grandi, 2006; Donkervoort et al., 2008). In some cases, lower-income countries might struggle to cover the cost of the numerous DNA analyses or have problems in accessing and retrieving medical data due to the limited access of victims to basic healthcare (Gunawardena et al., 2019). An example is the Tsunami that hit Thailand's coasts on Boxing Day in 2004. Of all the identifications carried out in Thailand, 95% of the European victims were positively identified, with more than 76% using odontology analysis. On the contrary, 67% of the Thai victims were positively identified but only 2% were identified using dental charts and dental X-rays due to unavailable medical and dental records of the victims (Petju et al., 2007). Another more recent example of low resource settings limitations is the Sri Lanka rubbish dump disaster in 2017, where the majority of the victims were identified using a combination of secondary identification markers. Indeed, primary identification markers were unavailable to the specialists since the DNA identification was too costly and with an expected low efficiency due to interrelated victims; also, victims lived in an area with no fingerprint records and poorly documented dental treatments and medical infrastructures (Gunawardena et al., 2019).
Another aspect that can impact the AM data collection and limit identification, is the impracticality in gathering the necessary AM data. For example, it can be due to difficulties in reaching out to relatives and families (Olivieri et al., 2018). This is certainly true in the identification of the migrants dying in the Mediterranean Sea during the sea crossings to reach the European coasts. Together with a general lack of interest by the government in identifying these people, the low rate of identification is partially associated with the organisational difficulties that come from contacting families and friends of the victims who might be looking for their loved ones but are sometimes too afraid to be contacted by the authorities (Olivieri et al., 2018; Pavlidis and Karakasi, 2020). Another reason for which AM data could be difficult to gather is associated with the destruction of local infrastructure holding personal identification data after the disaster. For instance, in 2005 Hurricane Katrina caused the destruction of local healthcare infrastructures containing dental and medical data, as well as the destruction of houses containing personal items such as toothbrushes (Donkervoort et al., 2008). This posed important challenges in the identification of the victims and on this occasion, most of the DNA analyses were conducted through kinship analysis.

In recent years, there has been a significant increase of unidentified bodies, owning to the migration movements to European countries (Cattaneo et al., 2020). However, the number of fatalities that involve immigrants, attempting dangerous crossings after fleeing from countries with difficult political and socioeconomic situations, is difficult to calculate (Grant, 2011). The International

Organization for Migration (IOM) has estimated that more than 60,000 migrants have died on the journey with 50 to 60% of the disasters taking place in the Southern EU borders (Laczko, Singleton and Black, 2017), where Italy, Spain, Malta and Greece are the most affected countries (Piscitelli et al., 2016; Pavlidis and Karakasi, 2020; Wilkinson and Castaneyra-Ruiz, 2021). On a smaller scale, there has been also a significant increase in immigrant deaths along the borders between Mexico and the US in the last decade (Laczko, Singleton and Black, 2017). Despite intensified border control efforts by the US government, these measures have not reduced the frequency of border crossings. On the contrary, they have contributed to making the crossings even more perilous and dangerous (Parks et al., 2004; Grant, 2011).

The identification of migrants has been defined by Cattaneo et al. (2022) as an "enormous paradox". It is recognised by the Geneva Convention that identifying a deceased person is a fundamental right and a moral obligation that should be respected with no discrimination (International Committee of the Red Cross, 1949). However, while identifying the deceased in a mass disaster context is standardised, regulated by internationally accepted procedures and conducted by adequately trained personnel, the identification process becomes slow and lacks urgency in the aftermath of disasters involving migrants (Olivieri et al., 2018; Cattaneo et al., 2022). This has led to an incredibly large number of unidentified victims buried without a name, leaving families to deal with the psychological consequences of not knowing the fate of their missing loved ones (Grant, 2011). From a humanitarian and legal point of view, the lack of identification for these victims can be considered a violation of human rights that does not only affect the dignity of the deceased but largely affects the rights of the living (Cattaneo et al., 2022). For instance, a child without their parent's death certificate cannot be adopted or reunited with other family members; in the same way, a husband without the certificate of the deceased wife cannot remarry (Cattaneo et al., 2000). From a practical point of view, the major challenges of these identifications range from the substantial number of bodies usually recovered and the spread over time and place of the disasters to more logistical and bureaucratic obstacles (Piscitelli et al., 2016). The reasons that explain the low rate of identification of these victims have been summarised in the following points by forensic experts with experiences in migrants DVI (mDVI) (Cattaneo et al., 2000; Grant, 2011; Piscitelli et al., 2016; Ellingham, Perich and Tidball-Binz, 2017; Ampuero Villagran, 2018; Triandafyllidou and McAuliffe, 2018; Pavlidis and Karakasi, 2020; Cattaneo et al., 2022) :

- Discrimination toward illegal migrants
- Lack of legal obligations in some countries to identify victims, unless their death is considered by the persecutors suspicious.

- Difficulties related to the state of conservation of the bodies due to decomposition in water or PM animal activity that can lead to loss of belongings and alteration of facial appearance
- Difficulties in AM data exchange between international agencies and governments
- Limited financial resources are available to carry out identification procedures. This is one of the largest problems since often identifications depend on charity funding, rather than legal imperatives.
- autopsies are not always mandatory, and sometimes only external examinations are performed. This makes the amount of PM data often insufficient for identification.
- Limited amount of AM due to logistical issues in gathering information from various health authorities or due to difficulties in contacting the relatives of the victims.
- Lack of governmental coordination in setting AM and PM teams.
- Lack of a centralised system to manage missing persons data (AM) and unidentified remains data (PM).
- Feeling that identifying these victims is impossible.
- If smugglers or traffickers are involved, migrant fatalities may be unreported.

The central issue for the forensic specialists involved in the identification procedure is mainly related to the lack of adequate AM and PM data, which ultimately affects the rate of positive identification. On one hand, the PM data collection can be improved by making sure that identification starts with a thorough recovery, analysis and documentation of the deceased, with the deployment of experienced DVI personnel, as it is done for any other mass disasters (Cattaneo et al., 2015). On the other hand, the difficulties of gathering AM data could be addressed by promoting cooperation with various agencies, government authorities, and the forensic team by building a centralised database accessible nationally and internationally. This initiative could benefit the identification procedures since data can be accessed by various humanitarian organisations that help the families of the missing people, often from countries with delicate political situations, to provide information about their loved ones (Cattaneo et al., 2015; Cattaneo et al., 2022). Also, Cattaneo et al. (2022) have highlighted how secondary methods of identification might become the key to supporting difficult identification. In many cases, photographs of AM are the only abundant – and useful - record gathered during AM data collection becoming crucial to visualise identifying facial or body details (Cappella et al., 2021).

Thus, the facial appearance and elements such as moles, creases, wrinkles and scars are resilient traits even with early PM changes and may be used for morphological assessment and identification (Caplova, 2017; Wilkinson and Castaneyra-Ruiz, 2021).

1.4 Facial identification of deceased individuals

The face is used by humans to identify, communicate and convey information through facial features, which can convey details such as gender, age, ethnicity, and emotional states. Humans possess a natural ability to recognise faces and comprehend various expressions and can analyse similarities and differences by assessing the overall facial characteristics (Jain, Klare and Park, 2011).

When discussing facial identification, it is important to clarify the distinction between facial recognition and facial identification, as they are often mistakenly used interchangeably. Facial recognition or visual recognition refers to the human ability to compare two faces and determine if they belong to the same person (Schüler and Obertová, 2020).

Facial recognition has been extensively researched and psychological studies revealing substantial differences between familiar and unfamiliar facial recognition in humans (Hancock, Bruce and Burton, 2000). When it comes to familiar facial recognition, individuals are excellent at identifying faces that are familiar to them, even from very low-quality images, however, their ability to recognise or match unfamiliar faces is rather poor (Burton and Jenkins, 2011), even under ideal image quality conditions (Hancock, Bruce and Burton, 2000). Despite that, matching unfamiliar faces is a common and accepted practice in legal settings. For example, trained personnel at border controls are asked to face match the individual with pictures registered in their passport (Jain, Klare and Park, 2011). Similarly, in police investigations, trained staff often evaluate suspects' faces by comparing them to surveillance footage (CCTVs) obtained from the location of the crime (Bindemann and Burton, 2021). Studies suggest that trained individuals generally performed better in unfamiliar facial recognition than laypersons (Wilkinson and Evans, 2009), but both trained and untrained individuals exhibit similar matching performance when dealing with low-quality photographic images (Lee et al., 2009).

Facial identification describes a more meticulous, systematic and well-documented approach than the facial recognition presented above and involves comparing faces of the living using video or photos (Cattaneo et al., 2012; Schüler and Obertová, 2020). The facial identification methods generally involve comparing the face of a target individual visible in photographs or video frames to a suspect face (Bacci et al., 2021a). It has become particularly relevant in many courtrooms across the globe (Wilkinson and Evans, 2009) due to the increased use and availability of video security footage worldwide (Jain, Klare and Park, 2012). Facial identification generally encompasses three possible approaches: photographic morphological comparison of facial features, metrical analysis, and face-to-face superimposition (Cattaneo et al., 2012). The methods will be presented more extensively in the next sections.

Differently from the applications to living individuals, the application of facial identification to deceased individuals has not received the same interest and less emphasis has been given to the role that face can have in PM identity investigation. This underexplored area of research can be explained by the fact that there is little ongoing research on quantification and description of how the decomposition changes affect the face (Caplova et al., 2018a). Only two studies have attempted to quantify the degree of early decomposition changes that affect the face. Wilkinson and Tillotson (2012) have conducted a pioneering study on the prediction of patterns of early decomposition affecting the face, using a 3D laser scan for the face finding patterns of decomposition. The major changes involved bloating of the lateral parts of the face, swelling of the orbits and darkening of the eyeballs, and compression of the midline region of the face and upper lips due to shrinkage (Wilkinson and Tillotson, 2012). Similarly, Caplova et al. (2018a) tracked PM changes in a controlled environment using 3D scanning technology. The results obtained were consistent with what was discovered by Wilkinson and Tillotson (2012), with the exception of insect activity, which did not occur as the bodies were stored in the mortuary at a controlled temperature and the timing and the progress of the changes were different.
The facial recognition and identification techniques that have been used or could be used to identify deceased people are described in the sections that follow. The importance and current state of research for living people will be discussed, along with how it applies to deceased people identification, highlighting its limitations and the application to provide positive identification of victims in mass disasters.

1.4.1 Visual recognition

Visual recognition, or visual identification, refers to the unique innate cognitive ability of humans to identify and recognise faces (de Boer et al., 2020) and can be described as the application of facial recognition to identification. As anticipated early in this chapter, visual recognition can both describe familiar and unfamiliar recognition of faces, and both have been studied in great detail in living individuals leading to the discovery that the two processes are characterised by distinct cognitive processes and influenced by various extrinsic factors (Johnston and Edmonds, 2009).
For what concern The application of visual recognition to the deceased, is a form of familiar visual recognition and it is the first preferred method in domestic medico-legal cases when the victims are considered fresh and well-preserved (Blau et al., 2021). Relatives are asked to view the deceased in person and assume legal responsibility for the identification in the first 48 hours when there is a suspect of identity; in some cases, this process can also be completed by visually identifying the deceased through photographs (Caplova et al., 2018b; Blau et al., 2021). Identity confirmed using

visual recognition is considered appropriate in non-suspicious circumstances, but its applicability to large-scale disasters has been the topic of much debate.
Visual recognition performed by relatives and friends is still used in the early phases of a disaster with well-preserved bodies to speed up the identification procedures (Laczko, 2016), even if Interpol (2018) discourages its use in mass disasters due to being highly erroneous.
Misidentification has been reported in many mass disasters when it has been used as the sole means of identification, including the 2004 Tsunami in the Indian Ocean (Tsokos et al., 2006) and the Bali bombings in 2002 (Lain, Griffiths and Hilton, 2003). If used in combination with other means of identification it can be valuable, as reported by Cattaneo, Angelis and Grandi (2006) after the experience with the identification of the victims of the aircraft disaster in Linate in 2001.
One of the problems with using PM images is that early decomposition changes such as slackness of the jaw and overall loss of muscular tone can make the face appear different (Wilkinson and Tillotson, 2012). Also, relatives with a strong desire to identify a loved one might imagine facial traits that are not visible or, on the contrary, the hope some relatives have to find their loved ones might preclude recognition in case the face is not well preserved (Wilkinson, 2014).
Along with this, it is mentally distressing for bereaved families and friends of relatives to view the deceased body, or bodies in case of mass disasters (Morgan, Tidball-Binz and Van Alphen, 2006).

Moving now to the other type of recognition that involves unfamiliar faces, this type of recognition finds most application in living individuals' access control and security purposes such as border controls and CCTV reviews of suspects involved in criminal activities.
Research studies have revealed the poor ability of humans to recognise unfamiliar faces when matching a living person to their photo (Burton and Jenkins, 2011) or high-quality photos of the same individuals, even when taken on the same day (Megreya, Sandford and Burton, 2013). So even if humans do not excess in facial identification tasks that involve matching unfamiliar faces, police officers are often called to the courtroom to confirm that images from CCTVs match the arrested person (Burton and Jenkins, 2011). In light of this, numerous studies have been conducted to investigate the accuracy of facial identification by experts in courtrooms, particularly in the context of matching the faces of suspects to targets using CCTV. These studies have revealed that relying on holistic recognition can lead to significant errors (Bruce et al., 1999; Burton et al., 1999). Also, Lee et al. (2009) investigated whether the performance of experts in facial identification was better than laypersons when using very poor CCTV footage, finding that experience did not increase the performance. However, the pilot experiment of Wilkinson and Evans (2009) suggested that if better quality CCTV footage is used the trained and experienced individuals perform better.

Also, some have looked into improving facial recognition tasks, for instance, Megreya and Bindemann (2018) conducted an experiment suggesting that if experts are asked to focus their attention on specific facial features their performance can improve.
While the above studies dealt with the recognition of unfamiliar living people, the recognition of unfamiliar faces of dead people has not been a popular subject of study (Caplova et al., 2018b). One of the few studies on the reliability and performance of unfamiliar face recognition in deceased individuals was conducted by Caplova et al. (2017). The study involved facial identification of experienced and non-experienced individuals who were asked to identify deceased individuals using Am and PM, with no obvious PM changes. The results did not differ in the two groups with an identification rate around 75% to 80% suggesting that visual recognition might be useful only as an initial identification screening tool but needs to be followed by a more systematic facial comparison approach. These results suggest that, in both deceased and living, unfamiliar holistic visual recognition does not hold good results and it is generally prone to error (Caplova et al., 2017).

1.4.2 Face recognition systems

Face recognition systems (FRS) are developed based on a database of faces that can vary in the number of individuals and quality (Huang et al., 2008). FRS have found applications in a variety of fields such as the entertainment industry, smartphones, education, security, law enforcement and surveillance industries (Zhao et al., 2003; Hu et al., 2010).
While face recognition systems have achieved incredible results in terms of accuracy of matching in constrained environments when poses, lighting and other factors are controlled (Kortli et al., 2020); their performance is often limited in the real-world application images have changes in lighting, posture, facial expression, in addition to partial occlusion (Adjabi et al., 2020).
Currently, research groups are constantly developing new algorithms and more sophisticated systems with the aim of increasing the identification performances in unconstrained situations (Tome et al., 2013; Srinivas, Flynn and Vorder Bruegge, 2016). However, some argue that rather than budling larger databases of faces might be more important of the algorithm itself (Yi et al., 2014). With the advancements of research on unstandardised images or "in the wild", there has also been an incredible increase in performance in the commercial database used in the forensic science (Jacquet and Champod, 2020).
The use of facial recognition systems in forensic science can have two distinct applications: verification and identification (Jain, Flynn and Ross, 2007). The first one refers to the use of FRS in one-to-one comparison where two images are compared, and the degree of similarity is calculated and if it is above a certain threshold the match is confirmed (Jacquet and Champod, 2020). An

example of this application is the security e-gate in airports. The term identification refers to the comparison of a single facial image to multiple images in the database and the system returns the most accurate match using a ranking system (Jain, Klare and Park, 2011). Matchings are then evaluated by a human operator (Jacquet and Champod, 2020), leading experts to narrow down the possible number of identities of a subject (Jain, Klare and Park, 2011).

Most of the face recognition technology research is on the face as a whole, however, some research is also looking into feature-based face recognition that can provide good results in recognition by extracting specific facial landmarks (Tome et al., 2015) or facial regions (Tome et al., 2013), with the latter in some occasions performing better than the whole face.

The current face detection and recognition systems for living faces are not designed to withstand the challenging characteristics of the deceased individual data (Labati et al., 2021). PM and AM photographs are often presented with the eyes closed, decomposed iris, deformations of the face due to PM changes, facial injuries, poor image resolution, and/or uncontrolled pose.

Generally, algorithms and landmarking detection systems tend to lose accuracy when faces are partially occluded, the pose and the facial expressions are different from the reference image, the illumination is poor or the distance from the camera is substantial (Tome et al., 2013; Srinivas, Flynn and Vorder Bruegge, 2016; Celine and Sheeja Agustin, 2019; Wu and Ji, 2019). The above characteristics are problematic, as shown in the studies carried out on living individuals using unstandardised images or "in the wild". Another major challenge encountered with face recognition on deceased individuals is the correct detection of the face. While the face of a very recent deceased with no damage or other PM change can be easily detected, more advanced stages of decomposition might result in the algorithm not recognising the face.

For a long time, the challenges associated with PM facial recognition have constrained research in the computing field. However, the significant advancements observed in facial recognition systems through deep learning methods, have demonstrated great performance with uncontrolled facial images (Wang and Deng, 2021). More recently, the advancement of face recognition and its potentiality have attracted an interest in the identification of deceased (Labati et al., 2021). Since facial photographs are crucial AM data in forensic investigations, especially in humanitarian and mass disasters, the application of facial recognition technology might help to accelerate the identification process (Cornett et al., 2019). So far, only two experimental studies have been conducted on the application of FRS to deceased identification. Cornett et al. (2019) explored the face detection and recognition abilities of four different commercial face recognition systems based on deep neural networks using acquired facial images from deceased individuals with various degrees of decomposition. Some systems showed satisfactory face detection rates even with advanced decomposition. However, during the recognition phase, all algorithms failed to correctly identify when facial images displayed visible deformation from PM changes. Although the study had some promising results, limitations included facial images taken in PM controlled environment and lack of traumatic injuries, which are not reflective of real-life scenarios. To address this, Labati et al. (2021) conducted a similar study using uncontrolled PM and AM images from victims of the Mediterranean Sea crossings. The study revealed that automatic face detection failed to recognise the face in 21% of cases, necessitating human operator adjustments. However, the identity performance achieved an error rate of 13.21%, which is generally comparable to the results obtained by human operators in similar scenarios.

Many academics in the field of facial recognition have looked at the application of soft biometric recognition systems to identify individuals. Soft biometrics are usually moles, scars, and other identifiers such as ears. Ears in particular appear an ideal candidate for biometric recognition as it is not affected by age-related changes or facial expressions (Purkait, 2007). For instance, Yan and Bowyer (2007) have looked into automated recognition systems on living individual identification using 2D and 3D images achieving high recognition rates even when partial occlusion by earrings or hair was present. Although this sounds promising, there has been no application for deceased individuals.

Overall, face recognition systems (FRS) have produced incredible results in the field of living identification, and just recently research on deceased individuals has highlighted how deep learning methods in FRS allow for promising results in correct detection and recognition of the decomposed face and acceptable error rate. However, PM facial recognition technology poses numerous challenges including alteration of the appearance of the face due to PM changes, uncontrolled images with inadequate illumination, and low image quality.

1.4.3 Craniofacial Superimposition (Skull-to-face)

Craniofacial superimposition (CFS) is a forensic facial identification technique that compares AM photograph or video frames with the skull of an unknown individual to evaluate the anatomical consistency between landmarks on the face and on the skull that determine if they are the same individual (Lee, Mackenzie and Wilkinson, 2011; Yoshino, 2012).

Generally, craniofacial superimposition is considered valuable in ruling out a match between the skull and the facial photographs (Yoshino, 2012).

At the early stage of CFS, the superimposition was carried out by overlaying or projecting the AM images to a video/photographic projection of the skull (Austin-Smith and Maples, 1994; Fenton, Heard and Sauer, 2008), however recent years, as computer technology advanced, the computer-aided CFS technique has become popular approach (Yoshino, 2012). This method can refer to the digitalisation of the skull and overlay to facial photographs using a video computer system (Ubelaker, Bubniak and O'Donnell, 1992) or to the digitalisation of the skull using 3D scan and overlay it to facial photographs using computer software (Damas et al., 2011). When employing digitalised 3D skull models, the key benefit is portability and how simple it is to rotate the skull to match the facial photograph (Gordon and Steyn, 2012).

CFS has been lacking for many years of international standards until craniofacial superimposition researchers worked together to produce a common international framework for CFS - 'New Methodologies and Protocols of Forensic Identification by Craniofacial Superimposition (MEPROCS)' (Ibanez et al., 2016). The framework was validated, showing an overall improvement in the performance (Ibanez et al., 2016; Damas, Oscar and Oscar, 2020). After MEPROCs, other initiatives have brought advancement in the practices such as the promising results in testing and automated systems based on fuzzy sets able to filter cases and establish conclusions (Campomanes-Alvarez et al., 2018).

The application of CFS is not limited to single unknown skull identification which is generally considered a suitable technique for exclusion of identity, rather than identification (Wilkinson and Lofthouse, 2015), but it has been used when multiple individuals are involved.

For instance, successful exclusion of identity was carried out in 2003 using CFS when commingled remains from five different people were found in Arizona, US (Fenton, Heard and Sauer, 2008). The application of CFS to mass disasters has been also tested to understand the reliability and applicability of DVI in a study conducted by Wilkinson and Lofthouse (2015). They used a database of passport-style images and 3D cranial scans.

The results confirmed the suitability of CFS in multiple deaths, however low identification rate was obtained where only frontal images were used. The unsuitability of frontal images was not surprising but corroborated by Yoshino et al. (1995) who stated in their study that a single frontal photograph should not be used alone since a skull might be consistent with multiple frontal photographs and better distinctive facial characteristics are visible from profile and three-quarter images.

The future advancement in CFS looks promising, with a shift from the final decision being practitioner-dependent and relying on their experience and anatomical knowledge (Campomanes-Álvarez et al., 2015) to a fully automated system that remains to this day a challenge (Ibáñez et al., 2021).

1.4.4 Face-to-face Superimposition

Face-to-face superimposition refers to the process of overlaying, resizing, and repositioning photographs of a target and a suspect to assess whether they are a match or not (Atsuchi et al., 2013). This is different from a craniofacial superimposition where the correspondence is between an unknown skull and a known AM individual.

Face-to-face superimposition is used in the field of photographic identification of the living and can be performed using 2D facial images (2D-2D superimposition) or a 3D model of the target and 2D image of the suspect (3D-2D superimposition). The 2D-2D superimposition has little use in forensic identification as the main limitation is that images need to have the same orientation and angle of the face and even minimal differences can produce high errors (Yoshino et al., 2000). To resolve the issues associated with 2D-2D superimposition, 3D-2D was developed (Yoshino et al., 1996). While the 3D model of the face helps with the orientation and angle, superimposition is difficult to apply to images where emotional facial expressions are involved (Atsuchi et al., 2013). Since 3D-2D provides some better results than 2D-2D, some researchers have also tried to quantify the standardise the technique by quantifying the match. Previous research has highlighted how combining superimposition with facial point distance measurement could provide good results and provide an element for a clearer interpretation in the courtroom, even when applied to disguised faces (Yoshino et al., 2002). One of the limitations is that the study was conducted on faces showing neutral facial expressions and in ideal quality and lighting situations. This is considered a limitation and poor applicability to a forensic scenario since most of the images collected for forensic investigations come from social media platforms or CCTVs, therefore presenting a wide range of poses, expressions, poor illumination and suboptimal quality (Gibelli et al., 2016).

Other researchers, however, have obtained poor results when performing an analysis of the distances of the coordinates of 7 annotated anatomical landmarks in 3D and 2D images, finding higher absolute errors between corresponding points in matching images than in non-matching images. (Goos, Alberink and Ruifrok, 2006). With contrasting opinions on reliability of distance between corresponding anatomical points when matching 2D images and 3D models, Cattaneo et al. (2012) attempted to explore a different approach aiming to quantify the facial profile match of 2D-3D images calculating the distance between maxima and minima points in the facial profile. The study obtained some promising results, but more research is needed. While it seems that there has been some research on using face-to-face superimposition in living individuals, there is a lack of research on deceased individuals. One of the main issues that can explain the absence of research in this field is related to the PM changes, which even during the early phases, can alter significantly the appearance of the face (Wilkinson and Tillotson, 2012), making the superimposition of facial features difficult.

Anthropometry as facial measurements and landmarking has been used as an important tool for biological anthropology. The use of facial and landmarking measurements has been applied to the identification by comparing anatomical landmark distances and proportions in facial photographs of two individuals that are believed to be a match (Iscan, 1993; Davis, Valentine and Davis, 2010). Various research on the metric method of facial identification have demonstrated that anthropometry-based identification is problematic (Kleinberg and Vanezis, 2007; Kleinberg, Vanezis and Burton, 2007). Indeed, various factors can have a significant influence on the trustworthiness of this approach. The most significant criticisms are that the measurements are not done in vivo on the individual, but rather on 2D photographs, making anatomical landmark localisation more difficult and inaccurate (Iscan, 1993). Furthermore, using 2D images - often from CCTV cameras- results in low-quality and inaccurate photographs of the face (Kleinberg and Vanezis, 2007).

Various attempts have been made to standardise and improve the reliability of anthropometric methods. Kleinberg, Vanezis and Burton (2007) attempted to add normalised proportionality indices for each measurement, allowing them to compare various photos with similar angles. If the proportionality indices differ, the two photos are most likely not of the same individual. However Moreton and Morley (2011), on the other hand, suggested that certain factors such as image quality, lighting and lens distortion will affect the face images in a way that limits the power of the indices, making them unsuitable for identity exclusion. Other researchers attempted to employ software-assisted face extraction of anatomical landmarks to reduce inter and intra-observer variability (Davis, Valentine and Davis, 2010; Tome et al., 2013), emphasising that measurement differences do not necessarily indicate different people, as extrinsic factors (hairstyle, ageing, etc.) can cause changes in appearance.

Given all that has been mentioned so far, the Facial Identification Scientific Working Group (FISWG) and the European Network of Forensic Science Institutes (ENFSI), who represent important international institutions in the forensic discipline, strongly discourage the use of photo-anthropometry and photographic superimposition in the courtroom and since the empirical research has found the methods unable to produce accurate results, as well as lacking repeatability and reliability (ENFSI, 2018; FISWG, 2019a). Up until now, face-to-face-superimposition and anthropometric analysis, which have been extensively studied and applied in living individuals, have not been tested on deceased individuals due to their limitations and inadequate applicability.

1.4.5 Morphological Comparison

Morphological comparison involves analysing facial images of two individuals, to assess the similarities and differences by examining the correspondence between shape, appearance, and location of features, as well as identifying features like scars and moles (FISWG, 2019a; Stephan et al., 2019; Schüler and Obertová, 2020). Facial comparison experts working for law enforcement, government organizations, and academic institutions routinely utilise this comparative analysis in legal scenarios. They are generally trained in anatomy, principles of image comparison and recognition as well as court proceedings (Steyn et al., 2018). Their role involves providing expert opinions on the identity of a target individual or their potential association with a criminal event by comparing facial images obtained from CCTVs and video security footage with those of suspect individuals discovered at a crime scene (Bacci et al., 2021b).

Morphological comparison and facial reviews are often confused, but it's important to note that they are distinct processes (FISWG, 2019a). While both involve the evaluation of facial features, they differ in their approach and purpose. Facial reviews are commonly used for identity verification in access control, but they are considered non-evidential. The staff involved in facial reviews are often not trained at the same level of expertise possessed by facial examiners (ENFSI, 2018).

Facial comparison is based on the assumption that the combination of morphological traits observable on faces is unique (Schüler and Obertová, 2020), however due to its subjectivity, lack of a standardised approach and basic principles of admissibility in courts (Mallett and Evison, 2013) as well as lack of quantifiable judgement on the matching (Porter and Doran, 2000) some concerns have been raised on its use in courtroom (Mallett and Evison, 2013).

Subjectivity is inherent due to the object of the analysis: the face. As pointed out by Cattaneo et al. (2012) the face and its unique features and shapes are difficult to assess quantitatively. Therefore, the final assessment is based on the description of similarities and differences, as well as a scale of support to express the level of confidence in the inclusion or exclusion of identity.

Nevertheless, standardisation attempts have been made through the years. Initially, atlases on morphological classification of facial features for living adult Caucasian male individuals (Vanezis et al., 1996) and adult male individuals from Germany, Lithuania and Italy (Ritz-Timme et al., 2011) were published underlying that understanding which characteristics are more common or less common could be used to exclude or include the identity of an individual (Ritz-Timme et al., 2011). but none of the atlas or approach has been considered suitable for personal identification.

More recently the international joint work of the Facial Identification Scientific Working Group (FISWG) has produced guidelines and protocols to provide facial comparison procedure, a comprehensive list of facial features to analyse during comparison, image quality factors to consider and type of training and competencies experts should have to reliably perform

comparisons tasks (Gibelli et al., 2016; Geradts, Filius and Ruifrok, 2020). The FISWG morphological features list is currently considered the most comprehensive and relevant protocol for the forensic facial comparison (ENFSI, 2018).
While the FISWG guideline constitutes an incredible improvement in the field of facial comparison some aspects still need to be addressed. The most relevant are the protocol validation on a large population, accuracy test and introduction of common criteria to perform the final judgment of inclusion or exclusion of identity to avoid highly subjective results (Schüler and Obertová, 2020). In light of the further empirical validation required for the FISWG morphological feature list, Bacci et al. (2021b) undertook some extensive tests to validate the accuracy of the morphological comparison using FISWG guidelines on living individuals. The study simulated a real-life scenario with various image types resulting in an accuracy between 71 to 99%, where the photographic samples had better accuracy compared to extracted CCTV images, confirming that quality has a big impact on accurate results. The latter is not only dependent on image quality but also on the strictness of the analysis. Taking a stricter approach to assessing the match results in more false negatives and fewer false positives in both photographic and substandard CCTV pictures. This should be utilised in forensic courts to limit the possibility of false allegations and suspect misidentification.
Currently, there is no minimum requirement for image quality and the images are usually assessed by the practitioner against the major quality factors such as pixel resolutions, distortion, pose and lighting obstruction caused by objects such as hats and sunglasses, to decide whether they are suitable for comparison (FISWG, 2021a). The relationship between correct assessment and the quality of the images has been investigated by different researchers in the field of facial identification research studies confirming the relationship between a lower accuracy of the match and the low quality of the photographic material (Zhao et al., 2003; Lee et al., 2009; Jain, Klare and Park, 2011; Moreton and Morley, 2011; Bacci et al., 2021b). Also, Bacci, Steyn and Briers (2021) and Bacci et al. (2021b) have reported higher accuracy results when performing the morphological analysis on optimal photographic material. Regarding the assessment results, they have been often considered too dependent upon the experience, knowledge and ability of the practitioner (Ritz-Timme et al., 2011).

In recent years, there has been a growing interest in using morphological comparison PM identification by comparing images of missing individuals and PM images collected during autopsy analysis (Caplova, 2017). In particular, the increasing number of unidentified bodies associated with migration disasters and mass disasters often lacks primary identification data and requires the use of alternative methods that involve facial photographs (Cappella et al., 2021).

Photographic materials are often a crucial piece of personal data that is easily available to investigators (Cappella et al., 2021) For example, PM images are routinely collected, and descriptions of the external morphological features of both the body and face are well-documented by pathologists (Acharya et al., 2017; Cattaneo et al., 2022). Also, the availability of personal photographs has significantly increased with the widespread use of social media platforms and smartphones equipped with cameras, meaning that often there is easy access to high-quality images of the faces of missing people. In the context of migration and photographic availability, Cappella et al. (2021) conducted an observational study were highlighted the great availability of images from families in a migrant disaster context, that were later used to aid identification. This highlights the importance of collecting photographs of missing individuals as a crucial component of personal identification (Cappella et al., 2021). A recent case that shows the importance of morphological comparison in deceased identification involved a large number of victims of a migration disaster in Italy. AM images showing moles and scars were compared with PM images, resulting in a match. The comparison of these distinct features, such as moles and scars, played a fundamental role in supporting the genetic results and achieving an identification (Olivieri et al., 2018). These examples show the value of morphological comparison and the use of photographic material in PM identification, particularly in cases involving missing individuals and mass disasters. The facial morphological comparison can have particular relevance in PM identification when individualising facial features are present and visible: facial marks, tattoos, ears and teeth are visible. Generally, these elements are listed as comparable features that should be analysed during a morphological comparison for living individuals, but they assume an even more significant role in the identification of deceased individuals. This is particularly true when they become the only available clues for establishing identity.

Skin marks

Skin marks such as moles and scars and any blemish visible on the skin are among the most common features diffused in different populations and often visible in photographs (Black et al., 2014; Jackson and Black, 2014; Jalal, Sharma and Sikander, 2021). The term “skin mark” encompasses a variety of skin irregularities such as moles (or nevi), scars, discolouration, acne, eczema lentigines, cherry hemangiomas, and seborrheic keratoses, with some of them being less stable through time (Nurhudatiana et al., 2016). Assessing the nature of skin marks from a photograph, especially if photographs are of low quality, is difficult, and experts suggest using only recent photographs for skin mark comparison.

Black et al. (2014) conducted an interesting study examining the significance of position, shape, and incidence of scars and nevi on the dorsum of the hand for identification purposes. The research highlighted how these characteristics can be crucial in identifying individuals, and included a forensic case in which the pattern of nevi on the offender's hands matched those observed on the accused.

Similarly, the identification of skin marks can be valuable in identifying living individuals, and the same principles can be extended to PM identification. However, applying these principles must consider the PM changes that affect the skin.

Facial lines

In the same way, skin irregularities can provide a clue for identification, Hadi and Wilkinson (2014) have argued whether facial lines or wrinkles are consistent enough to be used for human identification and if decomposition processes, such as bloating, affect their visibility using a photographic sample of cadavers before and after bloating. The preliminary results of their study suggest that analysis of the creases might be a valuable part of the examination, with most creases being stable after bloating, however, the authors admit that facial 3D scanning over photographs might held better results due to better visibility and depth of facial lines.

Ears

Another element of the face that has been found particularly unique is the human ear. As seen in biometric recognition the stability and the minimal changes ears undergo during a lifetime, as well as the stability maintained with different facial expressions (Hoogstrate, Van Den Heuvel and Huyben, 2001; Chattopadhyay and Bhatia, 2009) make it useful for identification.

The individuality of the ears has been observed by undertaking studies that looked at combination of the features among different populations (Kapil et al., 2014; Krishan et al., 2019; Petrescu et al., 2018; Purkait, 2016; Rubio et al., 2015; Verma et al., 2016), in identical twins (Nejati et al., 2012), but also within the same individuals where right and left ear were never found to be identical (Purkait and Singh, 2008; Purkait, 2016). Nevertheless, Cameriere, DeAngelis and Ferrante (2011) suggested caution in affirming the uniqueness of ears, as this can only be confirmed when the probability of occurrence of the uniqueness in the population is assessed with a model for external ear patterns.

From a practical point of view, the morphology of the external ears has been used in forensic cases to aid identifications comparing 2D photographs. However, due to the complex shape of the ear that is sensitive to image perspective, magnification, and pose variation (Spaun, 2007), 3D-2D comparison should be preferred as it produces better results than 2D-2D comparisons (Tharewal et al., 2022; Yan and Bowyer, 2005, 2007).

Examples of its use in living identification include the morphological comparison between the ears of the suspect and the offender was used in an Italian robbery case, where it helped to confirm that the two individuals were not the same persons and it was accepted in courtroom as evidence (Ventura et al., 2004). Similarly, the external morphology of the ear has also been used for the identification of unknown deceased individuals suffering from severe mutilations (Krishan, Kanchan and Thakur, 2019). For instance, Carvalho and Bantim (2019) describe the applicability of ear morphology to identify a severely burned and beheaded individual, based on the comparison of 2D images taken PM and AM The ear morphology helped with the identification that was later confirmed through DNA analysis.

1.5 Post-mortem morphological comparison protocol design

The methodology of facial image comparison applied to PM identification using AM images of the missing people and PM images of deceased can have a substantial relevance in the context of personal identification (de Boer et al., 2019), as the analysis of facial details such as moles, ears provide unique information that can be used for identification (Caplova, 2017).
As seen in sections 1.3.2 and 1.3.3 it would be particularly beneficial in those contexts in which there is a substantial lack of AM data, as is often the case of migration victims (Cattaneo, Angelis and Grandi, 2006). It is in these cases that images are one of the most abundant, and in some cases, the only data available to identify the victims (Olivieri et al., 2018). In an observational study, Cappella et al. (2021) discussed the quality and quantity of AM images of unidentified migrants obtained using social media platforms or provided by family members. The study highlighted how images can be important for identification, enabling the comparison of facial and body details between images of the missing people and victims in a well-preserved state.

The application and value of facial comparison to the identification of the deceased have not been investigated formally in empirical research studies. However, Olivieri et al. (2018) reported that in identifying the migrant victims of the disaster on October 3rd 2013 they used photographic comparison in the identification of some of the victims, combined with a biological analysis. However, the authors refer to photographic comparison including body photographs and photographs of tattoos and moles on the body, so it is unclear when the comparison was performed on facial images only.
As a consequence of the lack of reported use of facial comparison in real case scenarios, there is also a lack of studies on the applicability of facial comparison guidelines developed for a living-to-living comparison for living-to-deceased comparison. The available FISWG guidelines are developed on l "living" facial appearance and they do not account for the early decomposition changes that affect the face after death. Therefore, the application of photographic facial comparison to deceased individuals would benefit from a tailored protocol, that will be proposed in this research study. The structure of the protocol reflects the morphological facial comparison protocol of the Facial Identification Scientific Working Group (FISWG). Together with a consultation of the publications that were relevant to the field of facial comparison, publications in the field related to PM facial identification and facial decomposition were also included. All the relevant resources are presented in Table 1.

1.5.1 Review of the literature and guidelines on forensic facial image comparison

Table 1. Summary of the literature used to design a protocol for PM morphological facial comparison

Author (s)	Title	Context	Relevant Section
Megyesi, Nawrocki and Haskell (2005)	Using accumulated degree-days to estimate the post-mortem interval from decomposed human remains	Face decomposition score	PM analysis
Wilkinson and Tillotson (2012)	Post-mortem prediction of facial appearance	PM changes affecting the face	PM analysis
ENFSI (2018)	Best Practice Manual for Facial Image Comparison		Protocol and Database design
FISWG (2018)	Facial image comparison feature list for morphological analysis		Protocol and Database design
FISWG (2019b)	Facial Image Comparison Best Practices for Markups and Annotations		Protocol and Database design
FISWG (2019a)	Facial Comparison Overview and Methodology Guidelines		Protocol and Database design
FISWG (2021b)	Physical Stability of Facial Features of Adults		Protocol and Database design
FISWG (2021a)	Image Factors to Consider in Facial Image Comparison		Protocol and Database design AM analysis

Bacci et al. (2021b)	Validation of forensic facial comparison by morphological analysis in photographic and CCTV samples	Validating the practice of feature-based facial comparison using suboptimal images	Comparison
Schüler and Obertová (2020)	Visual identification of persons: Facial image comparison and morphological comparative analysis	Overview of facial photographic comparison	AM analysis
Caplova et al. (2017)	The Reliability of Facial Recognition of Deceased Persons on Photographs	Non familiar recognition of deceased persons and most used facial features during recognition	Facial review
Caplova et al. (2018a)	3D quantitative analysis of early decomposition changes of the human face	Assessment of decomposition changes in early stages after death	PM analysis Comparison
Moreton (2021)	Forensic Face Matching	Levels of support for evaluation	Evaluation
Hadi and Wilkinson (2014)	The post-mortem resilience of facial creases and the possibility for use in identification of the dead.	Observed resilience of certain facial creases after bloating suggesting that they can be utilised for deceased identification	Comparison

The protocol follows the ACE-V (Analysis, Comparison, Evaluation, Verification) workflow which is an approach made of 4 distinctive phases, well described in both FISWG publications and ENFSI guidelines. When one-to-multiple comparison is performed, the ACE-V workflow is proceeded by a holistic review of the reference and questioned individual images, to quickly assess if there are obvious dissimilarities between some individuals that can be excluded as a match, even before conducting a thorough comparison. In short, Analysis (A) is the stage where the quality, lighting and other elements of the images are assessed for their suitability for comparison. Comparison (C) is the analysis of similarities and differences of the facial features visible from the images using the FISWG facial feature list as a reference. Evaluation (E) is the expression of a level of support for the match and Verification (V) involves the verification of the comparison by another practitioner (ENFSI, 2018).

Each stage and how could be adapted for living-to-deceased comparison is presented in the tables below.

1.5.2 Facial Review

Table 2. The Facial Review Phase in living-to-living facial comparison and relevant adjustment to make in a living-to-deceased facial comparison

Living-to-Living Protocol	**Adjustments for Living-to-Deceased Protocol**
The practitioner has the option to rapidly assess the faces and eliminate obvious non-matches. The "Facial review" stage is based on the natural abilities of humans to identify facial similarities and differences.	This phase would be particularly relevant in facial comparison involving deceased and living, as this approach would be useful to exclude obvious non-match in a DVI scenario (For instance, when the PM subjects possess a significantly dark skin tone while the AM target exhibits a light skin tone). This stage is to be performed after the Analysis (A) stage to allow an initial full analysis of the decomposition changes and image factors of PM and AM. Also, to address this issue and facilitate decision-making during the facial review stage, a decision-making flowchart is incorporated. The flowchart provides a standardised approach to the facial review, allowing practitioners to make an informed decision about whether two individuals might be a potential match and whether further comparison is required, ensuring that potential matches are not overlooked. Furthermore, the flowchart is designed to be accessible to individuals who are not experts in facial comparison and will not be proceeding onto a full comparison. It relies on

	the innate ability of any human to recognise differences and similarities in unfamiliar faces (See Appendix A).

1.5.3 Analysis (A)

Table 3. The Analysis (A) Phase in living-to-living facial comparison and relevant adjustment to make in a living-to-deceased facial comparison

Living-to-Living Protocol	**Adjustments for Living-to-Deceased Protocol**
This phase helps to determine if the quality of the images qualitatively sufficient for a morphological comparison and in what degree the facial features and facial details are visible. In the living guidelines both the reference and questioned images are compared analysing the same image factors and this analysis is not done at the same moment to avoid confirmation bias especially when one of the two images is high quality while details are not visible in the questioned imagery	While the analysis of AM images can follow the analysis phases outlined for the living guidelines, PM images do not typically need an analysis focused on image factors such as lighting and resolution, since are usually captured with high resolution, under controlled lighting conditions and generally depict faces in various poses. Consequently, the Analysis phase should be divided into two distinct stages: - Analysis of AM images - Analysis of PM images The structure of the Analysis of AM images will reflect that of the Analysis phase designed for comparisons between living individuals. In contrast, the Analysis of PM images necessitates the documentation of PM changes and an evaluation of their suitability for comparison. Please refer to Table 4 for a comprehensive list of factors to be taken into account during the Analysis of AM and Analysis of PM images.

Factors to consider in the Analysis of AM images and PM images

Table 4. The factors evaluated in the Analysis(A) Phase of AM images and potential factors to consider when analysing PM Images.

AM images	**PM images**
- Head angle - Distance from camera - Source of images - Facial marks and facial alterations - Presence of photographic distortion - Light exposure - Noise - Image alteration - Distractions - Facial expressions - Image quality score (Schüler and Obertová, 2020)	- Presence of teeth images: when teeth are visible in AM and PM can provide a solid base for identification. See section 1.3.1 about dental superimposition using images. - Location where the body was found. - Presence of facial marks and facial alteration (moles, scars etc..) as they can be identifiers. - Decomposition changes and decomposition score (Megyesi, Nawrocki and Haskell, 2005): recording changes is important since even at an early stage facial features can be altered. See 1.2.1 section on decomposition. - Facial bloating: Bloating can make some features appear larger, obscure facial marks or hide furrows and wrinkles (Wilkinson and Tillotson, 2012). - Traumatic injuries that alter facial appearance. - Obscuring matters such as blood or clothes.

1.5.4 Comparison (C)

Table 5. The Comparison (C) Phase in living-to-living facial comparison and relevant adjustment to make in a living-to-deceased facial comparison.

Living-to-Living Protocol	**Adjustments for Living-to-Deceased Protocol**
This stage involve a methodical analysis of similarities and differences of the facial features observable when looking at the questioned and reference images. The comparison should be done by using image that have a similar pose, following face feature list	There are no changes that need to be made in the actual comparison process or list of feature to consider. However each feature analysed should take into account the PM changes.

(FISWG, 2018) and should consider possible image conditions .	

1.5.5 Evaluation (E)

Table 6. The Evaluation (E) Phase in living-to-living facial comparison and relevant adjustment to make in a living-to-deceased facial comparison.

Living-to-Living Protocol	**Adjustments for Living-to-Deceased Protocol**
In this stage examiner should conclude, after looking at similarities and differences, if the reference and questioned image are from the same person. This conclusion should be made by using a graded support scale, however , there is no universally accepted scale available. Generally, the scale should include an inconclusive grade to be used by the examiner when neither support of support can be given. Also, the scale generally should provide grades that are useful, meaningful and repeatable among different examiners. The level of support provided is dependent on the examination of several factors: • Number and type of visible features • Experience of the examiner on common and uncommon features • Transient or permanent nature of the feature • Quantity and quality of similarities and differences and if they can be explained by images factors • Time gap between images observed	Similarly to the living-to-living protocol a added scale is adopted for this stage. The scale chose is adapted from Moreton (2021) and with the following level of support: - Strong Support - Support - Moderate Support - Limited Support - No Support Where Moderate and Limited support are the inconclusive levels. The scale is extensively described in the next section and can also be found in the Post Mortem Comparison Protocol available in the Appendix A (3.16).

Level of support

The level of support refers to the degree of confidence that can be attributed to a particular conclusion made by comparing two individuals' images. It measures how strongly the available evidence supports a particular interpretation or conclusion.

The scale used for the level of support is adapted from Moreton (2021) and includes 2 positive levels of support, expressed as "Strong Support" and "Support"; two inconclusive levels indicated as "Moderate Support" and "Limited Support"; and a level of negative support expressed as "No support".

Below is the level of support used with the relative descriptions:

- **Strong support**: the evidence provides strong support for the proposition that the images depict the same individual. Strong support should be expressed when identifiers such as facial marks and facial alteration or tattoos match.
- **Support:** the evidence provides support for the proposition that the images depict the same individual.
- **Moderate support**: the evidence provides moderate support for the proposition that the images depict the same individual.
- **Limited support**: the evidence provides limited support for the proposition that the images depict the same individual.
- **No support**: the evidence provides no support for the proposition that the images depict the same individual.

1.5.6 Verification (V)

Table 7. The Verification (V) Phase in living-to-living facial comparison and relevant adjustment to make in a living-to-deceased facial comparison.

Living-to-Living Protocol	**Adjustments for Living-to-Deceased Protocol**
The verification phase refers to the task of having a second independent examiner to carry out the comparison blindly, without being aware of the prior examiner's results. Alternatively can be done knowing the conclusion of the first examiner.	Verification should be performed by a second examiners following the living guidelines.

2. AIMS AND OBJECTIVES

2.1 Aims

Part 1 Methodology development

- To develop a protocol for PM morphological facial comparison that addresses and mitigates the challenges of comparing images of living individuals to deceased.

Part 2 Post-mortem morphological facial comparison study

- To investigate if correct identification of PM subjects by morphologically comparing facial unstandardised AM and PM photographs is possible.
- To assess the reliability of morphological comparison of facial photographs through an inter-observer blind study using unstandardised AM and PM images.

2.2 Objectives

To achieve the aims listed above the following objectives were set:

- To produce a workflow for forensic facial comparison incorporating existing literature on living morphological facial comparison and facial decomposition changes.

- To conduct the morphological comparison blind study and interobserver study using an unstandardised sample of AM and PM images of identified individuals, collected during PM examinations.

- To analyse the identification rates of the blind study and interobserver test.

- To identify potential limitations and areas of improvement, providing recommendation for future research.

3. METHODOLOGY

In this methodology chapter, the research methods and the sample employed for the study are outlined. The chapter is divided into three sections:

- Part 1 Post Mortem Morphological Comparison Protocol and Form
- Part 2 Facial morphology comparison study
    - Part 2a Blind study: a blind photographic facial comparison will be carried out using unstandardised AM and PM data collected from forensic cases. The developed protocol will be utilised in this comparison.
    - Part 2b Inter-observer test: the inter-observer reliability study is carried out to assess the level of consistency of the prescribed process, including the level of support given for matches.

3.1 Ethics

The project design and use of deceased images received ethical approval by the Ethics Committee of the University of Milan on the 30th June 2022 (Allegato 7) and by the Liverpool John Moores University Research Ethics Committee (UREC Reference 22/LSA/006) on the 8th July 2022.

3.2 Protocol and Form

- **Post-mortem Facial Comparison Protocol**: adapted guidelines for AM-PM Comparison Template with reference material and decision-making flowcharts.
- **Post-mortem Facial Comparison Form**: field template that can be used to document the various phases of facial comparison and store information about the cases. It should be used in conjunction with the Protocol.

3.2.1 Post-Mortem Photographic Facial Comparison Protocol

The protocol for PM photographic facial comparison provides a detailed, step-by-step guide for using the Excel spreadsheet called "PM Photographic Facial Comparison Process." This tool can be highly beneficial in aiding decision-making during the process of conducting photographic morphological facial comparisons in PM cases.

It is important to note that PM photographic facial comparison is primarily used to exclude identities and suggest cases that may require further DNA testing to confirm or exclude potential matches. It should not be relied upon as the sole means of definitive proof of identity. (Schüler and Obertová, 2020)

In order to use this protocol, practitioners should:

- Have access to images of unidentified deceased individuals (PM case) and missing persons (AM case).
- Have access to the "PM Photographic Facial Comparison Process" Excel spreadsheet.
- Possess knowledge of facial anatomy, PM changes, environmental factors, and the ways in which decomposition can impact the appearance of facial features over time.
- Be familiar with the resources and guidelines outlined in Table 1.

Protocol Structure

The protocol and accompanying spreadsheet are structured by the FISWG guidelines, which were initially developed for facial comparison in living individuals (Stephan et al., 2019; Schüler and Obertová, 2020). The protocol employs the ACE-V (Analysis, Comparison, Evaluation, and Verification) workflow, which is usually employed for other forensic methods such as fingerprint identification. These stages are preceded by a holistic review of the face to determine whether the reference and questioned images present obvious differences that do not require further investigation with a full comparison analysis (FISWG, 2019a; Bacci et al., 2021b).

Various sections of the protocol correspond to the different sections of the PM Photographic Facial Comparison Process Excel (Appendix B) organised as follows:

- **AM Lis**
- **PM List**
- **Phase 1-AM Analysis** (equivalent to Analysis in the ACE-V): In this phase, AM images are analysed against specific image factor requirements such as lighting quality, and identifiable features such as facial marks, piercings or scars are recorded.
- **Phase 1-PM Analysis** (equivalent to Analysis in the ACE-V): In this phase, PM images are analysed recording the identifiable facial features (either from the autopsy report or from visual analysis), decomposition stage, and other PM modifications. Any obstruction or trauma should be noted at this stage.
- **Phase 2-Facial Review**: In this phase, individuals who are clearly not a match will be eliminated, and those who are a possible or uncertain match will progress onto the second phase.
- **Phase 3-Comparison** (equivalent to Comparison in the ACE-V): In this phase, images of potential matches are analyzed following the feature list provided by FISWG. Each feature

is analysed to identify similarities, differences (and if the differences are due to PM changes, image factors or actual differences), or reasons why a given feature is not comparable.

- **Phase 4-Evaluation** (equivalent to Evaluation in the ACE-V): This phase involves an overall evaluation of the results obtained during the comparison phase to determine the level of support.

Figures 4 and *5* provide illustrations of the protocol's structure and how sections are presented and explained. For a complete view of the protocol, please refer to Appendix A.

Recommendations and notes for the practitioners:

If the dentition is visible in both AM and PM images (such as in smiling photographs), it is recommended to involve odontology experts to analyze specific dental traits as they are crucial for identification purposes. (Silva et al., 2015; Forrest, 2019).

PM facial comparison can offer significant advantages in several situations, for example:

- When there is a substantial number of deceased individuals and missing persons with facial images available.
- When resources for conducting extensive genetic testing on victims and their relatives are limited.
- When access to primary identification data such as DNA, fingerprints, and radiographs held by organisations or facilities is restricted.
- When the genetic makeup of the deceased is of limited use due to kinship between the victims.

PM List

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **PM List** sheet. Once there, follow the below instructions to complete the columns.

b.1 PM code
Insert the post mortem case identifier code

b.2 Presented gender/ sex if known	
Select the presented gender that better describes the individual in the pictures or biological sex (if known from the autopsy report) using the list below. ⚠*The biological sex reported in the autopsy report might not be representative of the presented gender of the individuals when alive. Use the b.6 Notes to add any relevant information.*	
F	Female: The individual in the picture presents physical gender expression that are generally typical of female individuals. This might include facial features, hairstyles, makeup, clothing.
M	Male: The individual in the picture presents physical gender expression that are generally typical of male individuals. This might include facial features, hairstyles, facial hair, clothing.
I	Indeterminate: The individual in the pictures presents physical traits that dot not fit into the traditional binary categories of female and male.

b.3 Skin colour	
Select the skin colour that better describes the individual in the pictures using the list below.	
Light	It typically appears as a pale or fair complexion. This skin tone is often associated with people of European or East Asian descent, but it can also be found in people of other ethnicities.
Medium	It typically appears as warm and golden complexion. It is common in people of Latin American, and Middle Eastern descent, as well as some South Asian and East Asian populations.
Dark	It typically appears as reddish-brown to black complexion. It is common in people of African, Afro-Caribbean, and some South Asian and Southeast Asian descent.

b.4 Estimated age– From Albert, Ricanek Jr and Patterson (2007)	
This description is to be used if the actual age of the missing individual is unknown. If the age is known, please make a note in the a.6 Notes section.	
Young adult	The individuals appear to be in the late teenage to young adulthood stage of life, exhibiting soft facial features and a generally youthful appearance.
Old adult	Individual that physically appear to be above 70 years of age. The individual might present gray hair or balding, skin texture changes (wrinkles, age spots, leathery skin etc..), increase ear and nose size, loss of facial fat and a more gaunt appearance. Their appearance might not reflect their real age.

Figure 4. Example of the Protocol - PM List section. Each section is subdivided into multiple subsections mirroring the Excel form's structure. The protocol should be used in conjunction with the Excel form for guidance.

1.14 Quality Score

The quality score is the six-point (1 to 6) evaluation scale introduced by Schüler and Obertová (2020).
Select from the drop-down list the quality level that better that better describe the image. Once the appropriate level is selected, the box will automatically turn green, yellow or red. The colours indicate the suitability of the image for comparison.

Quality level	Description	Colour	Suitability
1 **Very Good**	The quality of the image corresponds particularly well to the requirements of a morphological analysis. The resolution, sharpness, and illumination of the image are excellent. Object is not obscured, and image artifacts are not present. Small-scale facial features and skin structures are visible and can be described in detail.	Green	Acceptable image quality, small and large facial details are visible. Strong positive level of support in the evaluation phase might be expressed.
2 **Good**	The quality of the image fully meets the requirements of a morphological analysis. Resolution, sharpness, and illumination are good. The percentage of object overlay, and image artifacts is a maximum of 5%. The small-scale facial features and skin structures are still visible, but details are unclear.		
3 **Satisfactory**	The quality of the image corresponds to the general requirements of a morphological analysis. A few deficits can be detected in the resolution, sharpness, or illumination. The percentage of object overlay or image artifacts is greater than 5% but smaller than 25%. Small-scale features can be described; skin structures are no longer visible.		
4 **Sufficient**	The quality of the image is sufficient to meet the requirements of a morphological analysis. In several areas of the image, deficits are detected in the resolution, sharpness, or illumination. The percentage of object overlay and image artifacts is greater than 25% but smaller than 75%. Small-scale features can be described to a very limited extent or not at all.	Yellow	Lower quality and restricted features visibility. If image is used alone, **strong positive** level of support in the evaluation phase are discouraged.
5 **Poor**	The quality of the image still meets the requirements for a morphological evaluation despite clear deficiencies; an evaluation is hardly possible without optimized comparative images. The resolution, sharpness, and illumination show clear deficiencies. The percentage of object overlay and image artifacts is more than 75% but less than 80%. Only large-scale features can be described. Insufficient		
6 **Insufficient**	The quality of the image is completely insufficient for a morphological analysis. The resolution,	Red	Very low quality, insufficient for

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Figure 5. Example of the Protocol – Quality Score. The protocol should be used in conjunction with the PM Morphological Facial Comparison Form for guidance.

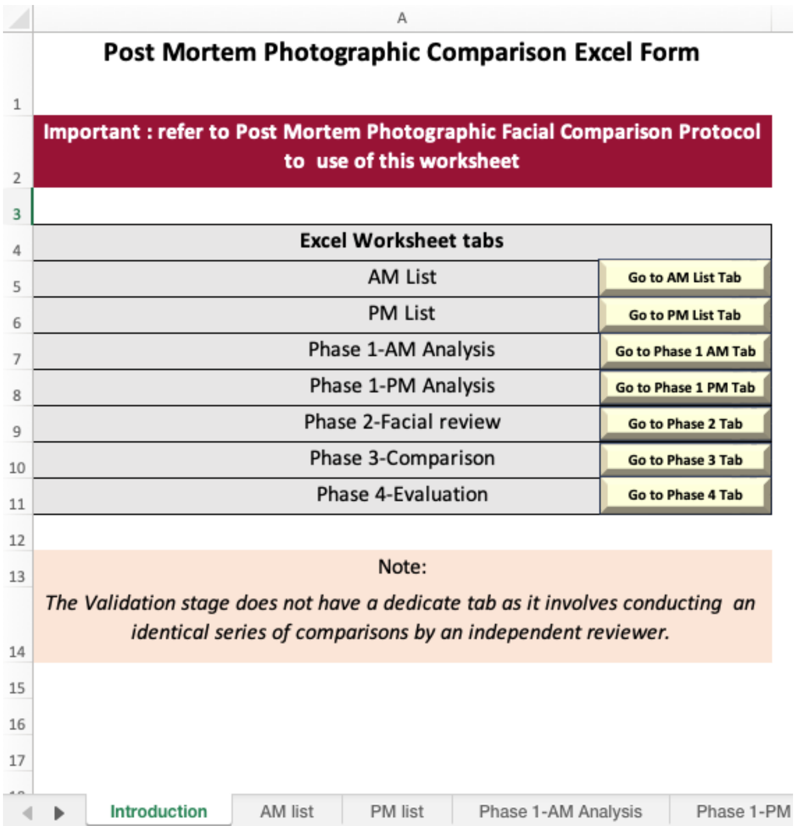
3.2.2 Post-Mortem Photographic Facial Comparison Excel Form

PM Facial Comparison Excel Form is divided into different worksheet tabs:

- Introduction
- AM List
- PM List
- Phase 1-AM Analysis
- Phase 1-PM Analysis
- Phase 2-Facial Review
- Phase 3-Comparison
- Phase 4-Evaluation

Introduction

The Introduction tab states the Excel template is a practical worksheet that should be used with the PM Comparison Protocol. It also includes the various phases required for a complete photographic comparison, with each stage corresponding to a different tab and a button that links it to the right tab. It is also indicated that Phase 5-Verification is a repetition of all phases by another practitioner to validate the results obtained by the previous practitioner on a set of comparisons, there is no specifically designated tab for this phase.



Post Mortem Photographic Comparison Excel Form

Important : refer to Post Mortem Photographic Facial Comparison Protocol to use of this worksheet

Excel Worksheet tabs	
AM List	Go to AM List Tab
PM List	Go to PM List Tab
Phase 1-AM Analysis	Go to Phase 1 AM Tab
Phase 1-PM Analysis	Go to Phase 1 PM Tab
Phase 2-Facial review	Go to Phase 2 Tab
Phase 3-Comparison	Go to Phase 3 Tab
Phase 4-Evaluation	Go to Phase 4 Tab

Note:
The Validation stage does not have a dedicate tab as it involves conducting an identical series of comparisons by an independent reviewer.

Introduction | AM list | PM list | Phase 1-AM Analysis | Phase 1-PM

Figure 6. Introduction tab in the Post Mortem Photographic Comparison Form.

AM List and PM List

The AM list tab (Figure 7) and PM (Figure 8) list tab consist of six columns each, with relevant prompts in row 2. Also, in row 3 there is an example available. To complete this tab, practitioners can refer to the AM List and PM List Section in the Post Mortem Photographic Facial Comparison Protocol (see Appendix A).

AM data of missing individuals are inserted in the AM List tab. Column a.1 is used to enter the unique AM code used for the investigation. In columns a.2, a.3, and a.4 there are drop-down lists to select the most appropriate element to describe the presented gender, skin colour, and estimated age. The option for estimated age should only be chosen for individuals who are very young adults or elderly. Additionally, column a.5 is to insert the total count of available images, along with any pertinent information related to the case in column a.6.

Similarly, information concerning victims is entered in the PM List tab. Column b.1 is for the unique code used for victim identification. Columns b.2, b.3, b.4, and b.5 offer dropdown list selections for entering data about presented gender or known sex, skin colour, estimated age (to be selected only for very young adults or elderly individuals), and number of images available. Column b.6 is intended for adding any relevant details about the victim's case.

	A	B	C	D	E	F
1	a.1 AM CODE	a.2 Presented gender	a.3 Skin colour	a.4 Estimated age **(note if extreme)**	a.5 Images available*	a.6 Notes
2	*Insert unique AM code*	*Select from the drop down list. M (Male); F (Female) I (indeterminate)*	*Select from the drop down list.*	*Select from the drop down list.*	*Insert total number of images available*	*Insert additional information*
3	*AMxx*	*F*	*Light*		*2*	
4						
5						
6						

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review

Figure 7. AM List in the PM Photographic Comparison Form to record information regarding the AM individuals will be used for photographic comparison.

	A	B	C	D	E	F
1	b.1 PM CODE	b.2 Presented gender/sex if known	b.3 Skin colour	b.4 Estimated age **(note if extreme)**	b.5 Images available*	b.6 Notes
2	*Insert unique PM code*	*Select from the drop down list. M (Male); F (Female) I (indeterminate)*	*Select from the drop down list.*	*Select from the drop down list.*	*Insert total number of images available*	*Insert additional information*
3	*PMxx*	*M*	*Light*		10+	
4						
5						
6						

Introduction | AM list | **PM list** | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Pl

Figure 8. PM List in the PM Mortem Photographic Comparison Form to record information regarding the PM subjects will be used for photographic comparison.

Phase 1-AM analysis

Phase 1-AM Analysis tab (Figure 9) encompasses 14 columns dedicated to documenting a range of images and individual characteristics that should be recorded prior to a comparison. An example is illustrated in row number 3, Figure 9. This phase is integral for evaluating the suitability of images for comparison purposes. To complete this tab, practitioners are advised to consult the Phase 1-AM Analysis chapter within the PM Photographic Facial Comparison Protocol, where there are visual references for various image factors and comprehensive explanations on the dropdown list selections.

The set of images of the same missing person needs to be examined independently. The AM case and image code should be recorded in columns 1.1 and 1.2, respectively. Details about the head's angle, camera-subject distance, and image capture location should be chosen from the dropdown lists available in columns 1.3, 1.4, and 1.5.

Columns 1.6 and 1.7 are designated for brief descriptions of skin marks, scars, tattoos, or any other facial alterations, as prompted in the relevant sections.

Columns 1.8 through 1.13 refer to diverse image factors and relevant drop-down list selections: photographic distortions, light exposure, noise, image alterations, distractions (e.g., hair covering the face), and facial expression.

Column 1.14 is for the selection of the analysed image Quality Score. This score can be chosen from the dropdown list. Upon selecting the relevant score, the box changes colour to green, yellow, or red, indicating varying levels of suitability for comparison in accordance with the protocol guidelines. Any additional information should be added as text in column 1.15.

1.1 AM case	1.2 IMG file	1.3.Head angle	1.4 Camera Shot	1.5 Source of the picture	1.6 Facial marks		1.7 Facial alterations		1.8 Presence of photographic distortions	1.9 Light Exposure	1.10 Noise	1.11 Image alteration	1.12 Distractions	1.13 Expression	1.14 Quality Score	1.15 Notes
Insert AM case number	*Insert file name*	*Select from the drop down list.*	*Select from the drop down list.*	*Select from the drop down list.*	*Describe visible skin marks*	*Describe scar/s*	*Describe any facial or neck tattoo/s*	*Describe any piercing/s*		*Select from the drop down list: 1.Well exposed 2. Slightly over or underexposed 3. Over or underexposed*	*Select from the drop down list: 1.No noise 2. Medium noise level 3. High noise level*	*Select from the drop down list.*	*Select from the drop down list.*	*Select from the drop down list.*	Select from the drop down list. **green**=suitable quality **orange**=caution during comparison **red**=caution during comparison, no small scale features	
AMxx	*Photoxx*	*Frontal (F)*	*Medium Full Shot (MFS)*	*Digital File (DF)*					*No*	*1*	*1*	*Yes (Colour correction)*	*Scarf*	*Neutral (teeth)*	5	

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Phase 3-Comparison | Phase 4-Evaluation | +

Figure 9. Phase 1-AM Analysis in the Post Mortem Photographic Comparison Form to record information regarding the image factors that are observed in the AM images. Also, this section is used to make notes of facial identifiers such as moles, scars or alterations that might be used later for identification.

Phase 1-PM analysis

The Phase 1-PM Analysis tab (Figure 10) includes 17 columns primarily focused on documenting visible PM changes in PM subjects. For an example of how the tab appears when populated with relevant information, see row 3, Figure 10. This phase helps to assess the visibility and preservation of facial features in the PM images. To effectively complete this tab, practitioners are encouraged to refer to the Phase 1-PM Analysis chapter in the PM Photographic Facial Comparison Protocol. This chapter contains comprehensive explanations of every selection.

Columns 1.16 and 1.17 are respectively reserved for recording the PM case and the number of images available. If there are images with visible dentition, the number of images should be entered in column 1.18, while the location in which the images were taken should be selected from the dropdown list options in column 1.19.

Columns 1.20 and 1.21 serve as spaces for providing brief descriptions of skin marks, scars, tattoos, or any other facial alterations.

Columns 1.22 through 1.25 are intended to document various PM changes observable in the deceased individual. Each selection is associated with a dropdown list, except for 1.23 where a brief description should be added if facial bloating is observed.

Column 1.26 doesn't require any selection or text entry. It will automatically generate a numerical decomposition score (1 to 13), based on the selection made in column 1.22 Decomposition changes. Additionally, the box will change colour to green, yellow, or red, to visually indicate if the score refers to early (green), medium (yellow) or advanced (red) decomposition stages - in line with the protocol guidelines. Any additional information can be added as text in column 1.27.

1.16 PM Code	1.17 Tot number of images	1.18 Teeth images	1.19 Location	1.20 Facial Marks	1.21 Facial Alterations			1.22 Decomposition changes (from Megysei, Nawrocki, Haskell 2005)	1.23 Bloating	1.24 Trauma	1.25 Obscuring matter (clothes/blood etc..)	1.26 Decomposition Score	1.27 Notes
Insert unique PM code	*Insert total number of images available*	*Insert number of images showing teeth*	*Select from the drop down list.*	*Describe visible skin marks*	*Describe scar/s*	*Describe any facial or neck tattoo/s*	*Describe any piercing/s*	*Select from the drop down list.*		*Select from the drop down list.*	*Select from the drop down list.*		
PMxx	*5*	*1*		*Multiple big mole near L ear and L cheek, L nose near alae, moles on forehead*			*R and L lobe piercings; nostril piercing*	A1		*No*	*No*	1	
												0	
												0	
												0	
												0	
												0	

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Phase 3-Comparison | Phase 4-Evaluation | +

Figure 10. Phase 1-PM Analysis in the Post Mortem Photographic Comparison Form helps to record information regarding the PM changes observed in the PM images. Also, this section is used to make notes of facial identifiers such as moles, scars or alterations that might be used later for identification or the presence of teeth images that might be helpful for identification.

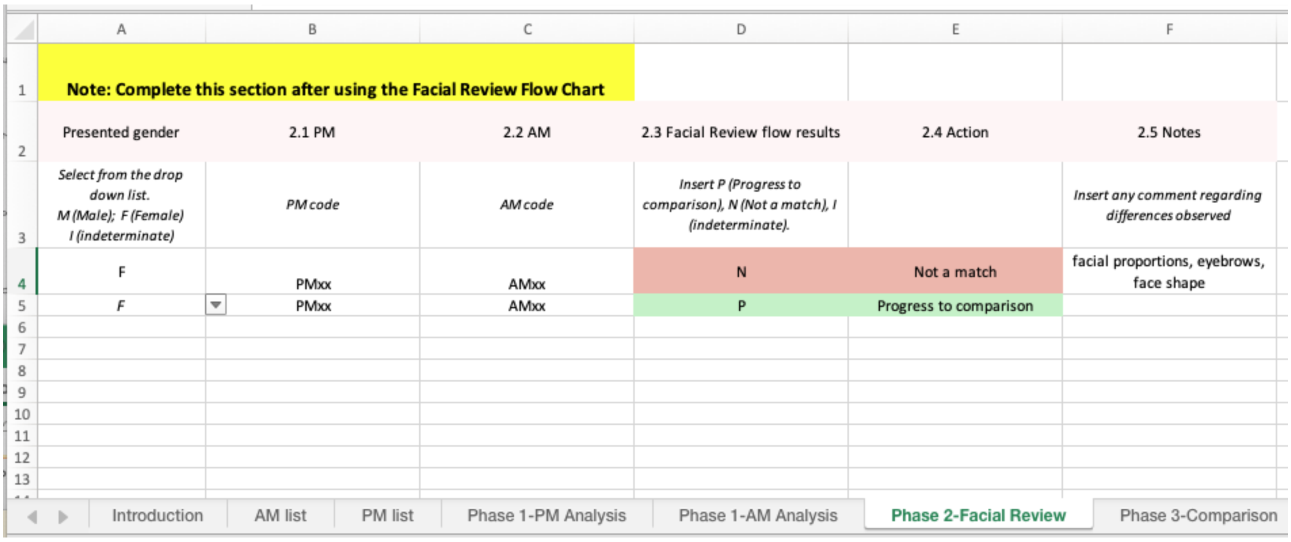
Phase 2-Facial Review

The Phase 2-Facial Review tab (Figure 11) comprises 6 columns designated to record the AM-PM pair and the relative outcomes obtained from the Facial Review Flow Chart, available in the Post Mortem Photographic Comparison Protocol.

Details of the gender, along with PM and AM case identifier codes, need to be inter in columns 2.1 and 2.2. Evaluate if the two individuals could be a match by looking at the flow chart. Insert the results obtained by selecting “N”, “I”, and “P” from the dropdown list in 2.3. If the results obtained after consulting the flowchart is "Possible match," select "P." For results indicating "Indeterminate," choose "I," while for "Not a match," choose "N" from the.

Upon selecting the appropriate response in 2.3, column 2.4 will then provide either "Not a match" or "Progress to comparison."

In cases where the AM-PM comparison is not a match, column 2.5 (Notes) should be utilised to report the observed differences.



	A	B	C	D	E	F
1	**Note: Complete this section after using the Facial Review Flow Chart**					
2	Presented gender	2.1 PM	2.2 AM	2.3 Facial Review flow results	2.4 Action	2.5 Notes
3	*Select from the drop down list. M (Male); F (Female) I (indeterminate)*	*PM code*	*AM code*	*Insert P (Progress to comparison), N (Not a match), I (indeterminate).*		*Insert any comment regarding differences observed*
4	F	PMxx	AMxx	N	Not a match	facial proportions, eyebrows, face shape
5	F	PMxx	AMxx	P	Progress to comparison	

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Phase 3-Comparison

Figure 11. Phase 2-Facial Review of the PM Mortem Photographic Comparison Form is dedicated to recording the outcomes of the *Facial Review Flowchart* in the PM Mortem Photographic Comparison Protocol. This phase helps to eliminate evident non-matches and determine cases that necessitate a more thorough comparison (Phase 3).

Phase 3-Comparison

Phase 3-Comparison (Figure 12) consists of 19 columns where practitioners should insert, from columns 3.3 to 3.15, a brief description and comments based on judgement of similarities and differences observed in the facial features. The analysis of each feature should be carried out in a descriptive way, following the guidelines of FISWG (2018).

To express whether the observed images belong to the same individuals, practitioners should use the levels of support outlined in Column 3.17. For detailed information on these support levels, refer to the PM Photographic Comparison Protocol. In cases where difficulties arise during the comparison process (e.g. due to poor image quality or PM changes), this should be documented by selecting the appropriate factor in column 3.16. Also, any particularly valuable identifying features used to decide on the level of support or any additional notes pertinent to the case should be respectively inserted in columns 3.17 and 3.18.
Refer to the example provided in row 3 of Figure 12 to see how each column should appear once it has been filled.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	3.1 PM	3.2 AM	3.3 Facial mark	3.4 Facial alterations (Scars, tattoos, piercings)	3.5 Face shape/outline	3.6 Hairline/ Forehead	3.7 Eyes	3.8 Cheeks	3.9 Eyebrows	3.10 Nose	3.11 Ears	3.12 Mouth	3.13 Chin and Jawline	3.14 Facial Hair	3.15 Facial Lines	3.16 Rationale for difficult comparison	3.17 Level of Support	3.18 Identifying features	3.19 Notes
2	*Insert unique PM code*	*Insert unique AM code*	*Insert feature description*													*Select the appropriate factor from the drop-down list*	*Select the relevant level of support from the drop-down list*	*Insert the identifying indicator (e.g teeth, moles etc..)*	
3	PMxx	*AMxx*	*similar pock mark on left side of forehead. similar marks at root of nose*	*none*	*similar*	*similar*	*simialr infraorbital crease and lower lid bags*	*consistent*	*similar shape and density*	*consistent in total*	*consistent*	*similr upper lip cupids bow.*	*similar small prominent chin and sagging jowls*	*n/a*	*similar NLCs and marionette lines, similar forehead creases*	PM changes	Moderate Support	marks and creases, lip and nose shape	
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Phase 3-Comparison | Phase 4-Evaluation | +

Figure 12. Phase 3-Comparison in the PM Mortem Photographic Comparison Form is used to document the comparison AM-PM task. The analysis of each feature is done by following the FISWG (2018) feature lists and for each features a brief description of similarities and difference observed between AM and PM should be provided.

Phase 4-Evaluation (Summary)

Phase 4-Evaluation tab (Figure 13) is interlinked with Phase 3-Comparison, displaying the analysed AM and PM pair of Phase 3, alongside the chosen Level of Support and the Identifying Feature that contributed to determining the level of support.

	A	B	C	D	E
1	3.1 PM	3.2 AM	3.17 Level of Support	3.18 Identifying features	
2	Hiperlink created with the Phase 3-Comparison Tab. Values will be automatically be copied here.				
3	PMxx	AMxx	Moderate Support	marks and creases, lip and nose shape	
4	0	0	0	0	
5	0	0	0	0	
6	0	0	0	0	
7	0	0	0	0	
8	0	0	0	0	
9	0	0	0	0	
10	0	0	0	0	
11	0	0	0	0	
12	0	0	0	0	
13	0	0	0	0	
14	0	0	0	0	
15	0	0	0	0	

Introduction | AM list | PM list | Phase 1-PM Analysis | Phase 1-AM Analysis | Phase 2-Facial Review | Phase 3-Comparison

Figure 13. Phase 4-Evaluation in the PM Mortem Photographic Comparison Form visually reports the level of support expressed for cases analysed Phase 3 comparison.

3.3 Post-mortem morphological facial comparison study

The blind study included a total of twenty-nine identified deceased subjects who had undergone routine PM examinations with presented AM and PM images.

The subjects were chosen from a database of forensic identification cases from 2001 to 2020 at the University of Milan, available at the Laboratory of Forensic Anthropology and Odontology (LABANOF), Section of Legal Medicine. The images were acquired as part of forensic judicial investigations and in accordance with the Italian Police Mortuary Regulation. To protect the identity of the individuals depicted in the images, the photographic material was not associated with any personal information, including name, date of birth, circumstances of death, pathologies associated and only facial images were made available for the research.

The supervisory team selected subjects for the blind study who met the following criteria:

- Over 18 years of age.
- At least one AM and PM image is available.
- Severely decomposed remains, including skeletonised, mummified, or commingled remains, were excluded as they would not have been considered suitable for facial comparison in forensic cases.

The supervisory team also anonymised the data using alphanumeric code for each subject.

To simulate a real-life mass disaster scenario, the digital images associated with each subject were not modified as they reflect the unstandardised or "wildtype" photographs that are usually collected both during PM examination and AM evidence from relatives, social media or personal devices. Therefore, the images of the subjects were characterised by various resolutions, lighting, head orientations, presence of facial hair, and age of the depicted person.

The images were divided and organised in folders, as follows:

- **AM folder** - included 29 subfolders, each corresponding to one of the 29 subjects, and contained at least one but up to ten AM images of each person. Each subfolder contained images from only one subject. Each subject received a numeric identifier code.
- **PM folder** - included 29 subfolders, each corresponding to one of the 29 subjects, and contained at least one but up to twenty-one PM images taken during medical examinations or the recovery of the body. Each subfolder contained images from only one subject. Each subject was assigned a unique identifier code made of a single or a combination of letters.

The data from the three observers obtained on the same comparisons was tabled in Microsoft® Excel 2016 and analysed using SPSSv28 (SPSS Inc, 2006) using descriptive analysis.

Inter-observer study

The inter-observer test was conducted in May 2023 to assess the reliability of morphological photographic comparison when carried out by different practitioners. Two experienced practitioners (+2 years of experience), who were part of the supervisory team that did not know the actual matchings, were selected.

The observers carried out a blind comparison of 15 AM and PM pairs and selected a randomised stratified proportionate sampling from the main pool of 72 AM and PM pairs.

The observers were provided with the necessary Microsoft® Excel Forms and guided protocols developed for this research. They were required to carry out the photographic facial comparison for each of the 15 pairs documenting similarities and differences and expressing the level of support using a 5-point ordinal scale (see 1.5.5), as per protocol.

The level of support expressed by each was tabled in SPSSv28 (SPSS Inc, 2006) and the results of the three observers were analysed using descriptive statistics, including calculation of accuracy rate and false and true positive and negatives (Altman and Bland, 1994). Also, the inter-observer reliability was calculated using the Interclass Correlation Coefficient (ICC) for the absolute agreement (Shrout and Fleiss, 1979) while Kendall's Coefficient (W) was used to determine the degree of agreement among observers (Shrout and Fleiss, 1979).

4. RESULTS

This chapter reports the results of the main comparison study and the interobserver test. It is organised as follows:

- General characteristics of the sample
- Main study results
- Inter-observer study results

4.1 General characteristics of the sample

A total of 29 AM subjects and 29 PM subjects were used as a pool for this study. Each subject had a variable number of images. The main comparison study and inter-observer test were conducted by following the protocol and Excel form outlined in the Methodology Chapter 3 (also see Appendices A and B). As part of the comparison procedure, the images were initially analysed considering various factors, such as gender, skin colour, quality of the images, and decomposition stages.

4.1.1 Demographic

In the AM sample, there were 12 female subjects (41%), and 17 male subjects (59%). In the PM sample, the presented gender was noted as 11 females (38%) and 17 males (59%), with one subject in the PM sample classified as indeterminate gender (3%) (Table 8).

In both the AM and PM samples, 15 subjects were categorised as having light skin (52%), and 14 subjects with dark skin (48%) (Table 8).

Also, as part of the analysis of the sample, it was calculated the total number of AM images for each subject (Figure 14). The majority of the subjects presented between 1 (8/29) and 2 (7/29) images available for comparison.

Table 8. Summary of the characteristics attributed to the sample before performing the comparison. Presented gender and skin colour expressed as frequency (n) and percentages (%).

	AM subjects	PM subjetcs
Presented gender	n (%)	n (%)
Female	12 (41%)	11 (38%)
Male	17 (59%)	17 (59%)
Indeterminate	/	1 (3%)
Skin colour	n (%)	n (%)
Light skin	15 (52%)	15 (52%)
Dark skin	14 (48%)	14 (48%)

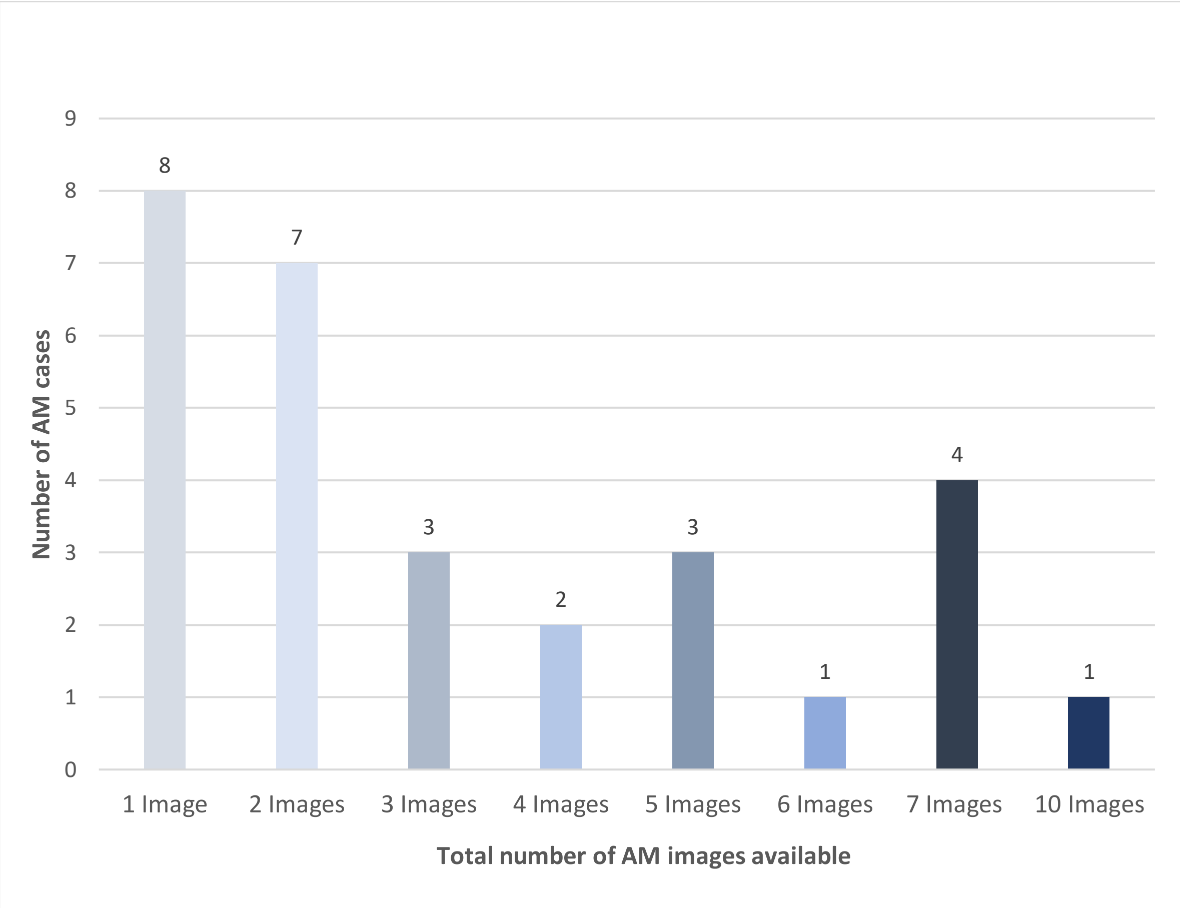


Figure 14. Number of AM cases with the relative number of AM images available for comparison.

4.1.2 Image quality scores of the AM subjects

The image quality score was previously introduced in the Methodology Chapter 3 as part of the AM Analysis section in the Protocol and Form. The image quality score constitutes one of the most relevant factors assessed during the Phase 1 AM Analysis and it helps score the quality of images for morphological comparison. The complete image factor analysis of each AM image carried out for Phase 1 AM Analysis can be found in Appendix C.

The scale is qualitative and ranges from 1 to 6. The lower end of the scale (1) represents the highest quality, indicating images with ideal quality for morphological comparison and visible facial details. The higher end of the scale (6) represents the lowest quality where the requirements for image comparison are not met and clear facial details are no longer observable (Figure 14).

To simplify the analysis, the image quality scores were categorised as follows:

- **1, 2, 3**: These scores indicate acceptable image quality, where both small and large facial details are visible.
- **4, 5**: These scores indicate lower-quality images with restricted visibility of the features.
- **6**: This score indicates very low image quality, not ideal for morphological comparison due to limited visibility of facial details.

51% of the images exhibit moderate quality (scores between 4-5), while higher quality images account for 34% of the total number of AM images included in the study. Additionally, images with very low quality, characterised by limited visibility of facial details, constitute 15% (Figure 15).

Additionally, given the importance of social media for image collection and the widespread use of camera and smartphone filters, it was calculated the number of images presenting specific types of image modifications, such as photo retouching or colour corrections (Figure 16). It was noted that photo-retouching was the most common alteration among all images, with 15 of the total AM images presenting this type of post-production correction.

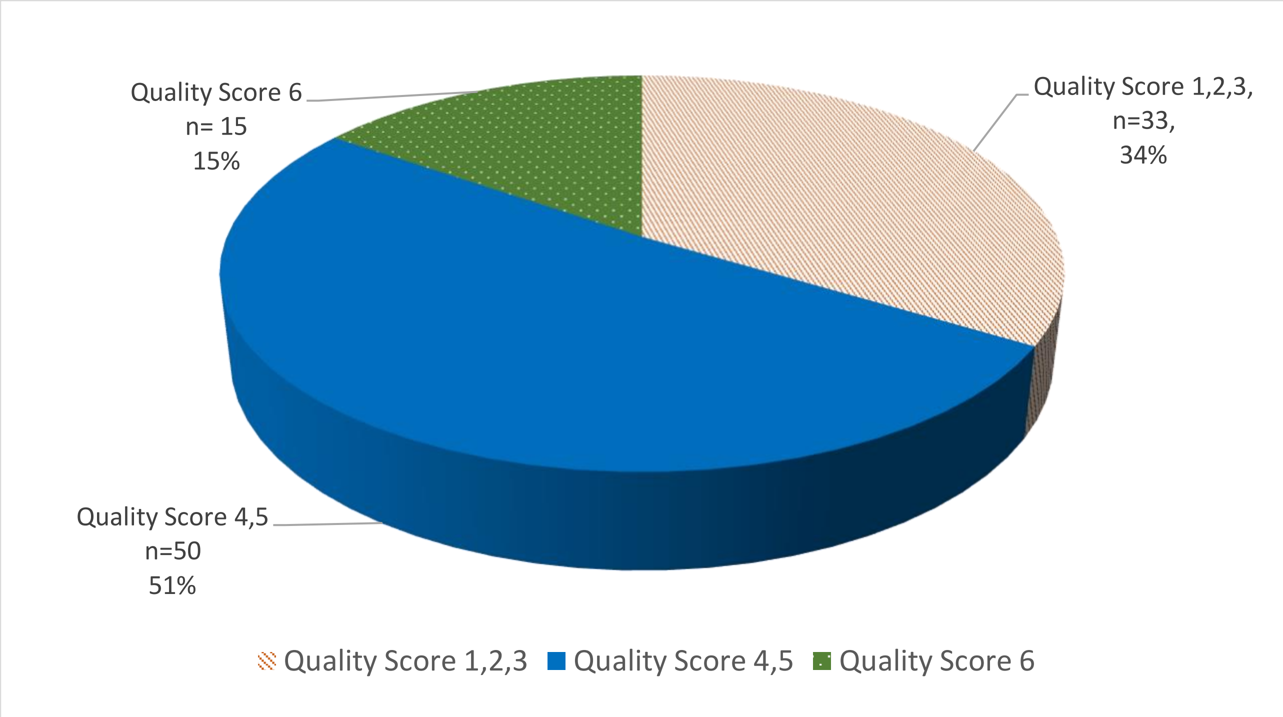


Figure 15. Total number of AM images divided into different Image Quality Score ranges. The quality score between 1-3 includes images with higher quality and visible facial details; the score between 4 and 5 represents images that still have acceptable quality for photographic comparison but the visibility of facial features might be restricted; the score 6 represents the worst quality that can be attributed to an image with very limited visibility of facial features.

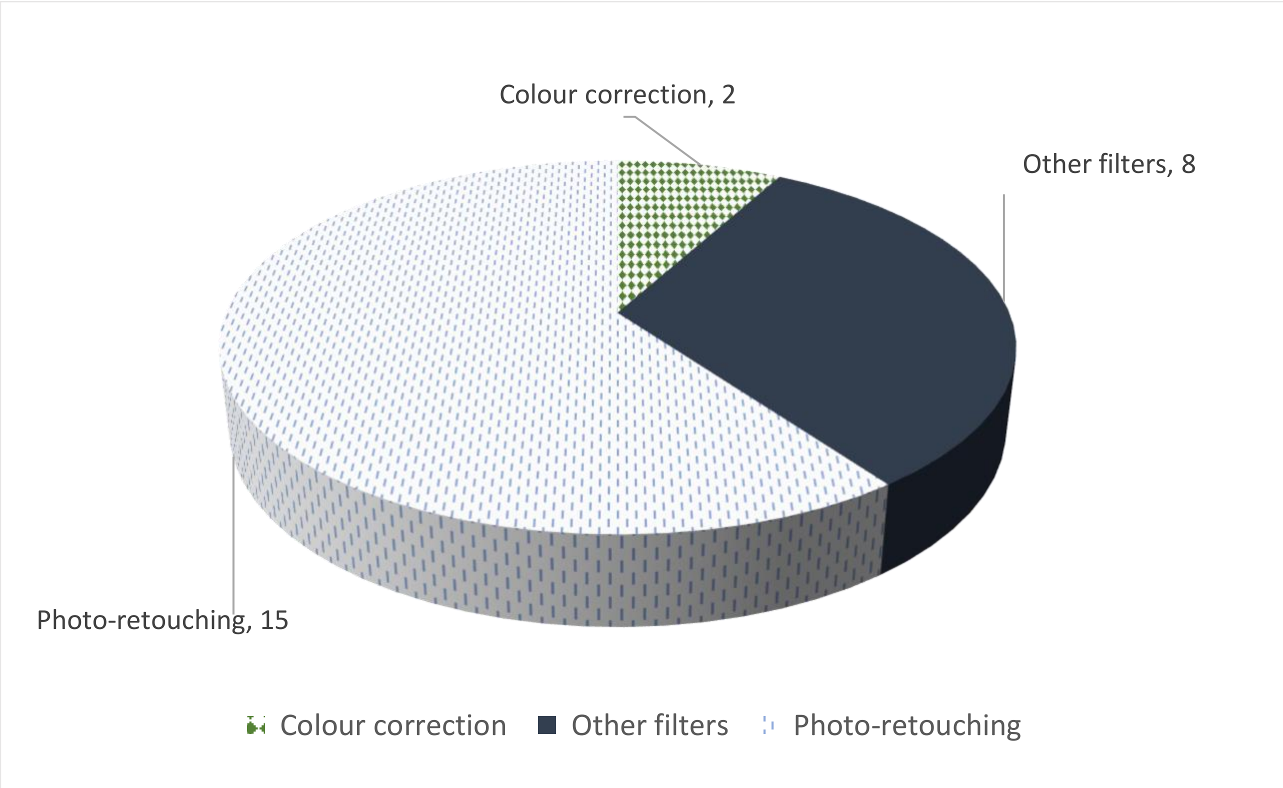


Figure 16. The number of images showing image alteration.

4.1.3 Decomposition scores of the PM subjects

The decomposition scores assigned to each PM subject help to define the level of preservation of the facial feature after death. The score is in a progressive order where the lower end of the decomposition scale starts with A1 indicating fresh deceased subjects with no PM changes affecting the face and ends with D4 for dry, skeletonised individuals where soft tissue and facial features are no longer recognisable. More than 75% of the subjects were assigned an A1(1) score, indicating that most of the PM subjects showed a high degree of facial preservation (Table 9).

Table 9. Decomposition Scores attributed to PM images during the Phase 1 PM analysis.

Decomposition Levels (Decomposition Scores)[a]	PM subjects	
	n	%
A1 (1)	22	75.9%
B1 (2)	2	6.9%
B2 (3)	3	10.3%
B3 (4)	1	3.4%
B5 (6)	1	3.4%

[a](from Megysei, Nawrocki, Haskell 2005)

4.1.4 Identifying features

Phase 3 Comparison includes a section where the practitioner carrying out the comparison can insert and highlight the identifying features considered most useful for supporting a match. Figure 17 displays the frequency at which specific features were recorded when deciding on a positive identification. In certain cases, multiple features were selected to support a single case.

The bar chart in Figure 18 summarises the number of times each feature was mentioned for each level of support when the identification was correct. It shows that facial marks were the feature mentioned the most, followed by ears, scars, teeth and piercings.

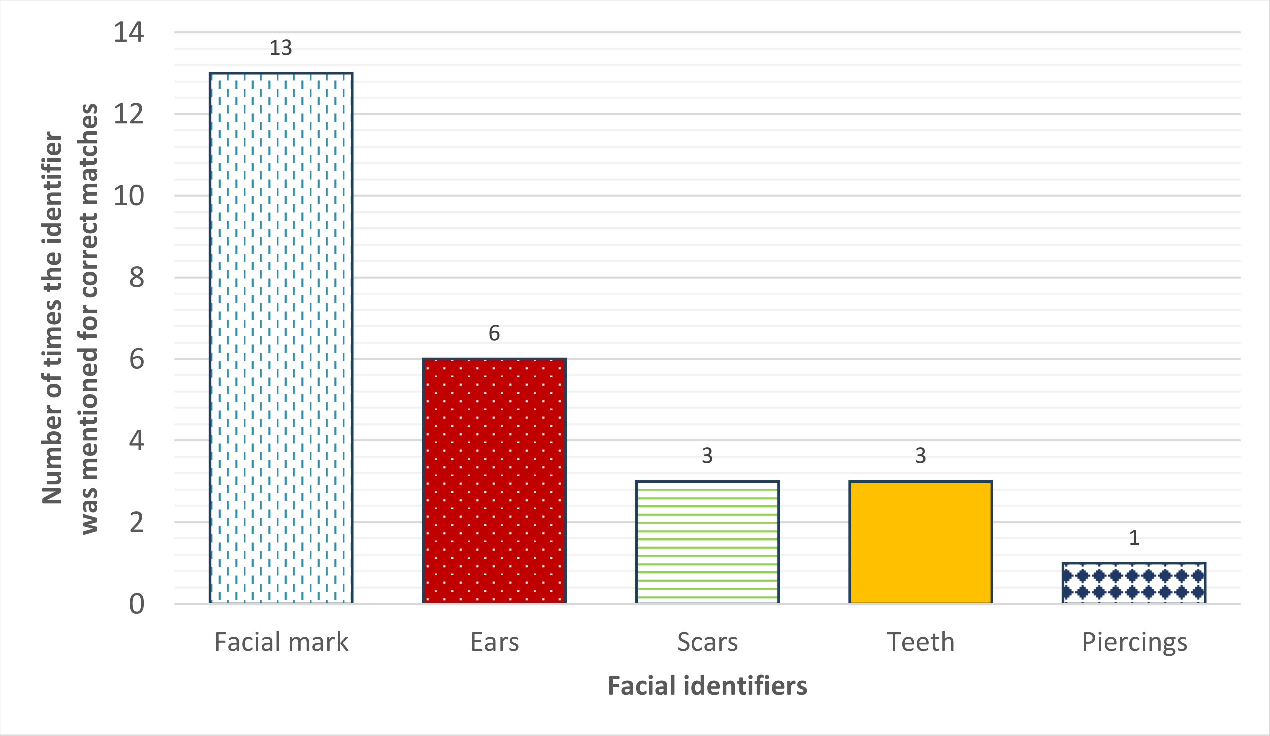


Figure 17. Frequency of occurrences of the identifying features to positively support correct AM-PM matches.

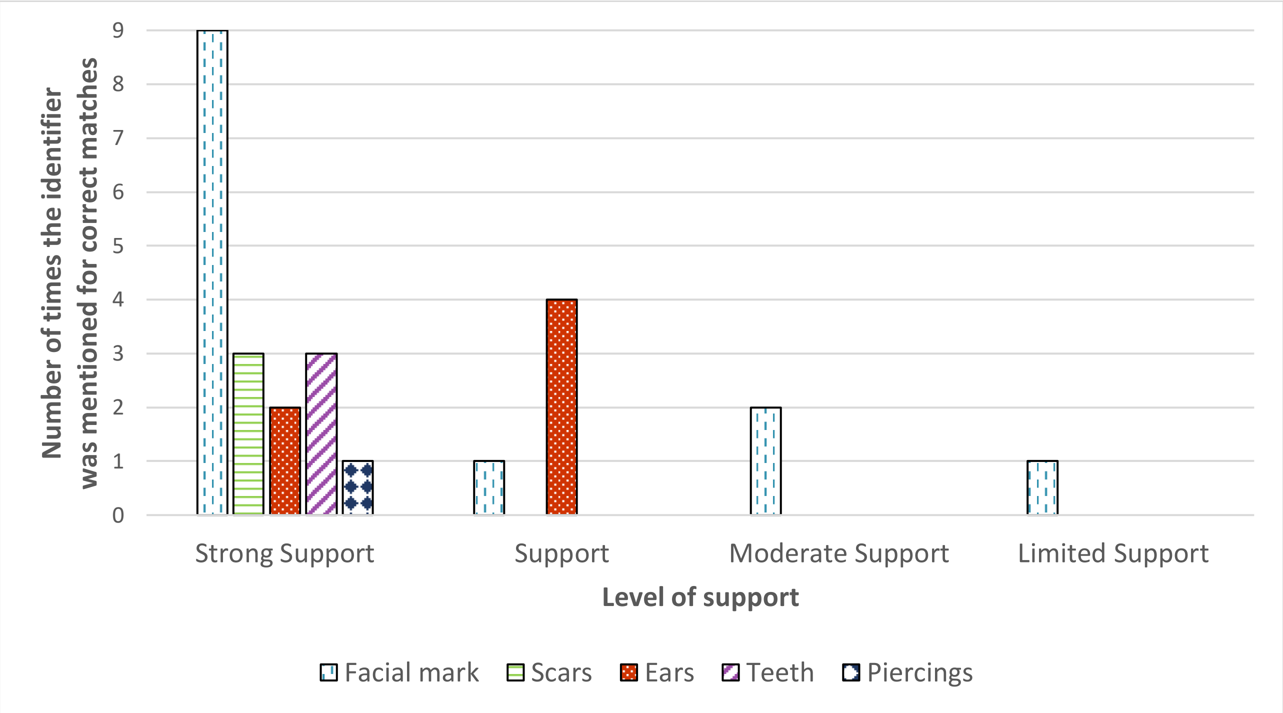


Figure 18. Frequency of occurrences of the identifying features used to positively support correct AM-PM matches and their distribution across different levels of supports.

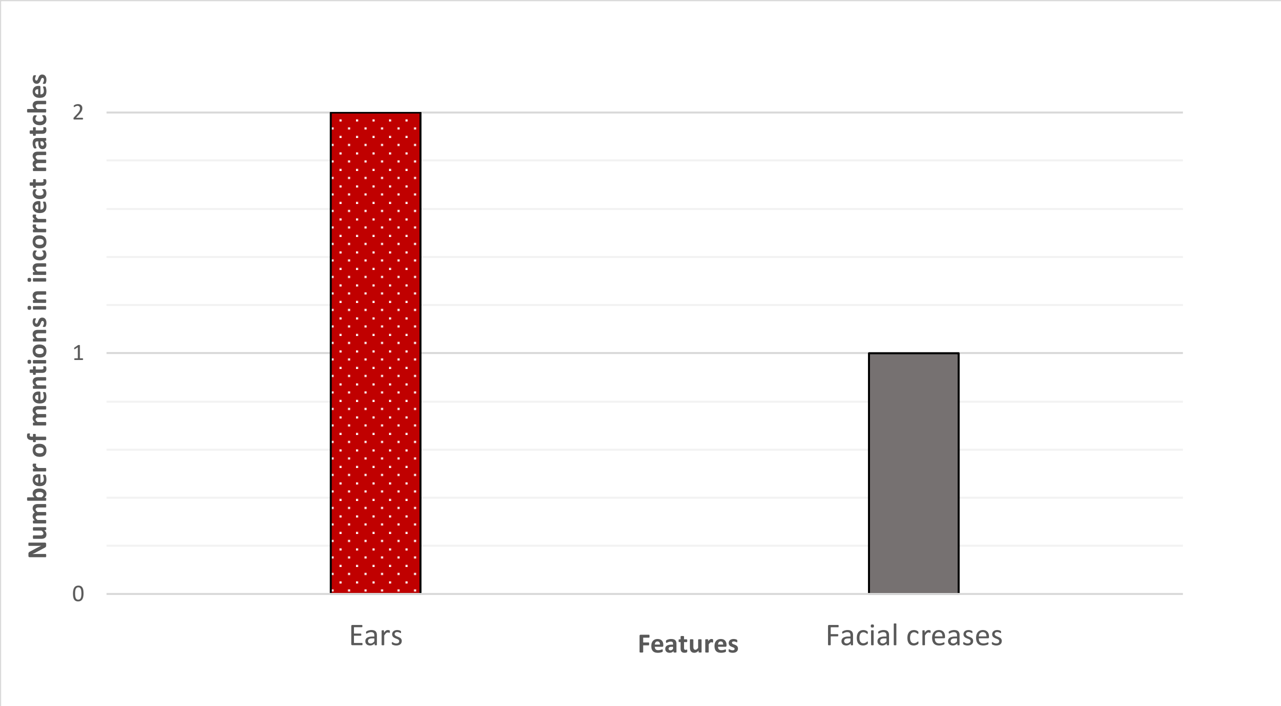


Figure 19. Frequency of occurrences of the identifying features used to express positive support for the 2 incorrectly identified cases.

Data from Figure 18 reveals that the recorded features are categorised into different levels of support, highlighting how facial marks were predominantly noted when "Strong Support" was recorded, and exclusively in cases of "Moderate" and "Limited Support". On the other hand, ears were exclusively noted when 'Support' and 'Strong Support' were provided. Furthermore, Teeth and Scars were noted solely when 'Strong Support' was recorded.

When positive support was expressed incorrectly, the most used features to support the identification were the ears followed by facial creases (Figure 19).

4.2 Main study results

The following section presents the results of the main facial comparison blind study (See Appendix C) which is presented in Table 10, with a summary of the 71 AM-PM comparison cases carried out. The AM-PM pairs were filtered after Phase 2 Facial Review, where only AM-PM pairs that presented overall similarities were selected for a complete comparison analysis. Table 10 also shows the level of support provided for each pair based on the scale adapted from Moreton (2021), as well as the AM target relative to the PM subject.

Table 10. Results of the photographic morphological comparison of the AM-PM pairs selected after Phase 2 Facial Review.

PM	AM selected after Facial Review and compared to PM[a]	Level of Support[b]	AM target
A	8	No Support	14
	14	Moderate Support	
	4	No Support	
AA	12	No Support	27
	27	Strong Support	
	28	No Support	
AB	3	Limited Support	29
	29	Limited Support	
	23	Moderate Support	
AZ	28	Strong Support	28
BS	6	No Support	10
	18	No Support	
	10	Moderate Support	
	1	Limited Support	
	4	No Support	
C	21	Limited Support	21
DS	17	Support	17
E	29	No Support	3
	3	Support	
F	3	No Support	15
	7	No Support	
	15	Moderate Support	
G	12	Support	12
	27	No Support	
	28	No Support	
H	19	Limited Support	19
I	11	Strong Support	11
JO	22	Support	22
K	15	No Support	23
	7	No Support	
	19	Limited Support	
	23	No Support	
L	25	Strong Support	25
M	19	No Support	7
	7	Strong Support	
N	9	No Support	5
	24	No Support	
	5	Strong Support	

O	16	Limited Support	20
	20	Support	
P	24	Support	24
	9	Limited Support	
QM	10	No Support	4
	1	No Support	
	2	No Support	
	4	Support	
R	24	No Support	16
	9	No Support	
	16	Moderate Support	
S	10	No Support	2
	2	Support	
	4	No Support	
	6	No Support	
T	14	Limited Support	18
	18	Strong Support	
U	10	No Support	6
	1	Moderate Support	
	2	No Support	
	6	Strong Support	
V	13	Strong Support	13
	2	No Support	
W	18	No Support	1
	10	Limited Support	
X	14	No Support	8
	1	No Support	
	8	Strong Support	
YT	5	No Support	9
	20	No Support	
	24	No Support	
	9	Moderate Support	
Z	26	Strong Support	26

[a]the PM cases incorrectly identified are highlighted in light blue ; the PM cases were matched to multiple AM are highlighted in orange. [b]In red is highilighted "No Support", while green indicated a positive level of support (Strong Support or Support) and in yellow an inconclusive level of support (Moderate and Limited Support).

4.2.1 Descriptive Statistics

The descriptive analysis of the results was carried out adopting a lenient accordance, meaning that if the matching AM-PM received “Strong Support”, “Support”, “Moderate Support” or “Limited Support” it was considered a correct match. On the contrary, an incorrect match was when “No Support” was expressed for the matching AM-PM pairs.

The true and false positive and negative rates were calculated, together with the overall accuracy rate. The accuracy was calculated with the following formula (Altman and Bland, 1994):

Accuracy rate = (True Positive True Negative)/(True Positive + True Negatives + False positives + False Negatives).

In the main study the practitioner correctly excluded the subjects in 34 out of the 35 non-match cases and only in 1 case there was an incorrect exclusion of the target AM. Also, in 9 cases out of 36 true matches, the practitioner expressed an incorrect identification, supporting the matching of a PM subject with a non-target AM subject. For the remaining 27 true matches, the practitioner performed a correct identification, providing a level of support for the target AM subject.

From these results, it was calculated that the true negative rate (TNR), also called specificity, was at 97% and the true positive rate (TPR) was 75%. Also, the false negative rate (FNR) was 2.9% and the false positive rate (FNR) was 25%, with an overall accuracy rate of 85.9%.

Table 11. Descriptive stats for matching AM and PM subjects for the practitioner in the main study.

		Actual condition		Total matches
		Not a match	True Match	
Predicted by the practitioner	No Support	34 (TNR[b] 97.1%)	1 (FNR[c] 2.9%)	35 (100%)
	Positive Support (SS, S, MS, LS)[a]	9 (FPR[d] 25.0%)	27 (TPR[e] 75.0%)	36 (100%)
Total matches		43 (60.6%)	28 (39.4%)	71 (100%)
Accuracy Rate[f]		85.9%		

[a]SS=Strong Support; S=Support; MS=Moderate Support and LS=Limited Support
[b]True Negative Rate, [c]False Negative Rate, [d]False Positive Rate, [e]True Positive Rate
[f]Accuracy rate = [(True Positive +True Negative)/(True Positive + True Negatives + False positives + False Negatives)]* 100 (Altman and Bland, 1994)

4.2.2 Strict and Lenient accordance

Strict and lenient accordance were calculated in the following ways:

- **Strict Accordance**: a correct identification is when the PM subject is only matched to the AM target image and no support is expressed for other AM subjects.

- **Lenient Accordance**: a correct match is when a positive level of support is given to the AM target or the AM target along with other AM subjects.

Under strict accordance, there were 21 correct matches and 8 incorrect matches, meaning that 9 PM subjects were correctly matched to only the AM target (Table 12). The 8 incorrect matches included 2 PM subjects that were incorrectly matched to an AM subject and 6 PM subjects where multiple potential matches were recorded, including the target (Table 13). Under lenient accordance 27 PM subjects were correctly matched to the AM target and 2 PM subjects were incorrectly matched to non-target subjects (Tables 12 and 14).

Table 12. Summary table of correct and incorrect matches analysed using strict accordance and lenient accordance.

	Strict Accordance		**Lenient Accordance**	
	n	*%*	*n*	*%*
Correct matches	21	72%	27	93%
Incorrect matches	8	28%	2	7%

Table 13. Analysis of correct and incorrect matches using strict accordance. Strict accordance is established by considering matches as correct solely when any level of support other than "No Support" is indicated exclusively for the AM target.

Strict Accordance			
		n	*%*
Correct matches 21 (72%)	Strong support or Support was expressed only for the AM target	15	51%
	Moderate support or Limited Support was expressed only for the AM target	6	21%
Incorrect matches 8 (28%)	PM subjects had multiple AM potential matches	6	21%
	PM Incorrectly matched	2	7%

Table 14. Analysis of correct and incorrect matches using lenient accordance. Lenient accordance is determined by considering matches as correct if there is any level of support other than "No Support," even when support is indicated for both the AM target and other AM subjects.

Lenient Accordance			
		n	*%*
Correct matches 27 (93%)	Support to AM target	19	66%
	Support to the AM target, but also to other AM subjects	8	28%
Incorrect matches 2 (7%)	PM Incorrectly matched	2	7%

Furthermore, of the total of 27 correct identifications made by the practitioner under lenient accordance, 15 matches were given a high positive level of support with only one AM subject being selected as the potential target. However, in 4 matches, despite the high level of support expressed for the AM target, other AM subjects were also considered potential matches.
In 6 cases, the AM target was the sole match, but a lower level of support was expressed, either as "Moderate" or "Limited Support". Additionally, in 2 cases, multiple AM subjects were recorded, with the correct match receiving “Moderate” or “Limited support”.

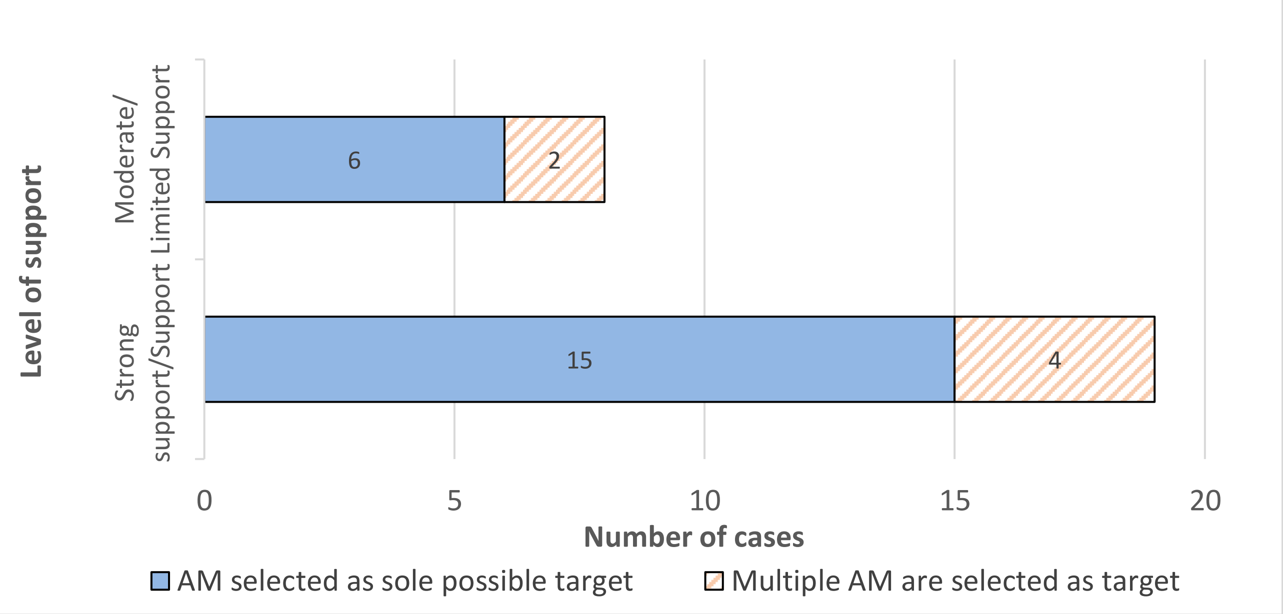


Figure 20. The total number of correct identifications (27 correct matches - as per lenient accordance) expressed by the practitioner divided by the levels of support expressed. Additionally, it presents the number of cases where a positive level of support was expressed for other AM subjects apart from the target AM.

4.2.3 Incorrect identification

In 2 cases K(PM) and W(PM), highlighted in light blue in Table 10 at the beginning of Section 4.2, the PM subjects were incorrectly matched with non-target AM subjects.

Subject W

The comparison documentation analysis carried out for case W is shown in Table 15.
The true match of subject W (PM) is subject 1 (AM) and this was not selected during Phase 2 as a potential match. In Phase 2 of the Excel work document, the decision to not progress with subject 1 was justified by the observation of a "Mole, chin" discrepancy. This means that the mole that was visible in PM was not present in the AM image, and there was also a noticeable difference in the shape of the chin between the two images. Also, the PM presented a crux tattoo on the forehead that was not visible in the AM, however this was not considered an exclusion criteria as the tattoo in the

PM could have been done after the AM pictures were taken. The observed differences in the appearance of the mole, chin shape and general facial led to the conclusion that subject 1 should not be considered as a potential match.

In addition, the quality of the images available was very low and the images were also affected by alteration so that small-scale features were not observable.

Instead, two other AM subjects (18 and 10) were considered to have some likeness to progress onto the more extensive morphological comparison of Phase 3. No support was recorded for case 18 and "Limited support" was given to case 10.

Subject K

Subject K (PM) and subject 23 (AM) were a match. AM 23 was selected during Phase 2 as a possible match, along with 3 other cases (Table 16). However, no level of support for the correct match was recorded in the evaluation phase. Instead, limited support was given for AM 19. The absence of comparable facial marks and the presence of only one image, scored 5, for subject 23 might explain why this image was excluded.

Table 15. Copy of the Phase 3-Comparison (Post Mortem Morphological Facial Comparison Form) that was filled out for the W-10 and W-18 comparison conducted in the Main Study.

3.1 PM – AM Comparison	**W - 10**	**W - 18**
3.3 Facial mark	Mole left chin below lower lip not in AM, but there is a mark on AM on chin, not well visible	Different
3.4 Facial alterations (Scars, tattoos, piercings)	Crux tattoos in PM, not in AM could be that AM images are prior to tattoo	Different
3.5 Face shape/outline	Similar facial shape	Some similarities
3.6 Hairline/ Forehead	similar	Different
3.7 Eyes	similar aperture	Different
3.8 Cheeks	non neutral expression in PM, difficult to assess	Difficult to assess
3.9 Eyebrows	full eyebrows in PM, tidier in AM but shape is somewhat similar	Different
3.10 Nose	Bifid nose in PM, feature not visible in AM due to quality	Different
3.11 Ears		
3.12 Mouth	Similar shape and fullness in upper and lower lip, but difficult to assess due facial expression in PM	Different
3.13 Chin and Jawline	similar	Different
3.14 Facial Hair		

3.15 Facial Lines	mark on nasolabial fold R and L	Different
3.16 Rationale for difficult comparison	AM quality	
3.17 Level of Support	**Limited Support**	**No Support**

Table 16. Copy of the Phase 3-Comparison (Post Mortem Morphological Facial Comparison Form) that was filled out for the K-7, K-15, K-19 and K-23 comparisons conducted in the Main Study.

3.1 PM - AM	**K - 7**	**K - 15**	**K - 19**	**K - 23**
3.3 Facial mark				
3.4 Facial alterations (Scars, tattoos, piercings)				
3.5 Face shape/outline	Different shape	Differences: head shape and feature distribution	Differences: head shape and features proportions	Differences: facial shape and features distribution
3.6 Hairline/ Forehead	Different hairline, straight in PM, also higher forehead in PM	Differences: baldness pattern and forehead height with PM visibly shorter, hair different colour darker in PM	Differences: forehead height and width, receding hairline in AM different in PM	Differences: hair texture and volume/ forehead width and shape Not comparable: hairline not visible due to hairstyle in PM
3.7 Eyes	Difficult to assess due to PM having half open half closed			

3.8 Cheeks	Broadly similar			
3.9 Eyebrows	Similar in shape, hair length is difficult to assess due to AM quality	Differences: shape of the eyebrows in AM more arched, while flat in PM, darker colour and density in PM	Similarities: eyebrows shape and size, thickness and hair distribution, texture/ eyes intercanthal distance, overall shape and distance from the eyebrows of the upper eyelid. Differences: more dense in PM, darker colour Not comparable: Due to eyes being closed and distorted in PM, comparison of other eye descriptors is not possible	Differences: even though eyebrows are not well visible in AM, the Pm are very thick and dark which suggest they are not similar / general eyes shape, intercanthal distance, protrusion of the eyes (deep set in AM)

3.10 Nose	Differences at the root and body of the nose with AM being larger in width, also base of the nose slightly deviated towards R, while AM shows deviation to left.	Differences: more defined cheeks in PM/ nose deviated on the L in PM (could be PM position related), wider nasal root in AM, larger nasal base in PM and wider nasal tip, Similarities: length of the nasal body Not comparable: more detailed description of alae, nostrils and columella cannot be visualise on AM	Differences: more pronounced cheeks in PM/ the nasal body look larger and wider from a frontal view and slight deviation on the right. Differences observed might be related to difference in age in the two pictures and/or pos-motem pressure on the nose Similarities: nasal base width/ columella/ nostrils Not comparable: nasal root covered by glasses	Similarities: nasal root, nasal length Differences: cheek shape and outline from frontal view/ nasal base look wider Not comparable: different head pose make comparison of nose difficult
3.11 Ears	Not completely visible, protuberance from frontal view and size look different	Not comparable	Only comparable from frontal view: in AM they appear to be more protruded, but this is not observed in PM	Not comparable

3.12 Mouth	Difficult to assess, different position of mouth in PM	Not comparable: most of the mouth features cannot be compared due to the position of the mouth in PM	Not comparable: most of the mouth features cannot be compared due to the position of the mouth in PM	Differences: mouth is not well visible in PM due to change in colour and presence of facial hair, however the lip fissure and dimension of the mouth look different (?)
3.13 Chin and Jawline		Differences: chin shape and jawline (Pm having a pointer chin and more elongated jawline)	Differences: chin shape and jawline (PM having a rounder chin)	Not comparable: presence of facial hair on the chin in PM
3.14 Facial Hair	Different facial hair, could be time gap,	Similarities: facial hair visible above upper lip and below lower lip similar in distribution and area covered to one of the AM picture Not comparable: a more detailed description of texture, density and	Not comparable: pictures take at different ages a comparison of the facial hair is not advisable, especially when the two subjects present such different facial hair style.	Differences: facial hair facial hair present in PM , no hair in AM but could be time gap between images

		colour cannot be made due to AM quality		
3.15 Facial Lines	Different pattern of facial lines in PN with vertical and horizontal facial lines not found in AM. Also AM shows market L and R periorbital creases, not found so marked in PM	Differences: very marked frontal facial lines, marks glabellar lines and periorbital creases as well as inferior palpebral creases and infraorbital creases. Also, circumoral striae	Not comparable: pictures taken at different ages, PM is visually older than AM and present a number of additional facial lines (wrinkles) age-related that are not visible in AM	Differences: deep frontal lines in Am, not visible in PM, shape of inferior palpebral crease different, shape and orientation of nasiolabial fold,
3.16 Rationale for difficult comparison		AM quality	Age difference	
3.17 Level of Support	No Support	No Support	Limited Support	No Support

4.2.4 Correlation between level of support, number of images and image quality factors

The analysis of the number of AM images in relation to the levels of support expressed when compared to the matching PM subjects, suggests that AM subjects with a low number of images available tend to receive inconclusive level of support when compared to their PM target (Figure 21). Additionally, the level of support expressed for AM subjects other than the AM target was recorded the majority of the time when the AM target had only a single image available.

The analysis of the quality of AM images revealed that 14 AM cases had at least one image with a high-quality score (ranging from 1 to 3), while 15 AM cases did not have any images scoring in the higher range (Figure 22). Additionally, the quality of the images was analysed about the level of support expressed when the AM target was compared to the matching PM subject, finding that "Strong Support" was more frequently expressed in cases where the AM subject had at least one high-quality image (Figure 22). However, AM cases with lower-quality images were still correctly matched to the PM subject, but with a lower degree of confidence. In some cases, despite the low quality of the available images, the practitioner was able to match AM-PM with a higher degree of confidence. For example, AM subject 12 had 6 out of 7 images scoring 6 which indicates the lowest quality, similarly AM subject 15 had all 3 images scoring 6. Interestingly, in both cases the practitioner matched them correctly to the PM subject expressing "Support" and "Moderate Support" respectively (Table 17). From the quality and number of AM images of the incorrectly matched cases, the two incorrectly matched cases (K-23 and W-1, Table 17) respectively had 1 AM image and 2 AM images both with medium to low quality, and one of the images of AM 1 also presented some image alterations.

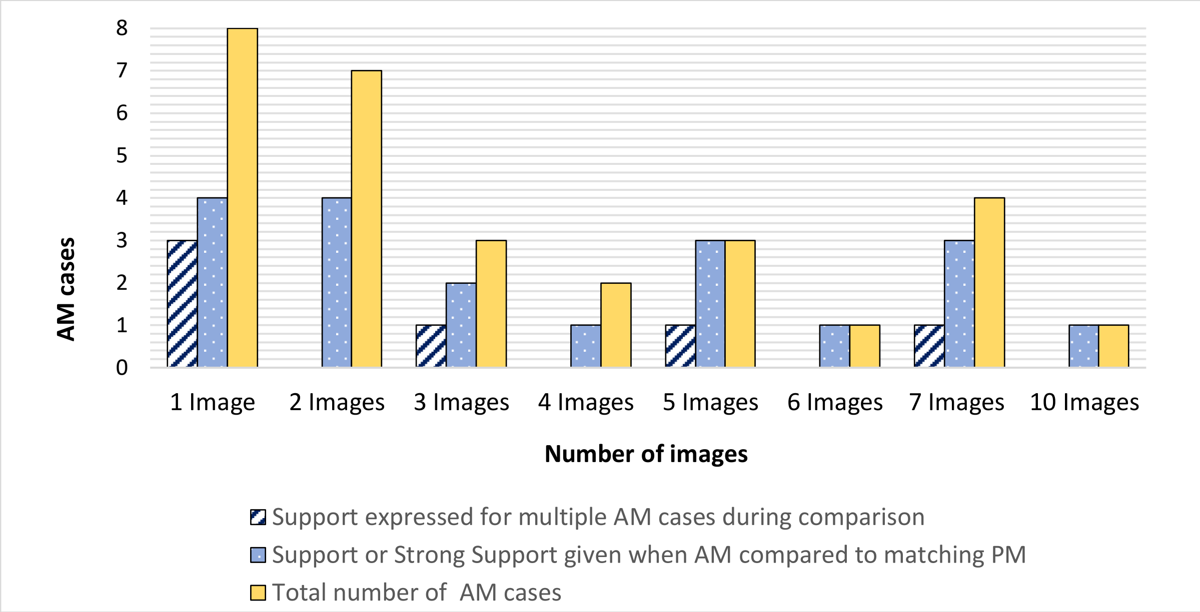


Figure 21- Relationship between the level of support expressed when matching AM-PM are compared and relative number of images per AM case

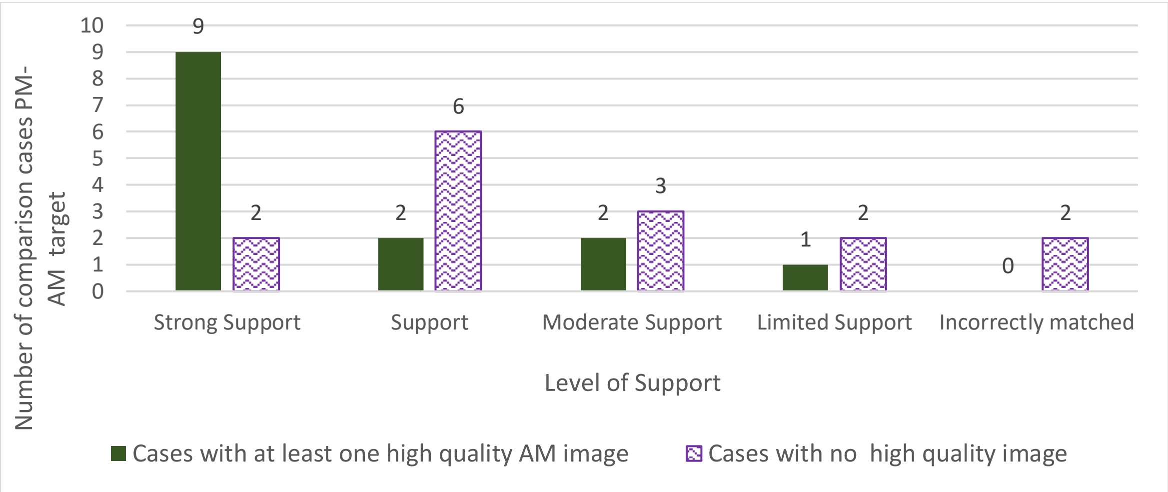


Figure 22. Distribution of the comparison cases having at least 1 high quality AM image scoring between 1 and 3 in the Image Quality Score range (14 cases) and those having no high quality AM images (15 cases) divided by the level support expressed when compared to the matching PM.

Table 17- AM-PM Matches arranged by total number of AM images (Gradient colours - with lighter shades for cases with fewer AM images and darker shades for cases with multiple AM images). The table also includes details about AM image quality and the level of support expressed for each AM-PM match.

AM	**PM**	AM Img score 1,2,3	AM Img score 4,5	AM Img score 6	Total AM images	AM images with alteration	Image alteration	Level of Support when compared to match PM*	Multiple supports
29	AB		1		1			2 (LS)	x
10	BS	1			1			2 (MS)	x
21	C		1		1			2 (LS)	
3	E		1		1			1 (S)	
11	I	1			1			1 (SS)	
22	JO		1		1			1 (S)	
23	K		1		1			0	
6	U	1			1			1 (SS)	x
14	A		2		2	2	PR[a]	2 (MS)	
28	AZ		2		2			1 (SS)	
19	H	2			2			2 (LS)	
25	L	1	1		2			1 (SS)	
7	M		2		2			1 (SS)	
13	V	1	1		2			1 (SS)	
1	W		2		2	1	CC[b]	0	
27	AA	1	1	1	3	1	PR	1 (SS)	
15	F			3	3			2 (MS)	
18	T	3			3			1 (SS)	x
17	DS		4		4			1 (S)	
16	R	2	2		4	2	PR	2 (MS)	
20	O		4	1	5	3	PR	1 (S)	x
4	QM	3	2		5	5	PR	1 (S)	
26	Z	2	3		5	1	OF[c]	1 (SS)	
5	N	6			6			1 (SS)	
12	G		1	6	7			1 (S)	
24	P		6	1	7			1 (S)	x
2	S	4	2	1	7	6	OF	1 (S)	
9	YT		6	1	7	4	PR	2 (MS)	
8	X	5	4	1	10			1 (SS)	

[a]PR: photo retouching; [b]CC: colour correction; [c]OF: Other filters

** 0=incorrectly matched; 1=Support (S)or Strong Support (SS) expressed; 2= Moderate Support (MS) or Limited Support (LS) expressed*

4.2.5 Correlation between level of support and decomposition changes

A total number of 7 PM subjects out of 29 matches were attributed a decomposition score above A1- Score 1 which corresponds to a fresh appearance (See Appendix A, Phase 1-PM Analysis 1.22 for the full list of decomposition stages). Notably, none of the PM subjects exhibited signs of trauma, however PM P, had over half of the face obstructed by blood or other element. Also, only three cases exhibited varying degrees of bloating.

Out of the seven cases, three of them received limited to moderate levels of support when matched to their target AM subject, while for the other four, the practitioner expressed “Strong support” or “Support”. Also, it is worth mentioning that the practitioner indicated for the subjects AB, O and P that there were other possible AMs other than the target that could be a potential match (Table 18). No apparent correlation emerged between a more advanced level of decomposition and an inconclusive level of support expressed when the PM subject was matched to the AM target.

Table 18. The table presents PM cases with a decomposition score above A1 (indicating fresh deceased, without discolouration), along with their corresponding target AM cases and the level of support expressed. The gradient colouring in the table shows darker shades for more advanced decomposition scores, while lighter shades indicate earlier stages of decomposition.

PM	AM target	Decomposition level	Bloating	Trauma	Obscuring matter (clothes/blood etc..)	Decomposition Score	Level of support *	Multiple supports
P	24	B1	some swelling around nose and lips	No	More than half	2	1	x
YT	9	B1		No	Less than half	2	2	
AB	29	B2		No	Less than half	3	2	x
C	21	B2		No	Less than half	3	2	
E	3	B2		No	No	3	1	
M	7	B3	Swelling around jawline, cheeks and nose	No	No	4	1	
O	20	B5	Swollen face, also R eye and area around the neck, R cheek	No	Less than half	6	1	x

*Level of Support: 1= Support /Strong Support 2 =Moderate Support /Limited Support 0=No support

4.2.6 Age gap between AM and PM images

It was noted that some of the AM-PM images of the subjects were taken years apart. The AM-PM pairs that displayed the larger visual age gap were L-25 and H-19, however, the exact time gap could not be confirmed.

In the Phase 3 comparison documentation of pair L-25, the researcher reported the age difference, but the age gap did not influence the final decision and the match was correctly identified with "Support". The decision was supported by the presence of matching facial marks that helped with the identification (see Phase 3 Comparison in Appendix B).

Differently, in the comparison of 19-H, the researcher's support for the match was "limited". The researcher recorded that the significant age difference was a complicating factor in the decision-making process. However, unlike the analysis of L-25, no facial marks or facial alterations were reported in the description and therefore this did not influence the level of support recorded (see Phase 3 Comparison in Appendix B).

4.2.7 Practitioner use of the facial features list

During the comparison process, several observations were made on the facial features list in use for facial comparison. In certain cases, the inherent characteristics of the PM subjects made certain features less useful for analysis. For example, in the majority of comparisons, assessment of the eyes was not possible and the box dedicated to eyes description in the Excel Form was left blank (See Appendix C). Also, the assessment of skin colour was often not taken into account due to variations in lighting, camera settings and environmental conditions, as well as due to initial PM changes. For example, in retouched AM images, the skin appeared overexposed and smoothed and many tones lighter than when compared to the skin tone of the PM target.

It was observed that when comparing the nose, it was sometimes found it was different in appearance (slightly diverted on the side or squeezed) in the PM subject, even if the two subjects were then found to be a match due to the presence of clear identifiers and features assessment.

4.3 Inter-observer study results

The inter-observer test was carried out with 3 independent observers. The observers were the study researcher and 2 other academics from Face Lab, Liverpool John Moores University who had long experience in facial identification using photographic and video materials as well as experience with human remains. Each observer was provided with the same 15 pairs of AM and PM images with 7 pairs being a match and 8 a non-match. The observers were also provided with the Protocol and the Form presented in Chapter 3 Methodology and asked to analyse, compare and document the AM-PM comparison following the provided guidelines. As part of the study, they were asked to provide a level of support for the AM-PM match following the 5-level support scale, ranging from "Strong Support" to "No Support". The full documentation of the observers can be found in Appendix D. The results of the interobserver comparisons study conducted by Observer 1, Observer 2 and Observer 3 suggest that in the majority of cases, observers have expressed similar levels of agreement or with one level of difference (for instance, I-11 where Observer 1 and 3 have expressed "Strong Support" and Observer 2 has expressed "Support"). However, it was noticed that Observer 2 was the only observer who never expressed a strong level of support in any of the cases, unlike the other two observers (Table 19).

The following sections will discuss the descriptive statistics, including accuracy rate, inter-observer reliability using the intraclass correlation coefficient (ICC) and Kendall's coefficient of concordance as well as analysing some interesting comparison cases where there was a high level of disagreement between observers.

Table 19. Level of Support indicated by each observer for the 15 comparisons in the Inter-observer Study. True matches are highlighted in bright green.

PM	AM	Observer 1	Observer 2	Observer 3	AM target
A	4	No Support	Limited Support	No Support	14
C	21	Support	Moderate Support	Limited Support	21
DS	17	Support	Support	Support	17
F	7	No Support	No Support	No Support	15
I	11	Strong Support	Support	Strong Support	11
M	19	No Support	Limited Support	Limited Support	7
N	24	Moderate Support	Moderate Support	No Support	5
O	20	Limited Support	Limited Support	Limited Support	20
QM	1	No Support	Limited Support	No Support	4

T	18	Strong Support	Support	Strong Support	18
T	14	No Support	Limited Support	Limited Support	18
W	18	No Support	No Support	No Support	1
YT	9	Limited Support	Moderate Support	Moderate Support	9
YT	5	No Support	No Support	No Support	9
Z	26	Strong Support	Moderate Support	Strong Support	26

4.3.1 Descriptive statistics

The results obtained by the comparison analysis carried out by the 3 observers are presented in the sections below. Any level of support provided from "Limited Support" to "Strong Support" was considered a positive support, meaning that the match was considered possible

Observer 1-Test Results

Observer 1 correctly identified the non-matches in 7 out of the 8 non-matching cases, and only in 1 case the observer expressed positive support for a non-match. Also, in none of the comparisons, Observer 1 expressed a negative support for a correct match, while they correctly identify all 7 true matches. From these results it was calculated that the true negative rate (TNR), also called specificity, was at 87.5% and the true positive rate (TPR) was 100%. Also, false negative rate (FNR) was 0% and false positive rate (FPR) was 12.5%, with an overall accuracy rate of 93.9% (Table 20).

Table 20. Descriptive statistics for matching AM and PM subjects for Observer 1 in the Interobserver Study.

		Actual condition		Total matches
		Not a match	True Match	
Predicted by Observer 1	No Support	7 (TNR[b] 87.5%)	0 (FNR[c] 0%)	7 (46.7%)
	Positive Support (SS, S, MS, LS)[a]	1 (FPR[d] 12.5%)	7 (TPR[e] 100%)	8 (53.3%)
Total matches		8 (100%)	7 (100%)	15 (100%)
Accuracy Rate[f]		93.3%		

[a]SS=Strong Support; S=Support; MS=Moderate Support and LS=Limited Support
[b]True Negative Rate, [c]False Negative Rate, [d]False Positive Rate, [e]True Positive Rate
[f]Accuracy rate = [(True Positive +True Negative)/(True Positive + True Negatives + False positives + False Negatives)]*100 (Altman and Bland, 1994)

Observer 2-Test Results

Observer 2 correctly identified the non-matches in 3 out of the 8 non-matching cases and in 5 cases the observer expressed a positive support for a non-match. Also, in none of the comparisons, Observer 2 expressed a negative support for a correct match, while they correctly identify all 7 true matches. From these results, it was calculated that the true negative rate (TNR), also called specificity, was 37.5% and the true positive rate (TPR) was 100%. Also, the false negative rate (FNR) was 0 % and the false positive rate (FPR) was 62%, with an overall accuracy rate of 66.67% (Table 21).

Table 21.Descriptive statistics for matching AM and PM subjects for Observer 2 in the Interobserver Study.

		Actual condition		Total matches
		Not a match	True Match	
Predicted by Observer 2	No Support	3 (TNR[b] 37.5%)	0 (FNR[c] 0%)	3 (20%)
	Positive Support (SS, S, MS, LS)[a]	5 (FPR[d] 62.5%)	7 (TPR[e] 100%)	12 (80%)
Total matches		8 (100%)	7 (100%)	15 (100%)
Accuracy Rate[f]		66.67%		

[a]SS=Strong Support; S=Support; MS=Moderate Support and LS=Limited Support
[b]True Negative Rate, [c]False Negative Rate, [d]False Positive Rate, [e]True Positive Rate
[f]Accuracy rate = (True Positive +True Negative)/(True Positive + True Negatives + False positives + False Negatives) (Altman and Bland, 1994)

Observer 3-Test Results

Observer 3 correctly identified the non-matches in 6 out of the 8 non-matching cases and in 2 out of the 8 comparison cases, the observer expressed a positive support for a non-match. Also, in none of the comparisons, Observer 31express a negative support for a correct match, while they correctly identified all 7 true matches. From these results, it was calculated that the true negative rate (TNR), also called specificity, was at 75% and the true positive rate (TPR) was 100%. Also, the false negative rate (FNR) was 0 % and the false positive rate (FPR) was 25%, with an overall accuracy rate of 86.67% (Table 21).

Table 22. Descriptive statistics for matching AM and PM subjects for Observer 3 in the Interobserver Study.

		Actual condition		Total matches
		Not a match	True Match	
Predicted by Observer 3	No Support	6 (TNR[b] 75%)	0 (FNR[c] 0%)	6 (40%)
	Positive Support (SS, S, MS, LS)[a]	2 (FPR[d] 25%)	7 (TPR[e] 100%)	9 (60%)
Total matches		8 (100%)	7 (100%)	15 (100%)
Accuracy Rate[f]		86.67%		

[a]SS=Strong Support; S=Support; MS=Moderate Support and LS=Limited Support
[b]True Negative Rate, [c]False Negative Rate, [d]False Positive Rate, [e]True Positive Rate
[f]Accuracy rate = [(True Positive +True Negative)/(True Positive + True Negatives + False positives + False Negatives)]*100 (Altman and Bland, 1994)

4.3.2 Inter-observer Reliability

The inter-observer reliability was calculated using the Intraclass Correlation Coefficient (ICC) and Kendall's Coefficient of Concordance. The data was inserted and analysed in SPSSv28 (IBM Corp. 2012). The intraclass correlation coefficient (ICC) two-way mixed model on absolute agreement was used to analyse inter-observer reliability for the level of support expressed by all 3 observers (Landis and Koch, 1977). The values of the ICC range from 0 to 1, with a higher value signifying better reliability. ICC less than 0.40 was considered poor, between 0.40–0.59 as fair, 0.60–0.74 as good, and greater than 0.75 as very good. (Landis and Koch, 1977). Normal distribution was not calculated since this assumption is not necessary for the valid estimation of ICC. The results for ICC was 0.813 with a 95% confidence interval between 0.620-0.923, which is considered a good inter-observer reliability score.

Table 23. Values calculated for the Intraclass correlation coefficient two-way mixed model on absolute agreement based on the interobserver test results (ICC 2,*k*).

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.813[a]	.620	.926	13.234	14	28	.000
Average Measures	.929[c]	.830	.974	13.234	14	28	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

[a] The estimator is the same, whether the interaction effect is present or not.

[b] Type A intraclass correlation coefficients using an absolute agreement definition.

[c] This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

In addition to the absolute agreement, Kendall's Coefficient of Concordance (W) was calculated to take into account the degree of agreement among the three observers (Field, 2005). In other words, the test helps to differentiate between levels of supports with only one point of difference versus not close at all. Kendall's coefficient ranks from 0 to 1 with higher values close to 1 highlighting a strong inter-observer agreement. Kendall's coefficient was found to be 0.885, which suggests a good inter-observer agreement (Table 24).

Table 24. Kendall's Coefficient (W) calculated for the Inter-observer test

Kendall's (W)[a]	
N	3
Kendall's W[a]	.885
Chi-Square	37.153
df	14
Asymp. Sig.	.001
[a] Kendall's Coefficient of Concordance	

4.3.3 Highlighted Comparison Cases

This section examines the instances where observers have exhibited a high level of disagreement on the level of support provided for a match or have selected the same inconclusive level of support in a true match. For each comparison case presented, are also included relevant elements and discrepancies as reported in the documentation that can be found in Appendix D.

Comparison case O-20*: low level of support for a target AM*

Table 25. Level of support expressed by the three observers for case O-20.

PM Case	AM Case	Observer 1	Observer 2	Observer 3	AM target
O	20	Limited Support	Limited Support	Limited Support	20

The 3 observers agreed on the lower level of support for PM subject O being a match to AM subject 20, despite AM subject 20 being the target.

Comparison Documentation

Due to the changes in the PM and the changes to the PM subject facial appearance, all observers experienced difficulties in this comparison. The observers indicated that analysis was either impossible or had limitations for more than one feature because of PM decomposition.

AM Image factors

5 images were available for AM subject 20 and all images scored above 4 with one scoring 6 and three presenting image alterations (photo-retouching and colour correction). One of the images also presented a high level of noise. Subject 20 was also one of the few cases with the worst set of images in terms of quality, as reported in Table 17, in section 4.2.4.

PM subject decomposition

PM subject O received a decomposition score of 6 (Decomposition level B5) which is equivalent to a face having brown to black discolouration of the skin. Also, the subject was found to exhibit a general bloating of the face, in particular around the right side of cheeks and eyes.

Comparison case C-21: *high level of disagreement*

Table 26. Level of support expressed by the three observers for case C-21.

PM Case	AM Case	Observer 1	Observer 2	Observer 3	AM target
C	21	Support	Moderate Support	Limited Support	21

The 3 observers expressed various levels of support and while none excluded the match, observer 1 was the only observer providing a higher level of support for the match.

Comparison Documentation

Observer 1 found most of the features to be similar, with facial shape, eyebrows, and right ear being the most similar. In addition, it was reported that there were no facial marks and the AM image quality made comparison difficult. Similarly, Observer 2 reported similar results adding that some moles that were visible on the face matched between the two subjects. In addition, they commented that PM changes observed on the face and tissue distortion made comparison difficult. Observer 3 reported moles not matching when comparing the two subjects with no factors making the comparison difficult, but agreed that most of the features presented some similarities.

AM Image factors

Subject 21 presented only one image that received a score of 5 out of 6, indicating low quality. It was also reported that the image had high level of noise.

PM subject decomposition

PM subject C scored B2 (5) in the decomposition evaluation carried out before the interobserver study, which corresponded to grey to green discolouration with the presence of relatively fresh skin. Some tissue deformation was noted, including a slightly deviated nose.

***Comparison case N-24**- high level of disagreement*

Table 27. Level of support expressed by the three observers for case N-24.

PM Case	AM Case	Observer 1	Observer 2	Observer 3	AM target
N	24	Moderate Support	Moderate Support	No Support	5

Observers 1 and 2 agreed on the same level of support when comparing N-24 despite it not being the same subject, however, Observer 3 expressed a very different opinion by correctly expressing no support for the case.

Comparison Documentation

Observer 1 noted numerous similarities in the majority of the facial features, excluding facial lines and marks. They acknowledged that the quality of the AM images impacted the comparison, but identified consistent similarities in the ears, which supported the identification. Similarly, Observer 2 identified similarities in certain facial features and confirmed that the visible ear exhibited a similar shape. They also reported the issue of AM image quality affecting the comparison. However, Observer 3 noticed a mark in the PM image that was not visible in the AM images, although the image quality was not ideal. Unlike the other two observers, Observer 3 did not report the facial hair to be similar, documenting no similarities in the pattern of growth between the two subjects.

AM Image factors

Subject 24 had a total of 7 images available for comparison, each captured from various angles. However, the quality of these images varied, ranging from a score of 4 to 6, with no image alterations. Notably, Subject 24 was part of the subset of subjects in the AM pool with the lowest image quality,

PM subject decomposition

PM Subject N received a score of A1, indicating a fresh appearance with no visible decomposition changes to the face. There were no signs of bloating or trauma observed during this phase, suggesting well-preserved facial features.

***Comparison case T-14** – high level of disagreement*

Table 28. Level of support expressed by the three observers for case C-21.

PM Case	AM Case	**Observer 1**	**Observer 2**	**Observer 3**	**AM target**
Z	26	Strong Support	Moderate Support	Strong Support	26

Observer 1 and Observer 3 expressed the same level of support for subjects Z and 26 being a match, providing the highest level of support for this evaluation. On the other hand, Observer 2 provided a lower level of support, despite Z- 26 being a correct match.

Comparison documentation

Observer 1 noted consistent features during the comparison, specifically emphasising the facial marks and finding no difficulties in the comparison process. Similarly, Observer 3 reported consistent features, specifically mentioning the facial mark on the forehead, also highlighted by Observer 1.

Observer 2 confirmed the consistency of the facial marks on the forehead between the subjects. However, Observer 2 also pointed out that certain features appeared slightly distorted due to changes occurring in the PM, despite the overall similarities.

AM Image factors

For AM subject 26, there were a total of five images available for comparison, all of which had sufficient quality for evaluation. Among these images, two received a score of 3 out of 6, indicating moderate acceptable quality, while the remaining three scored 4, suggesting slightly lower quality. Also, one of the images displayed some alterations due to postproduction filters.

PM subject decomposition

The decomposition score subject Z received was 1 (Decomposition level A1), indicating that the subject was relatively fresh and had not undergone significant PM changes that would alter facial features. However, it was noted that bloating partially affected the face.

5. DISCUSSION

5.1 Introduction

This chapter discusses the evaluation of reliability and use of the photographic morphological facial comparison method.

The aim of the research was both to create and implement an ad-hoc documentation system for AM-PM image comparison to better describe and assess the similarities between compared AM and PM subject, and to test the reliability of AM-PM facial comparison using unstandardised images. Following a developed protocol, a blind morphological comparison study and an interobserver error evaluation were carried out on a sample of 29 subjects with AM and PM images.

This pilot study produced interesting results that can be taken into consideration for the application of morphological facial comparison in post-mortem identification. In particular, this research proposed a new protocol and associate worksheet for practitioners (See Appendices A and B) that integrated the existing guidelines for the facial image comparison of living individuals with established facial decomposition changes, whilst providing one of the first inter-observer evaluations of morphological facial comparison for PM identification.

The chapter will discuss the following aspects:

- Observation on the use of the protocol and sample
- Assessment of reliability of morphological facial comparison applied to PM subjects in the main study
- Role of decomposition and image quality in expressing a level of support
- Assessment of the results of the interobserver study
- Limitations

5.2 Main Study

5.2.1 Protocol and sample

Adapting the existing FISWG guidelines to the requirements of AM-PM facial comparison was fundamental to this study due to the variety of unconstrained AM images and the unique early decomposition changes and alteration of facial appearance visible in PM images. The photographic material used in this study originates from forensic cases and as such they are a good representation of a typical DVI scenario where the quality and type of images are quite varied (Cappella et al., 2021). One of the central novelties of this facial comparison protocol is the creation of a dedicated analysis for PM subjects' facial decomposition changes. Analysis of the changes that affect the face after death can help to understand if the PM images are suitable for comparison, meaning that the facial appearance is preserved and not severely altered. This addition to the protocol for PM comparison has the same utility as the AM image factors analysis that is currently in use in the living morphological comparison and was also used for the analysis of AM images in this protocol. The analysis stage helps to determine whether the quality of the images is suitable for comparison (ENFSI, 2018).

Also, the Comparison Phase (Phase 3) was conducted following the comprehensive guidelines provided by FISWG for image comparison, using a set of 18 facial features, each associated with multiple descriptors. It was noted that certain features have less utility or applicability when used for AM-PM facial comparison. For instance, the eyes were frequently excluded from feature assessment because the eyes of most deceased subjects were closed or because the colour of the iris or the appearance of the eyes was altered due to PM changes. This observation aligns with existing knowledge about early decomposition changes. Wilkinson and Tillotson (2012) documented such changes in a pilot study on PM facial appearance alterations, noting that the eyes lose volume, and become sunken, whilst orbital swelling can obscure the orbital features entirely. In addition, the fact that eyes were not particularly relevant during the comparison task seems to be consistent with a study conducted by Caplova et al. (2017), where groups of students and professionals were asked to identify the most useful features after completing a photographic recognition task on the deceased. The participants never selected "eyes" among the most useful features for the recognition task, suggesting that the comparison of the eyes between AM and PM subjects could potentially be disregarded.

Furthermore, an interesting observation emerged from the analysis of two PM subjects BS and V. The nasal appearance of these deceased subjects exhibited a tilted appearance that was not observed in the AM target images and did not appear to be related to any perimortem trauma. The altered nasal appearance, particularly affecting the nasal tip, could potentially be explained by the pressure exerted by a body bag on the skin during the algor mortis phase, a time when the tissues are sensitive to such influences, causing the body to retain a certain shape (Dix and Graham, 1999). Since the nose was one of the most useful features for recognition of deceased, as reported by the participants in the study on deceased facial recognition carried out by Caplova et al. (2017), caution should be applied when considering differences between the PM and AM subjects presenting alteration in the nasal appearance possibly due to pressure of the body bag on the face.

The above observations suggest that the feature list might need a revision for AM-PM comparison. A similar observation was documented by Bacci et al. (2021a) for living subjects comparison, expressing the need for optimisation of the feature list to improve the analysis of facial similarities and differences. For instance, they mentioned that often skin colour and luminance were ignored during comparisons as they were difficult to assess. Similarly, in the analysis of the quality and characteristics of AM images of migrants Cappella et al. (2021) highlighted how skin colour can appear different between AM and PM images due to post-production filters that can make the skin appear smooth and lighter.

The sample used for the study was made of 29 AM and PM subjects and for each AM there were a corresponding PM subjects. This type of sample resembles a closed disaster setting where the number and identity of victims are known. This represents a limitation as it limits applications of the findings mainly to similar real cases circumstances. Future studies could use a larger pool of AM subjects, where only a limited amount has matching PM subjects. Such an approach would help to evaluate the methodology in open disaster scenarios.

5.2.2 Reliability of post-mortem facial morphological comparison

The analysis of the AM image quality revealed that more than half of the images presented an insufficient quality, scoring between 4 and 5. Despite the non-ideal quality observed in the AM sample, correct matchings were possible with an accuracy rate of 85.9%, with a high specificity (97.1% true negative rate). This indicates that the method correctly identifies non-matches most of the time. Moreover, a satisfactory sensitivity of 75% was observed, implying that the method correctly identifies matches when comparing PM subjects with their AM target image. In terms of sensitivity, a positive correct match was judged as any level of support other than "No support," encompassing any support above "Limited support".

The false negative rate was low and recorded at 2.9%. In forensic science and forensic identification methodologies, it is crucial to maintain a low false negative rate as misidentifying (or convicting, in the case of living) can lead to severe legal consequences (Du, 2017). Therefore, the obtained low false negative rate is highly encouraging for the use of the methodology in the forensic identification process.

The results obtained by the main study were also examined by using a "strict" and "lenient" accordance. The first one considers correct matchings when only one AM target was indicated as a potential match and the second one indicates any level of support given to the AM target, independently of how many other AM were considered potential matches along with the target. The lenient accordance at 93% of correct identifications suggests that morphological facial comparison in deceased individuals can help to select potential matches from a pool. However, the results obtained with the strict accordance of 72% of correct identification suggest that narrowing down the selection to one single AM target is more difficult. However, both results suggest that morphological comparison can be beneficial in the initial stage of a PM identification (Caplova et al., 2017). It allows filtering of the potential matches which could then be either confirmed or rejected using other more tested and reliable means.

Given that some identifiable facial details such as moles, scars and tattoos can be relevant for identification, as seen in the literature (Caplova et al., 2017; Olivieri et al., 2018; Rangel, Amundarain and Leal, 2022), the developed protocol and worksheet incorporated a section where practitioners could make a note about the presence of distinguishing elements that contributed to inclusion or exclusion of identity. The analysis of the results suggests that correct matches with strong support were associated with the presence of one or multiple facial identification elements, in particular facial marks such as moles or other skin marks. At the same time, lower support levels were generally associated with a very limited number of identifiable features, and in some cases none. This is in line with the belief that identifiers such as moles, scars and other facial marks can aid positive identification, even with wild-type images (Caplova et al., 2018b).
In addition, the most common identifiers recorded for positive identification were facial marks, followed by ears, scars, teeth and piercings. It is not surprising that facial marks, such as moles, emerged as useful identifiers, since their role in morphological identification has been investigated in relation to living individuals (Black et al., 2014; Nurhudatiana et al., 2016), in forensic recognition systems (Lee, Jain and Jin, 2008; Becerra-Riera, Morales-González and Méndez-Vázquez, 2019) and as secondary identifiers for DVI procedures (Cattaneo, Angelis and Grandi, 2006; Interpol, 2018). Surprisingly, the ears emerged as the second most crucial feature recorded for informed identifications. This outcome aligns with existing literature that highlights how the external ear morphology is unique and can be considered an identifying factor among living individuals (Verma et al., 2016; Gibelli et al., 2018) and deceased individuals (Carvalho and Bantim, 2019), although it has been used for the latter only on case studies. Another facial feature that has proved to be a useful element for deceased identification is dentition visible from smiling images (De Angelis, Cattaneo and Grandi, 2007; Silva et al., 2008; Silva et al., 2015; Valente-Aguiar et al., 2021). However, the teeth were among the less frequently mentioned features aiding in identification. One plausible explanation could be the limited availability of AM and PM dental images in the sample used for this study. This scarcity of dental images may have been a deliberate choice by the research group when providing the images for the study or simply the nature of the data provided. While the lack of dental images in a real case scenario would be a limitation, it

proved advantageous for the study, forcing the practitioners to consider all facial features rather than relying solely on dental morphology alone.

Another element to consider is that in some DVI scenarios, especially where migrants are involved, the families providing images might have not seen their loved one for years and might only have an old picture available that might not reflect the appearance of the person at the time of death (Olivieri et al., 2018).
Only 2 cases presented a substantial age gap between the AM and PM images. In one of the two cases, L-25 presented similar facial marks clearly visible in both sets of images, leading to a correct identification (level of support = Support). Differently, in the other case (H-19), the level of support expressed was "Limited Support" and no identifier was visible to support a more confident identification. These results suggest that under certain circumstances, the presence of clear, visible, and permanent identifiers like scars and moles can offer identification evidence, even when there is a significant age gap between the two sets of images.

5.2.3 Decomposition and level of support

The majority of PM images depicted individuals who showed early PM changes, with more the 75% of the individuals showing a high degree of facial preservation.

There was no apparent relationship between the level of decomposition and the level of support recorded. This outcome is surprising, given that decomposition changes, including bloating and trauma, can substantially alter the facial features of deceased individuals even during the early stages of decomposition (Wilkinson and Tillotson, 2012) For example, the PM case that showed the highest decomposition score was case O (Decomposition score 6 – Decomposition Level B5 - Brown to black discolouration of flesh) and this was correctly matched with a positive level of support to AM 20 (although other AM subjects were also considered a potential match).
Although limited research surrounds the application of AM-PM facial comparison, there is a general consensus that morphological facial comparison should only be conducted using images captured when the body is still fresh (Caplova et al., 2018b) so the facial features are well-preserved (Cappella et al., 2021). However, it is difficult to quantify "well preserved" when the decomposition changes are no longer acceptable for morphological facial comparison. The results obtained from the pilot study suggest that even if there is a more advanced stage of decomposition (e.g. bloating or discolouration) the presence of identifiable facial details, along with a distinct combination of facial attributes, can offer adequate facial information for positive morphological

comparison. For example in PM case O, the subject exhibited brown to black discolouration and with some facial bloating, nevertheless, a correct match with the AM target was possible due to a combination of distinctive facial features that were observable from the images.

5.2.4 Image quality and level of support

To explore the potential impact of image quality on the accuracy of identification, a correlation assessment was conducted between the presence of a high-quality image and the level of support recorded (refer to Section 4.21, Figure 7). The findings revealed that AM subjects who had at least one high-quality image (an image with a quality score between 1 and 3), were more frequently matched with a "Strong Support" to the PM image. On the contrary, AM subjects with no high-quality images received a less confident positive level of support when matched to matching PM. This suggests that having access to high-quality images allowed practitioners to observe more relevant details, such as moles, scars and other facial elements which can ultimately ensure a more confident evaluation of a potential match supported by a higher level of support.

This expected correlation between image quality and the accuracy of identification is consistent with a study conducted by Bacci, Steyn and Briers (2021) to evaluate the performance of morphological facial comparison in optimal and sub-optimal CCTV recordings for living individuals, finding that the quality was indeed closely associated to the performance of morphological comparison and optimal images yielded better performance. These results are also in line with a recent study conducted by Bacci et al. (2021b) that found morphological comparison to perform better when standardised and high-quality photographs are used.

5.2.5 False negatives excluded from Facial review Phase 2

Facial review is the stage where the practitioner performs a quick comparison between AM and PM subjects evaluating the overall face to exclude any obvious non-matches. This stage is not a complete comparison as it relies on the holistic ability of humans to recognise the overall facial differences and similarities. To prevent practitioners from conducting a feature-by-feature comparison at this stage, a decision-making flowchart was introduced to guide the practitioner in deciding whether the match should be progressed onto the comparison phase or if it is an obvious no-match (Figure 23). While the associated chart can help the practitioner in excluding obvious matches, as it filtered 28 cases out of 29, it should be used with caution. In fact, from the main study, it has emerged that for one of the two false positive matches, the target AM image was excluded in Phase 2 (Facial Review) when it was compared to the PM image. This can be explained by the limited number of AM images (n=2) of low quality (image quality scores 4 and 5) and with a post-production filter (colour correction). In addition, it was observed that the PM subject presented a crux tattoo on their forehead and a mole that was not visible in the AM images and, in particular, the absence of the mole could have influenced the practitioner's decision to exclude the AM subject. While the Facial Review stage is effective for narrowing down the number of potential matches, it also carries the risk of false exclusion. Also, the risk of conducting a facial review is that the practitioner might rely on some selected identifying features (such as facial marks) to progress or not progress a match to full comparison, as seen in the false negative case mentioned beforehand, where the absence of a mole.

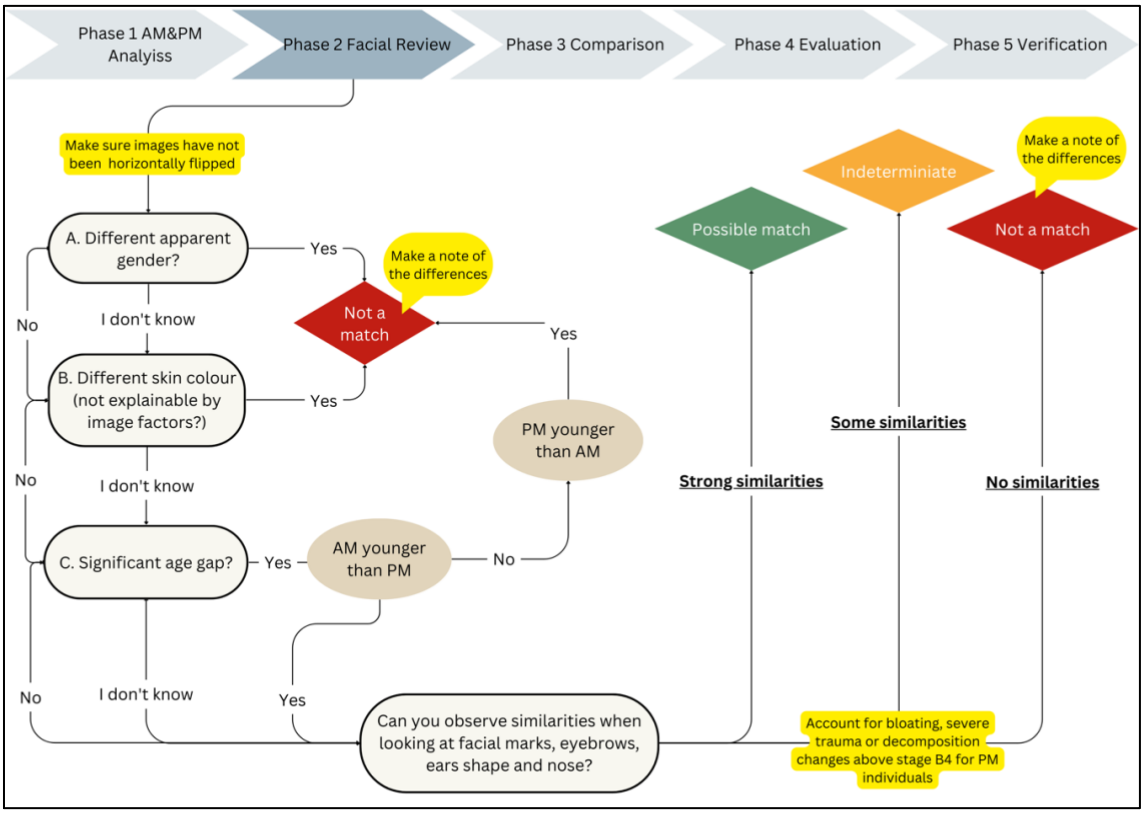


Figure 23. Facial Review Flowchart part of the Phase 2 Facial Review in the AM-PM Photographic Facial Comparison Protocol.

5.3 Inter-observer test

5.3.1 Assessing the level of support expressed by different observers.

The three observers showed an overall good accuracy score between 66.67% and 93.6%. The accuracy score measures both the correct matches and the correct exclusions and the results obtained appear to be promising. Surprisingly, all observers obtained a 100% true positive rate, having correctly matched the PM subjects to their AM targets. Also, all observers had obtained a low false negative rate of 0% meaning that none of the observers incorrectly matched any of the cases. Having obtained a low false negative rate across different observers is desirable when it comes to forensic identification methods. It is better to express no support for two individuals who were a match, rather than having a false positive rate, where an individual is wrongly assessed as a match (Thompson, Taroni and Aitken, 2003; Du, 2017). Such results could suggest that, even if facial morphological analysis is inherently a qualitative and subjective approach that relies on practitioner experience and quality and characteristics of the sample, it can provide some important clues as to the identity of the individuals.

Interestingly, the false positive rate, calculated based on the cases where the observers supported an incorrect match, was found to be higher in Observer 2 (67%) compared to the rates obtained by Observer 1 and 3 (25%). This might suggest that Observer 2 was more cautious in exclusions and preferred to express a lower level of support ("Limited Support") rather than a more definitive "No Support". While adopting caution in the exclusion of cases produces high false positive rate results and reduced precision, adopting this approach might avoid inadvertently excluding potential matches. Given the substantial non-standardisation of PM and AM photographic samples, adopting a cautious approach could prove advantageous, particularly in cases where decomposition has progressed significantly and facial features might have undergone some changes.

Turning now to the inter-observer reliability, the value obtained by the analysis was very good (absolute agreement ICC = 0.813), indicating reliable results among observers when providing support for a match. Also, the observers showed a good level of agreement based on the similarities in the level of support expressed (Kendal's W 0.885). The lower value obtained with the absolute agreement can be attributed to the subjective nature of the support scale. While the category of "No support" unequivocally excludes identity, the distinction between "Moderate" and "Limited support" as well as "Strong support" and "Support" is less distinct and defined. Although having a scale that includes various levels of potential support is valuable in a courtroom setting where the identification process can either exclude or implicate a suspect, the identification process for post-mortem identification might require different terminology. For example, implementing a simplified

3-point scale of "Support," "Moderate to Limited Support," and "No Support" has the potential to enhance the absolute agreement between observers. Moreover, this simplified scale could prove beneficial in multiple AM-PM comparisons, as it facilitates the analysis even for practitioners who are not experienced with such a support scale. Limitations in the inter-observer study include the limited sample size with only 15 comparisons carried out by observers. To gain more reliable insights, it is recommended that further investigations are conducted involving a larger number of observers and comparisons.

5.3.2 Disagreement on the level of support recorded by different observers

The comparison of cases N-24, Z-26, T-14, and C-21 revealed a higher level of disagreement, with at least two levels of support. One explanation for the disagreements among observers could be related to the quality of the AM images and the level of facial details visible for comparison. For example, despite the variety of AM images available for AM subject 24, the quality was medium to very low. Similarly, AM subjects 14 and 21 had respectively two and one medium to low-quality images available for comparison. These observations suggest that both the limited number of images and lower image quality that restrict facial features' visibility might have contributed to the inconsistency between observers.

Furthermore, an interesting observation was made for O-20, where all observers expressed "limited support" for the match, despite it being the correct match. The inability to provide a higher level of confidence in their assessment can once again be attributed to the quality score of the AM images associated with AM subject 20. These images were rated between 4 and 6 on the quality scale, indicating medium to very low quality. The lower quality may have hindered the analysis of finer facial details. As a result, observers were limited in their ability to provide a more definitive level of support despite it being the same subject.

Also, the inter-observer test was designed to evaluate the reliability of the AM-PM facial comparison method across different observer using a 5-point assessment scale.

While the findings are promising, it is important to acknowledge the limitations of the interobserver test, which was conducted with a relatively small sample size of 15 comparisons. A more extensive dataset involving a larger number of cases and observers might produce different results.

Additionally, a limitation stems from the fact that one of the observers (Observer 3) also carried out the main study. Consequently, this observer performed a higher number of AM-PM comparisons and was also the practitioner involved in the protocol and Excel worksheet creation. Despite the extensive experience and expertise in facial identification of the other two observers, this discrepancy has the potential to unintentionally introduce a bias, mainly due to differences in contextual information provided to the observers (Cooper and Meterko, 2019). However, it was Observer 1, who was not involved in carrying out the main study or the design of the protocol and worksheet, to show the higher accuracy rate indicating that in this instance, exposure to the whole analysis and comparison of the sample did not enhance performance.

5.4 Conclusion

2D AM-PM Photographic facial comparison can often be the last resource in some DVI investigations where other personal data such as DNA or dental information might not be available to forensic experts to identify the victims. Because of the role that images can have when other personal information is not available, this thesis aimed to produce a novel protocol and workflow based on the knowledge and guidelines of living individuals in comparison with what is known about early post-mortem changes and how they affect facial appearance. Also, it aimed to investigate the reliability of AM-PM facial comparison and how it is the performance across different observers, as well as the use of the aforementioned protocol. The results of the main study are promising, with only 2 of the 29 possible matches in lenient accordance that were incorrectly identified. This result suggests that facial comparison of AM-PM subjects can indeed be used to narrow down the number of possible matches, even when the PM subjects are showing early post-mortem changes. This could help to suggest possible identities and be particularly useful in large-scale disasters which could potentially help to save resources as only the potential matches would need to be verified using other identification means, if available. In the main study, along with the expected correlation between image quality and level of confidence in the evaluation of the match, it was found that facial identifiers such as moles and scars have been revealed to be particularly relevant when conducting a photographic comparison and their presence can help to reach a strong support for both rejections or acceptance of a match. The same encouraging results have been observed for the interobserver study that, while being a small pilot study, the inter-rate reliability and agreement of the level of support expressed showed good rates. The analysis of the results of the interobserver test also revealed that in some cases there was a big disagreement on the support level provided by observers. In some cases, this was due to the quality of the AM images, but it was also found that possibly the nature of the 5-point level of support scale made the evaluation of the appropriate level more difficult and open to interpretation. Therefore a 3-point scale with only "positive support", "inconclusive support" and "no support" could have been more appropriate. Overall, the results of both the main study and the interobserver test are promising. Even if the morphological facial comparison is a qualitative and subjective method, successful evaluation of potential matches is still possible, even when the deceased individuals show early PM changes.

5.5 Future consideration

This research has provided the first tailored protocol for AM-PM facial comparison, highlighting the differences that an AM-PM comparison presents compared to living image comparisons. In light of this, future research should investigate the use of the protocol across observers with various levels of experience and provide suggestions on how to improve the protocol and workflow to enhance the AM-PM morphological comparison process. Also, evaluating which features are the most useful in AM-PM morphological comparison and how they can be used to improve the reliability of the method.

Since the photographic sample used in this research involves using 2D AM and PM images, it would be interesting to test whether the comparison of 3D scans of deceased individuals with 2D AM images can ultimately yield better results, also evaluating costs associated with the process and time involved in the scanning process.

Also, in relation to the sample used, in this research, a significant part of the PM cases presented well-preserved facial features with minimal to no PM decomposition changes, which might not accurately reflect real-world situations, especially mass disasters, where individuals can be affected by severe trauma or exhibit more advanced PM changes. For this reason, future research designs should aim to select a dataset that comprises individuals with medium decomposition changes, peri-mortem trauma or exposure to different environments (such as humid environments, prolonged time in water etc....).

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APPENDIX A-Post Mortem Photographic Facial Comparison Protocol

AM LIST

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **AM List** sheet**.** Once there, follow the below instructions to complete the columns.

a.1 AM code
Insert the ante mortem case identifier code

a.2 Presented gender	
Select the presented gender that better describes the individual in the pictures using the list below.	
F	Female: The individual in the picture presents physical gender expression that are generally typical of female individuals. This might include facial features, hairstyles, makeup, clothing.
M	Male: The individual in the picture presents physical gender expression that are generally typical of male individuals. This might include facial features, hairstyles, facial hair, clothing.
I	Indeterminate: The individual in the pictures presents physical traits that dot not fit into the traditional binary categories of female and male.

a.3 Skin colour	
Select the skin colour that better describes the individual in the pictures using the list below.	
Light	It typically appears as a pale or fair complexion. This skin tone is often associated with people of European or East Asian descent, but it can also be found in people of other ethnicities.
Medium	It typically appears as warm and golden complexion. It is common in people of Latin American, and Middle Eastern descent, as well as some South Asian and East Asian populations.
Dark	It typically appears as reddish-brown to black complexion. It is common in people of African, Afro-Caribbean, and some South Asian and Southeast Asian descent.

a.4 Estimated age – From Albert, Ricanek Jr and Patterson (2007)	
This description is to be used if the actual age of the missing individual is unknown. If the age is known, please make a note in the a.6 Notes section.	
Young adult	The individuals appear to be in the late teenage to young adulthood stage of life, exhibiting soft facial features and a generally youthful appearance.
Old adult	Individual that physically appear to be above 70 years of age. The individual might present gray hair or balding, skin texture changes (wrinkles, age spots, leathery skin etc..), increase ear and nose size, loss of facial fat and a more gaunt appearance. Their appearance might not reflect their real age

a.5 Images available
Insert the total number of images available.

PM LIST

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **PM List** sheet**.** Once there, follow the below instructions to complete the columns.

b.1 PM code
Insert the post mortem case identifier code

b.2 Presented gender/ sex if known	
Select the presented gender that better describes the individual in the pictures or biological sex (if known from the autopsy report) using the list below. ⚠*The biological sex reported in the autopsy report might not be representative of the presented gender of the individuals when alive. Use the b.6 Notes to add any relevant information.*	
F	Female: The individual in the picture presents physical gender expression that are generally typical of female individuals. This might include facial features, hairstyles, makeup, clothing.
M	Male: The individual in the picture presents physical gender expression that are generally typical of male individuals. This might include facial features, hairstyles, facial hair, clothing.
I	Indeterminate: The individual in the pictures presents physical traits that dot not fit into the traditional binary categories of female and male.

b.3 Skin colour	
Select the skin colour that better describes the individual in the pictures using the list below.	
Light	It typically appears as a pale or fair complexion. This skin tone is often associated with people of European or East Asian descent, but it can also be found in people of other ethnicities.
Medium	It typically appears as warm and golden complexion. It is common in people of Latin American, and Middle Eastern descent, as well as some South Asian and East Asian populations.
Dark	It typically appears as reddish-brown to black complexion. It is common in people of African, Afro-Caribbean, and some South Asian and Southeast Asian descent.

b.4 Estimated age– From Albert, Ricanek Jr and Patterson (2007)	
This description is to be used if the actual age of the missing individual is unknown. If the age is known, please make a note in the a.6 Notes section.	
Young adult	The individuals appear to be in the late teenage to young adulthood stage of life, exhibiting soft facial features and a generally youthful appearance.
Old adult	Individual that physically appear to be above 70 years of age. The individual might present gray hair or balding, skin texture changes (wrinkles, age spots, leathery skin etc..), increase ear and nose size, loss of facial fat and a more gaunt appearance. Their appearance might not reflect their real age.

b.5 Images available
Indicate the number of images selecting the appropriate categories. Usually PM images are abundant

⚠ *If image quality is low or images are blurred, document it in the b.6 Notes*

<10 or 1to3	Less than 10 PM images are available
4 to 9	Between 4 and 9 PM images are available
10+	More than 10 PM images are available

a.6 Notes
Insert additional information relevant to the PM case.

PHASE 1 – AM ANALYSIS

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the Phase 1-AM **Analysis** sheet**.** Once there, follow the below instructions to complete the columns.
In this stage, you are required to analyse the quality and suitability of the AM images for facial comparison against different technical image factors. You are not required to assess the morphology of every single facial trait.
The factors you will consider include lighting, obstructions and quality of the images. The latter in particular plays a crucial role in facial comparison as it influences the strength and level of confidence of the final result (Schüler and Obertová, 2020; FISWG, 2021).
To minimise the confirmation bias, the practitioner **should** analyse AM and PM images separately.

Before starting, familiarise with the image factor concepts explained in "Image factor to consider in facial image comparison" and "Best Practice Manual for Facial Image Comparison" - see Table 1 on how to access the material.

1.1 AM case
Insert the ante mortem case identifier code

1.2 IMG file
Insert the ante mortem image file name

1.3 Head angle	
Frontal (F)	Right and left ears are generally visible (or the area where the ear would be if covered by hair). Depending on the vertical tilt of the head, the chin and forehead might be more or less visible
Mid-Lateral Right (MR) **Mid-Lateral Left (ML)**	One ear (or the area where the ear would be if covered by hair) and one jawline are apparent, while a portion of the other side of the face is partially obscured. Also, part of the alae superior and lateral margin of the opposite side are visible, depending on the vertical tilt of the face
Lateral Right (R) **Lateral Left (LR)**	One ear (or the area where the ear would be if covered by hair) one jawline and the facial profile are visible. The opposite side is completely obscured.

1.4 **Camera Shot** – (Quentin 2015)
The camera shot is intended as the distance at which the camera is positioned in relation to the subject being photographed (Figure 24). Select from the relevant drop down list the distance camera-subject listed in the image**.**

Figure 24. Distance camera-subject with relevant photographic examples (Slatan (n.d) Young Businessman Full Length (Canva.com image [online image] Available at: https://www.canva.com [Accessed 28th August 2023])

1.5 **Source of the picture** (adapted from Cappella et al. (2021))	
Original paper photo (OP)	original photograph printed on photo paper
Scanned paper photo (SP)	scan of original photograph on photo paper.
Scanned copy photo (SC)	scan of a non-original paper photo
Original File (OF)	original digital file (usually .jpg, .png or .tiff)
Digital File (DF)	digital file, but unsure if it is the original or obtained from social media
Social media image (SM)	image downloaded from social media.
Picture of picture (PP)	image obtained by photographing a pre-existing digital or paper photograph.
Screenshot (SS)	Screen-shot or shot of a video frame

1.6 Facial Marks

Facial marks are intended any type of permanent or transient skin marks. This includes acne, age spots, moles, birthmarks, blemishes, freckles.

Insert a description of facial marks observed on the individual, when relevant.

⚠ *In some cases image artifacts (due to lighting, quality etc…) might be mistaken for facial marks. State it in the description when you unsure about the nature of the facial mark observed.*

1.7 Facial Alterations

Facial alterations are intended any type of permanent skin modification. These include scars, tattoos (tattooed eyebrows and lips included) and piercings.

Insert a description of the alteration observed on the individual, when relevant.

⚠ *In some cases image artifacts (due to lighting, quality etc…) might be mistaken for scars. State it in the description when you unsure about the nature of the mark observed.*

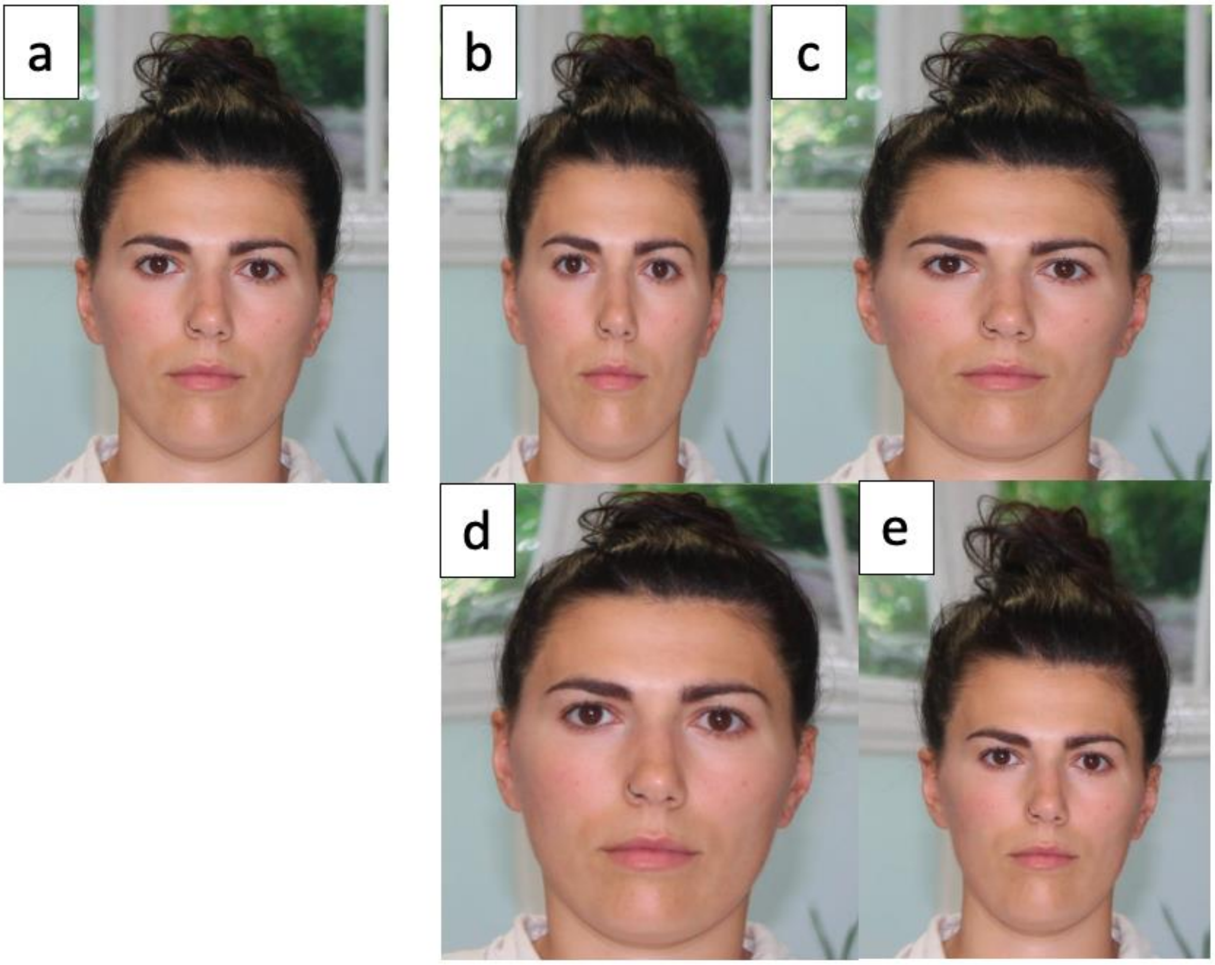
⚠ *In some cases individuals might be wearing fake piercings in a way that mimic the appearance of real piercings.*

1.8 Presence of Photographic Distortion

Photographic distortions refer to the way an object can appear bended or warped due to distance lens-object or camera lens or post production manipulation (Figure 25).

Type	Description	Score
Normal face	Face proportion appear normal – no visual distortion (Figure 25,a).	No
Barrell	The lines close to the edges appear to curve outward. The central features of the face might appear bigger (Figure 25,d).	Yes
Pin-cushioning	The lines close the edges appear to curve inward. The face gives the impression of being centrally squeezed or pinched (Figure 25,e)	
Thinner	Aspect-ratio manipulation can produce a thinner facial appearance. All the facial features are compressed horizontally and appear thinner (Figure 25,b).	
Wider	Aspect-ratio manipulation can produce a wider facial appearance. All the facial features are stretched horizontally and appear wider (Figure 25,c).	

Figure 25. Image with no distortion (a) and some common photographic distortions (b,c,d,e) (Photographs by author).



1.9 Light Exposure

Light exposure refers to the amount of light an image has and influence the visibility of some facial features (Figure 26).

Exposure intensity	Description	Score (Figure 4)
Well exposed	The amount of darkness and light of the image is balanced. No excessively dark areas or brength areas. All features should be well visible (Figure 26,1).	1
Slightly overexposed **Slightly underexposed**	The image is slightly bright or over exposed, some areas are more difficult to distinguish (Figure 4,2a). The image is slightly dark or underexposed, some areas are difficult to identify and features in shadow cannot be described in great detail(Figure 26,2b).	2
Overexposed **Underexposed**	The overall face is very bright, loss of shadows and details are not easily distinguishable (Figure 26,3a). The overall face is very dark, only few brightest details are now visible(Figure 26,3b).	3

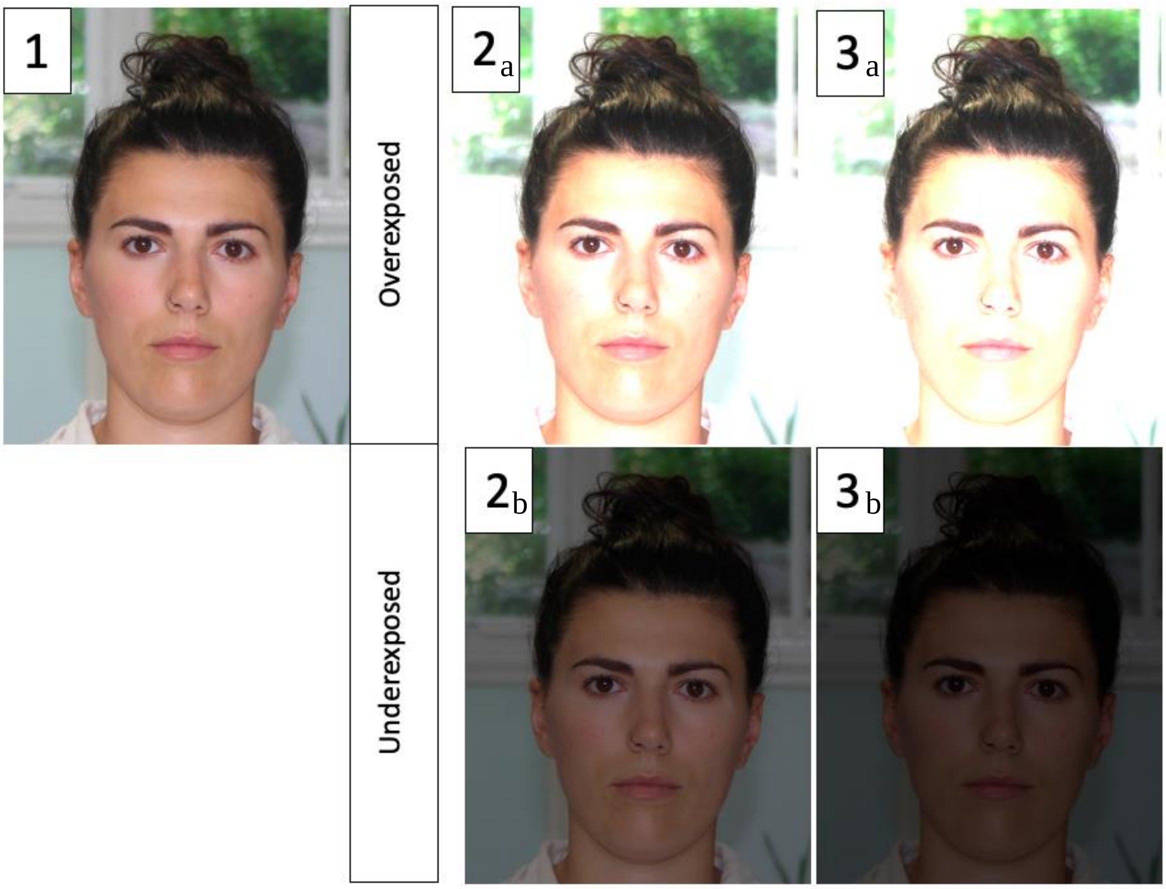


Figure 26. Different levels of underexposure and overexposure in photographs (photographs by the author).

1.10 Noise

Noise refers to the spots or grain noticeable in the image that can be the results of low light, camera settings or, in some cases, deliberate post production filters (Figure 27).

⚠*Noise is different from pixel. Noise appears as random spectacles, while pixels are the unit of an image visible as small scale squares.*

⚠*In some cases, high noise levels can make identification of facial marks difficult. Note any relevant observation in the 1.15 Note or in the 1.6 Facial marks boxes.*

Level of noise	Description	Score (Figure 27)
No noise	The image appears smooth and no grains are visible. If the image is low quality you might observe blocks (pixels)	1
Medium noise level	The image appears to have some noticeable fine grains. Facial details and marks on the skin are generally still visible.	2
High noise level	The image appears to have numerous grains of difference sizes and colours that cover the whole surface. The colour of the image might be altered in some areas. The image appears rough and the skin is a lacking of fine details. Identifying facial marks might be difficult at this stage.	**3**

Figure 27. Examples of different type of noise that can affect an image (Photographs by author).

1.11 Image alteration

Image alteration refers to editing images to improve or change the appearance. There is a variety of alterations that can be performed and that can change the appearance of the subject drastically.

Select the appropriate one using the drop-down list.

Alteration	Description
No alteration	Images appear to have not been manipulated and should represent a truthful depiction of the subject (Figure 28, a).
Colour correction	Examples include: saturation of the images by increasing colour intensity, sepia effect, greyscale effect (Figure 28, f).
Photo-retouching	Examples include: skin retouching to reduce the appearance of wrinkles and line. The face usually appears brighter and flat; Teeth whitening; background removal; eyes colour correction (Figure 28, g).
Other filters	Alterations that are not colour corrections or photo-retouching .
Multiple alteration	Images that present multiple alterations (Figure 28.h).

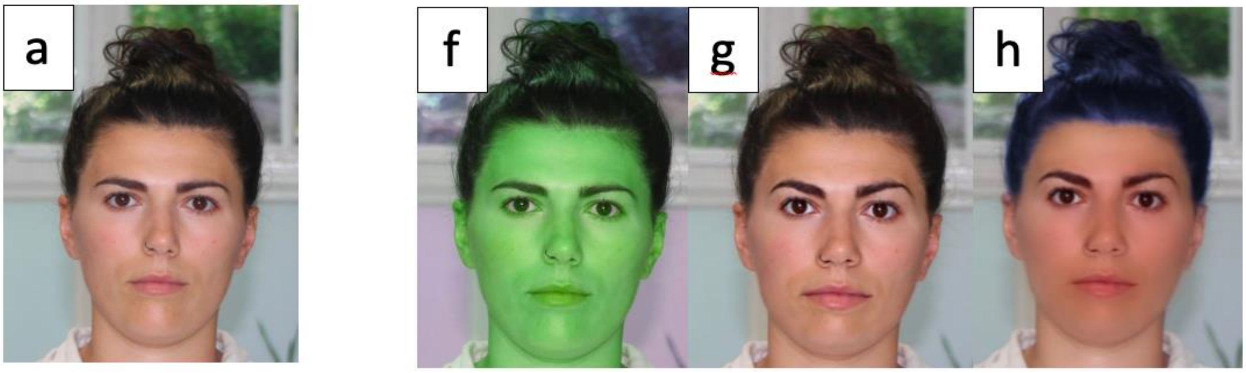


Figure 28. Examples of image editing : colour misrepresentation [g]; photo-retouching [g]; multiple alteration [h]. [a] show the original photograph with no alteration (Photographs by author).

1.14 Quality Score

The quality score is the six-point (1 to 6) evaluation scale introduced by Schüler and Obertová (2020).

Select from the drop-down list the quality level that better that better describe the image. Once the appropriate level is selected, the box will automatically turn green, yellow or red. The colours indicate the suitability of the image for comparison (Figure 29).

Quality Score	Description	Colour	Suitability
1 **Very Good**	The quality of the image corresponds particularly well to the requirements of a morphological analysis. The resolution, sharpness, and illumination of the image are excellent. Object is not obscured, and image artifacts are not present. Small-scale facial features and skin structures are visible and can be described in detail.	Green	Acceptable image quality, small and large facial details are visible. Strong positive level of support in the evaluation phase might be expressed.
2 **Good**	The quality of the image fully meets the requirements of a morphological analysis. Resolution, sharpness, and illumination are good. The percentage of object overlay, and image artifacts is a maximum of 5%. The small-scale facial features and skin structures are still visible, but details are unclear.		
3 **Satisfactory**	The quality of the image corresponds to the general requirements of a morphological analysis. A few deficits can be detected in the resolution, sharpness, or illumination. The percentage of object overlay or image artifacts is greater than 5% but smaller than 25%. Small-scale features can be described; skin structures are no longer visible.		
4 **Sufficient**	The quality of the image is sufficient to meet the requirements of a morphological analysis. In several areas of the image, deficits are detected in the resolution, sharpness, or illumination. The percentage of object overlay and image artifacts is greater than 25% but smaller than 75%. Small-scale features can be described to a very limited extent or not at all.	Yellow	Lower quality and restricted features visibility. If image is used alone, **strong positive** level of support in the evaluation phase are discouraged.
5 **Poor**	The quality of the image still meets the requirements for a morphological evaluation despite clear deficiencies; an evaluation is hardly possible without optimised comparative images. The resolution, sharpness, and illumination show clear deficiencies. The percentage of object overlay and image artifacts is more than 75% but less than 80%. Only large-scale features can be described. Insufficient		
6 **Insufficient**	The quality of the image is completely insufficient for a morphological analysis. The resolution, sharpness, and illumination are deficient, or the color depth of the image is completely insufficient (less than 8 bit). The percentage of	Red	Very low quality, insufficient for evaluation. If only image available,

	object overlay and image artifacts exceeds 80%. The number of describable features is insufficient for an evaluation.	Strong Positive or Positive level of support during the evaluation phase are discouraged.

Figure 29. Examples of the AM descending six-level scale of image quality Each image is associated with a specific number that corresponds to the relative quality score as detailed in section 1.14 (Schüler and Obertová, 2020).

1.12 Distractions

Some objects can obscure facial features in an image.

Select the appropriate one using the drop-down list.

⚠*If other elements such as lighting, head pose etc… are obscuring some features this should be noted in the relevant section and a detailed descriptions of what features are obscured should be made in the 1.15 Notes box.*

Distraction	Description
No	No feature is obstructed by an object.
Clothes	Hoodies might cover the head an the neck areas
Glasses	Glasses and sunglasses can cover eyes, completely or partially.
Jewelry	Big piece of jewelry such as necklaces and earrings might partially obscure ears and neck.

Hat	Hats might cover completely or partially the upper half of the face, including forehead and ears.
Scarf	Scarves, headscarves and balaclavas might cover the upper and lower half of the face, including mouth, nose and chin.
Hair	Some hairstyles such as bangs, and long hair worn on the side can cover forehead, eyebrows, and cheeks. Also, facial hairs might cover the lower half of the face depending on their length.
Others	Other elements such as surgical masks, ceremonial veils etc… might partially or totally cover some facial features.

1.13 Expressions

Facial expressions can affect the appearance of certain facial components. For example, when smiling muscles around the cheeks are activated and wrinkles and lines can appear and cheeks lift, making the cheekbones more prominent.

Expression	Description
Smile (no teeth)	The lateral corners of the mouth are upturned, and the lips are closed, touching at the midline point. The lateral end of the eyes might crinkle. The teeth are not visible.
Smile (teeth)	The lateral corners of the mouth are upturned, and the lips are open, not touching at the midline point. The lateral end of the eyes might crinkle. The superior and inferior rows of frontal teeth are visible.
Neutral (no teeth)	The lateral corners of the mouth are horizontal or downturned and the lips are closed, touching at the midline point. The eyes are normally open. The teeth are not visible.
Neutral (teeth)	The lateral corners of the mouth are horizontal or downturned and the lips are slightly open, not touching the midline point. The eyes are normally open The teeth are visible, generally only the -incisors.
(Other)	The lateral corner of the mouth might be unevenly position and the mouth might be closed or open. Teeth might or might not be visible. The eyes and nose might be distorted by the facial expression.

1.15 **Notes**

You may add any additional information relevant to the ante mortem analysis in this section.

This could include notes about obstructing elements. If there is no additional information to include, this section may be left blank.

PHASE 1 – PM ANALYSIS

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **Phase 1-PM Analysis** sheet**.** Once there, follow the below instructions to complete the columns.

During this stage, you will evaluate the suitability and quality of the PM images by assessing various factors, such as lighting, resolution, feature visibility, obstructions, decomposition changes, and trauma. Notably, post mortem changes can significantly impact the accuracy and confidence level of the final result.

Unlike AM images, which come in various formats from different sources, PM images are usually taken during post-mortem examinations with high-quality cameras and different angles. Therefore, no assessment will be made regarding image quality.Additionally, to rank the extent of decomposition visible in each image, the protocol uses the decomposition categories and stages for the head and neck developed by Megyesi, Nawrocki and Haskell (2005). It has been found that assessing decomposition-related changes using photographs and video frames is a dependable approach, and basing evaluations on what is visible in the images has been shown to be reliable (Dabbs, Bytheway and Connor, 2017).

1.16 PM case

Insert the ante mortem case identifier code.

1.17 Total Number of images

Insert total number of images available for the PM case.

1.18 Dentition images

Insert number of close up images of dentition.

1.19 Location

Select the scenario where the PM images where taken.

Scenario	Description
Scene	Images were captured at the location where the body was found. The individual might still be in their clothing.
Mortuary	Images were taken during the routine autopsy. The images might depict the individual before or after the post mortem procedure.
Other	Images may also be taken during other procedures, such as during embalming or when the deceased is in the casket.
Multiple	The images available were taken at least in two different locations. For example, images might depict the individual where the body was found and during the autopsy.

1.20 Facial Marks

Facial marks are intended any type of permanent or transient skin marks. This includes acne, age spots, moles, birthmarks, blemishes, freckles.

Insert a description of facial marks observed on the individual, when relevant.

⚠ *In some cases image artifacts (due to lighting, quality etc…) might be mistaken for facial marks. State it in the description when you unsure about the nature of the mark observed.*

1.21 Facial Alterations

Facial alterations are intended any type of permanent skin modification. These include scars, tattoos (tattoed eyebrows and lips are included) and piercings.

Insert a description of the alteration observed on the individual, when relevant.

⚠ *In some cases image artifacts (due to lighting, quality etc…) might be mistaken for scars. State it in the description when you unsure about the nature of the mark observed.*

⚠ *In some cases individuals might be wearing fake piercings in a way that mimic the appearance of real piercings.*

1.22 Decomposition Changes (from Megysei, Nawrocki, Haskell 2005)

This stage employs decomposition stages for the head and neck originally published by Megyesi, Nawrocki and Haskell (2005).

The decomposition changes are classified into four categories: (A) Fresh, (B) Early Decomposition, (C) Advanced Decomposition, and (D) Skeletonization. Each category is further divided into progressive stages, which are identifiable by an abbreviation. You are required to choose the most suitable stage based on its corresponding abbreviation.

⚠ *You do not need to manually input the decomposition score at this stage. The Decomposition Score will be calculated automatically in section 1.26.*

Decomposition changes			**Decomposition Score (See 1.26)**	
A. Fresh	1.	Fresh, no discoloration	A1	**1pt**
B. Early Decomposition	1.	Pink-white appearance with skin slippage and some hair loss	B1	**2pts**
	2.	Gray to green discoloration: some flesh still relatively fresh	B2	**3 pts**
	3.	Discoloration and/or brownish shades particularly at the edges, drying of nose, ears, and lips	B3	**4 pts**
	4.	Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face might be present	B4	**5 pts**
	5.	Brown to black discoloration of flesh	B5	**6 pts**
C. Advanced Decomposition	1.	Caving in of the flesh and tissues of eyes and throat.	C1	**7 pts**

	2.	Moist decomposition with bone exposure less than one half that of the area being scored.	C2	**8 pts**
	3.	Mummification with bone exposure less than one half that of the area being scored.	C3	**9 pts**
D. Skeletonisation	1.	Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.	D1	**10 pts**
	2.	Bone exposure of more than half the area being scored with desiccated or mummified tissue.	D2	**11 pts**
	3.	Bones largely dry but retaining some greases.	D3	**12 pts**
	4.	Dry bone.	D4	**13 pts**

1.23 Bloating

Bloating is a post-mortem change that typically occurs within a few hours to several days after death. This change is a result of bacterial activity within the body, which produces gases that cause the body to swell and become distended. The face is particularly susceptible to bloating, with the most noticeable swelling occurring in the cheeks, eyelids, eyeballs, and lips,(Clark, Worrell and Pless, 1997). The bloatin**g** can make the face appear larger and distorted and along with insect activity, is considered the most influential factor for changes in facial appearance (Wilkinson and Tillotson, 2012).

Describe the degree and distribution of bloating present on the face of the deceased individual. Additionally, please indicate which facial features are affected by the bloating.

1.24 Trauma

Severe and extensive head trauma can prevent morphological comparison **(Caplova, 2017)**. Facial trauma may include incisions, stab wounds, chops, scratches, abrasions, bruises, or bites. Select the appropriate term from the dropdown list to describe the extent of the trauma observed.

⚠ *Provide a detailed description of injuries observed on the face in the Notes column 1.27.*

Extent of the facial trauma	Description
More than half (of the face)	"More than half of the face" generally means that the damage or alteration to the face affects more than 50% of the total facial area.
Less than half (of the face)	"Less than half of the face" typically means that the damage or alteration to the face affects less than 50% of the total facial area.

No	"No " means that there are no signs or indications of physical injury to the body.

1.25 Obscuring Matter

The term "obscuring matters" refers to any element that obstructs or hides facial features. This may include blood or other purging fluids expelled from the nose, ears, mouth, or eyes, debris, soil, hair, or clothing. Select the appropriate term from the dropdown list to describe the extent of the obstruction.

⚠ *Provide a detailed description of any obstructed facial features in the Notes column 1.27*

Extent of the facial obscuring	Description
More than half (of the face)	"More than half of the face" generally means that the elements obscuring the face cover more than 50% of the total facial area.
Less than half (of the face)	"Less than half of the face" typically means that the obscuring the face cover more than 50% of the total facial area.
No	"No " means that there are no elements obscuring the facial features.

1.26 Decomposition Score (from Megysei, Nawrocki, Haskell 2005)

Every decomposition change stage selected in section 1.22 is associated with a corresponding numerical value 1 to 13.

Once a selection is made in column 1.22, the value will be calculated automatically. The lowest possible score a case can receive is 1, which corresponds to stage A1 (fresh, no discoloration), while the highest possible score is 13, corresponding to stage D4 (dry bone).

Decomposition changes (See 1.22)	Decomposition Score
A1	1pt
B2	3 pts
B3	4 pts
B4	5 pts
B5	6 pts
C1	7 pts

C2	8 pts
C3	9 pts
D1	10 pts
D2	11 pts
D3	12 pts
D4	13 pts

1.27 **Notes**

You may add any additional information relevant to the post-mortem analysis in this section. This could include notes about previous observations, such as traumatic injuries or obstructing elements. If there is no additional information to include, this section may be left blank.

PHASE 2 – FACIAL REVIEW

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **Phase 2-Facial Review** sheet**.** Once there, follow the below instructions to complete the columns.

The facial review takes advantage of the unique and natural ability of humans to compare faces by looking at the face as a whole, recognising various information including gender, age range and population affinity without focusing on single parts in isolation (ENFSI, 2018).
The AM and PM images of individuals will be assessed rapidly to determine whether two individuals could potentially be a match, prior to conducting a detailed feature-by-feature comparison, by using a decision making flowchart available below. The result of the flowchart will inform the decision.

Instructions:

I. Fill in the AM and PM cases in columns 2.1 and 2.2 of the Excel spreadsheet according to the provided instructions.
II. Utilise the "Facial review flowchart" depicted in Figure 30 to evaluate if two individuals may be a possible match.
III. Record the outcome determined from the flowchart in columns 2.3 and 2.4 of the Excel spreadsheet as directed.

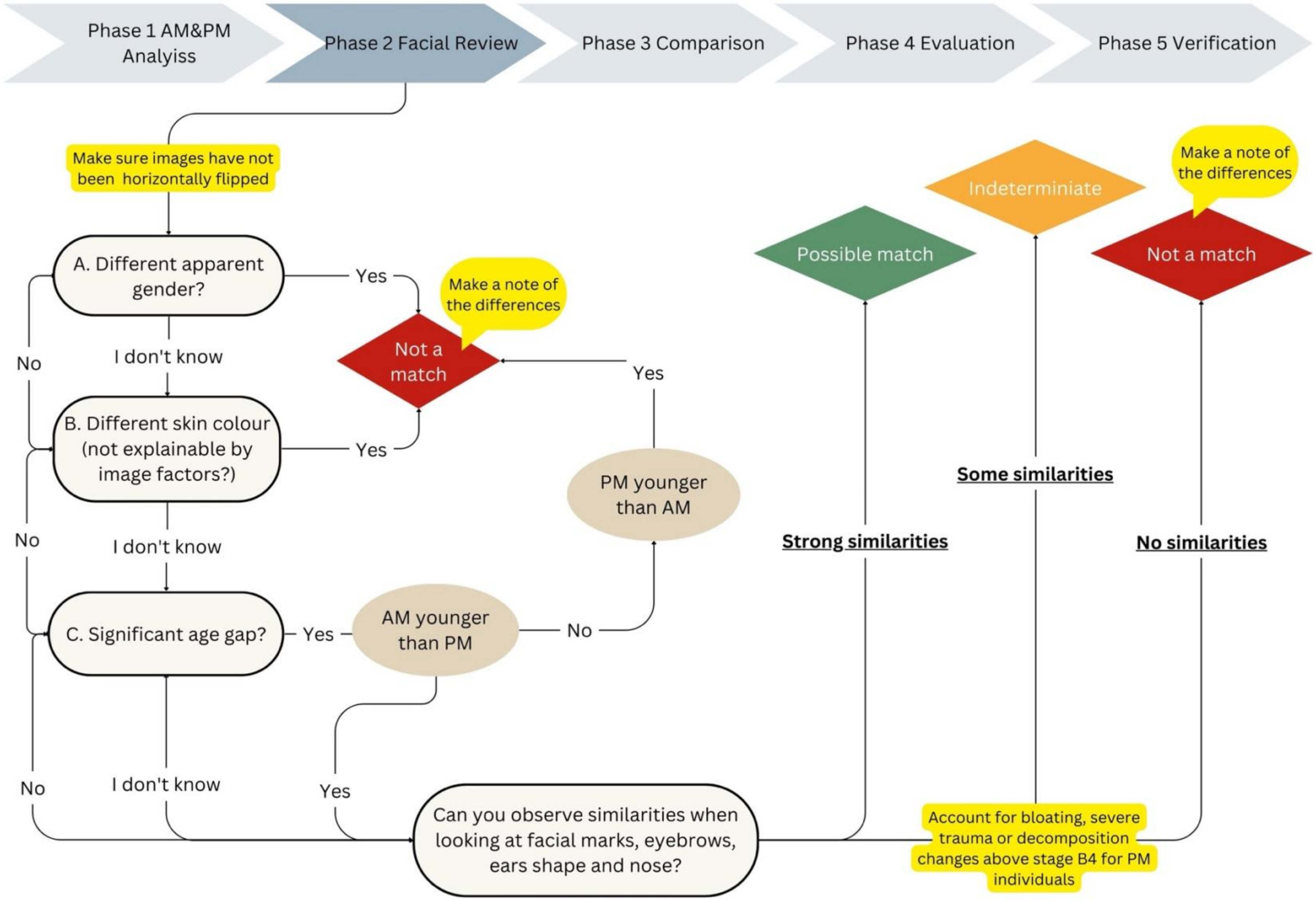


Figure 30. Facial Review Flowchart

2.1 PM case

Insert the post mortem case identifier code you are comparing.

2.2 AM case

Insert the ante mortem case identifier code you are comparing.

2.3 Facial review flow result

Provide the correct response based on the results of the post mortem facial comparison flow chart using the given abbreviation.

Abbreviation	Description
P	“Potential match “
I	“Indeterminate”
N	“Not a match “

2.4 Action

According to the results inserted in 2.3, the action is **automatically** generated in this box.

No selection or insertion is required on your part.

Action	Description
Progress to comparison	If "P" or "I" is entered in the 2.3 Facial Review flow results, the box will change its color to green and show the message "Progress to comparison". The
Not a match	If "N" is entered in the 2.3 Facial Review flow results, the box will change its color to red and show the message "Not a match".

2.5 **Notes**

The purpose of this section is to briefly report differences found during the quick facial review and provide a rationale for why they were deemed as not matching.

PHASE 3- COMPARISON AND PHASE 4-EVALUATION

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **Phase 3-Comparison** sheet**.** Once there, follow the below instructions to complete the columns.

Also, Open similar head pose ante mortem and post-mortem images of the considered case. You can use any image software.

In the comparison phase, a thorough analysis of facial components, characteristics, and descriptors in both pre and post-mortem images is conducted. To aid in observations, images may be resized or rotated, but it is preferable to compare images that were captured under similar camera angles, poses, expressions, and lighting conditions (FISWG, 2018; FISWG, 2019a). During the assessment of similarities and differences, practitioners may use markups and annotations such as circles, boxes, arrows, and numbers, but they should always refer back to the original images to evaluate minutiae (FISWG, 2019b). These markups and annotations should follow a consistent format in accordance with the Facial Image Comparison Best Practices for Markups and Annotations - FISWG (2019b).

Evaluation

Once the features have been analysed and compared, a decision must be made regarding whether each feature is similar, different, or indeterminate. Use the level of support listed in 3.16 down below.

3.1 PM case
Insert the post mortem case identifier code.

3.2 AM case
Insert the ante mortem case identifier code.

3.3 to 3. 15 Facial Features

Examine the facial features according to the instructions provided in "Facial Image Comparison Feature List for Morphological Analysis" guideline. To ensure consistency and clarity in the analysis, it is recommended to use state if the feature are similar, somewhat similar, different or inconclusive.

- 3.3 Facial Marks
- 3.4 Facial Alterations
- 3.5 Face shape/outline
- 3.6 Hairline/Forehead
- 3.7 Eyes
- 3.8 Cheeks
- 3.9 Eyebrows
- 3.10 Nose
- 3.11 Ears
- 3.12 Mouth
- 3.13 Chin and Jawline
- 3.14 Facial Hair

- 3.15 Facial Lines

3.16 Rationale for difficult comparison

The rationale for difficult comparisons refers to the reasons behind why certain comparisons may be challenging or complicated to make.

Select the factor that better describe it from the drop-down list.

Rationale	Description
AM image quality	The majority of the AM images are low quality (with low resolution, poor lighting, blurriness, digital alterations). Consequently, these factors have made it challenging to discern facial details required for accurate comparisons.
PM changes/trauma	The extent of post-mortem changes or traumatic injuries has made photographic comparisons challenging.
Time lapse	AM and PM photographs were taken at different times/age and comparisons was difficult due to changes in appearance that may occur over time, such as changes in weight, hair, or skin tone.
Other	Other elements made comparisons difficult.
None	The comparison was carried out without encountering any difficulties.

3.16 Level of support (Adapted from Moreton (2021))

The level of support in image comparison refers to the degree of confidence that can be attributed to a particular conclusion made based on the comparison of images. It is a measure of how strongly the available evidence supports a particular interpretation or conclusion.

To determine the level of support, refer to the description below and follow the instructions provided in Figure 5.

Choose the option from the drop-down menu that best describes the strength of the observation.

Level of support	Description
Strong support	The evidence provides strong support for the propositions that the images depict the same individual.
Support	The evidence provides support for the propositions that the images depict the same individual.
Moderate support	The evidence provides moderate support for the propositions that the images depict the same individual.
Limited support	The evidence provides limited support for the propositions that the images depict the same individual.
No support	The evidence provides no support for the propositions that the images depict the same individual.

3.17 Identifying indicators visibility used for comparison adapted from Cappella et al. (2021))
If you choose "strong support" in column 3.16 Level of support, specify in this section the features among ears, facial marks, facial alterations (e.g., scars or tattoos) and teeth that were visible and matched between the two individuals being compared.

3.18 Notes
The note section can be utilised to include supplementary comments about the comparison case. If another comparison has been previously conducted and was found to have strong support, you can indicate in the note section that a brief analysis was carried out to verify that the current comparison is negative. If the comparison is negative, the note section can also be used to specify the major dissimilarities observed between the two individuals. This information can be helpful in understanding why the comparison was deemed negative and assist in the validation stage.

PHASE 4- EVALUATION (SUMMARY)

Access the "PM Photographic Facial Comparison Process" Excel spreadsheet and navigate to the **Phase 4-Evaluation** sheet**.** Once there, follow the below instructions to complete the columns.

Phase 4-Evaluation tab is interlinked with Phase 3-Comparison, displaying analysed AM and PM (3.1 and 3.2), alongside the chosen Level of Support (3.16) and the Identifying Feature (3.17) that contributed to determining the level of support.

AM case
Interlinked to Phase 3-Comparison Tab column 3.1

PM case
Interlinked to Phase 3-Comparison Tab column 3.2

Level of support
Interlinked to Phase 3-Comparison Tab column 3.17

Identifying features (from Cappella et al., 2022)
Interlinked to Phase 3-Comparison Tab column 3.18

Notes
The note section can be use to include supplementary comments.

STAGE 5- VERIFICATION

To mitigate these concerns, a verification stage is often employed, allowing for the examination to be independently and blindly verified by another examiner. This verification stage adds an important layer of objectivity and rigour to the analysis process, reducing the potential for errors and increasing the accuracy of the results.

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APPENDIX B - Post Mortem Photographic Facial Comparison Form

Excel Template available at:

https://ljmumy.sharepoint.com/:x:/g/personal/lsampizz_ljmu_ac_uk/Ea5NB9fht7ZDt_vhkcHoChUBE--ICTIzFSCMcGNekfynPw?e=dhaQYN

Appendix C- Main study raw data

Appendix C- Main Study Raw Data

Table 1. AM sample characteristics summary

Presented gender AM	**n of subjects**	**%**
Female AM	12	41%
Male AM	17	59%
Indeterminate	0	0%
Total	29	
Skin colour AM	**n of subjects**	**%**
Light AM	15	52%
Dark AM	14	48%
Total	29	
Img quality score (only AM)	**n of images**	**%**
Img Quality Score 1	1	1%
Img Quality Score 2	10	10%
Img Quality Score 3	23	24%
Img Quality Score 4	16	16%
Img Quality Score 5	32	33%
Img Quality Score 6	15	15%
	97	
Img quality score divided by suitability colour	**N of images**	**%**
Orange (4-5 Image Score)	48	49%
Green (1-3 Image Score)	34	35%
Red (6 Image Score)	15	15%
Total	97	

Table 2. *PM sample characteristics summary*

Apparent sex PM	**Number of individual**	**%**
Female PM	11	38%
Male PM	17	59%
Indeterminate PM	1	3%
Total	29	100%
Skin colour PM	**Number of individuals**	**%**
Light PM	15	52%
Dark PM	14	48%
Total	29	100%
Decomposition points - 1 to 13	**Number of individuals**	**%**
Decomposition score 1	22	76%
Decomposition score 2	2	7%
Decomposition score 3	3	10%
Decomposition score 4	1	3%
Decomposition score 6	1	3%
Total	29	

Appendix C- Main Study Raw Data

Table 3. Correspondant matches

PM	AM
A	14
AA	27
AB	29
AZ	28
BS	10
C	21
DS	17
E	3
F	15
G	12
H	19
I	11
JO	22
K	23
L	25
M	7
N	5
O	20
P	24
QM	4
R	16
S	2
T	18
U	6
V	13
W	1
X	8
YT	9
Z	26

Appendix C- Main Study Raw Data

a.1 AM CODE	a.2 Presented gender	a.3 Skin colour	a.4 Estimated age (note if extreme)	a.5 Images available*	a.6 Notes
1	F	Dark		2	
2	F	Dark		7	
3	M	Light	old adult	1	
4	F	Dark		5	
5	M	Dark		5	
6	F	Dark		1	
7	M	Light		2	
8	F	Dark		10	
9	M	Dark		7	
10	F	Dark		2	
11	M	Light		1	
12	M	Light		7	
13	F	Dark		2	
14	F	Dark		2	
15	M	Light		2	
16	M	Dark		4	
17	M	Light		4	
18	F	Dark		3	
19	M	Light		2	
20	M	Dark		5	
21	F	Light		1	
22	M	Light		1	
23	M	Light	old adult	1	
24	M	Dark		8	
25	F	Light	young adult	2	
26	F	Light		5	
27	M	Light		3	
28	M	Light		2	
29	M	Light	old adult	1	

Figure 1. AM List

Appendix C- Main Study Raw Data

b.1 PM code	b.2 Presented gender (sex if known)	b.3 Skin colour	b.4 Esimated age	b.5 Images available	b.6 Notes
A	F	Dark		10+	
AA	M	Light		10+	
AB	M	Light	old adult	10+	
AZ	M	Light		1 to 3	
BS	F	Dark		10+	
C	F	Light		10+	
DS	M	Light		10+	
E	M	Light	old adult	10+	
F	M	Light	old adult	10+	
G	M	Light		10+	
H	M	Light		10+	
I	M	Light		1 to 3	
JO	M	Light		4 to 9	
K	M	Light	old adult	10+	
L	F	Light		10+	
M	M	Light		10+	
N	M	Dark		4 to 9	
O	M	Dark		1 to 3	
P	M	Dark		1 to 3	
QM	F	Dark		4 to 9	
R	M	Dark		1 to 3	
S	F	Dark		1 to 3	
T	F	Dark		4 to 9	
U	F	Dark		1 to 3	
V	F	Dark		4 to 9	
W	F	Dark		4 to 9	
X	F	Dark		1 to 3	
YT	M	Dark		4 to 9	
Z	I	Light		10+	

Figure 2. PM List

Appendix C- Main Study Raw Data

1.16 PM Code	1.17 Tot number of image	1.18 Teeth images	1.19 Location	1.20 Facial Marks	1.21 Facial Alterations			1.22 Decomposition changes (from Megysei, Nawrocki, Haskell 2005)	1.23 Bloating	1.24 Trauma	1.25 Obscuring matter (clothes/blood etc	1.26 Decomposition Score	1.27 Notes
	Insert total number of images available	Insert number of images showing teeth	Select scenario where the PM were taken	Skin marks	Scar/s	Tattoo/s	Piercing/s						
A	5	1	Scene	multiple big mole near L ear and L cheek, L nose near alae, moles on forehead			R and L lobe piercings; nostril piercing	A1		No	No	1	
AA	10	0	Mortuary		scar like feature on L eyebrows towards the medial end - unsure			A1		Less than half	Less than half	1	Camera in frontal image is close to subject, slightly distorting the features (barrel-like distortion)
AB	16	0	Mortuary					B2		No	Less than half	3	Dry skin around cheeks and nose. Bruises and darkened skin aroound cheeks and forehead. Facial hair (beard) covering mouth and jaw.
AZ	3	0	Mortuary		Skin mark (mole) dark on the R lower cheek		Mark on the visible R ear on the lobe that looks like a piercing - unsure	A1	Some sweeling around the nasal root near the medial eyebrows	Less than half	Less than half	1	various traumatic marks on forehead L side , R eyebrow, and upper lip covering the cupid's bow; redness around the medial eyebrows and nasal body
BS	12	3	Scene	Mole on chin	Scar on chin and on L forehead near hair line but they both could be the sign of the bag on the face?		R and L lobe piercings	A1		No	Less than half	1	Mole chin, scar middle chin?
C	22	0	Mortuary				R and L lobe piercings	B2		No	Less than half	3	R ear look bigger-pictures taken during autopsy when brain was exposed, loose skin around that area, Nose looks deviated towards the L, could be trauma after death/body bag or other post-mortem causes
DS	41	0	Mortuary	Pattern of small moles on the R cheek, one visible on the L cheek				A1		No	No	1	

Figure 3. Phase 1 AM Analysis

Appendix C- Main Study Raw Data

1.16 PM Code	1.17 Tot number of image	1.18 Teeth images	1.19 Location	1.20 Facial Marks	1.21 Facial Alterations			1.22 Decomposition changes (from Megysei, Nawrocki, Haskell 2005)	1.23 Bloating	1.24 Trauma	1.25 Obscuring matter (clothes/blood etc	1.26 Decomposition Score	1.27 Notes
	Insert total number of images available	Insert number of images showing teeth	Select scenario where the PM were taken	Skin marks	Scar/s	Tattoo/s	Piercing/s						
E	18	0	Mortuary	Mark on the R chin, could be dirt				B2		No	No	3	Post mortem skin blue patches visible on the face,
F	29	0	Mortuary	Mark on the R neck near the jawline; R nasal body below the medial R canthus				A1		No	No	1	
G	17	0	Mortuary	Dark facial mark (mole) on mid R cheek and on the chin				A1	Sweeling of the nasal body and tip	No	No	1	Trauma on the chin and bruise on the L cheek, bruise under the columella above the upper lip
H	12	5	Multiple					A1		No	No	1	Most of the images are too close suffering from barrell distorsion.
I	2	0	Mortuary	Number of facial spots around cheeks and nose, one on the chin below the R mouth corner is particularly visible				A1		No	No	1	Even is fresh, some redness around nasal area near the cheeks and on the cheeks near the hairline. Also Frontal picture has been taken very close to the face, some barrell distorsion to be aware of.
JO	5	0	Mortuary					A1	Some swelling on lower lip, L cheek, but could be just the head position	Less than half	More than half	1	Forehead, nose, mouth area and lower L cheek covered in blood. Nose looks deviated towards the left, could be due t trauma or position the body was found or body bag pressure. Also, photos suffer from barrel distorsions-faces too close to the camera
K	10	0	Mortuary					A1		No	More than half	1	In some pictures blood covering most of the face, darker skin tint around ears and neck visibkle form lateral views
L	62	0	Mortuary	Moles under L eye, Moles next to R mouth corner Number of moles on R cheek			R and L lobe piercings	A1		No	No	1	

Appendix C- Main Study Raw Data

M	38	0	Mortuary					B3	Swelling around jawline, cheeks and nose	No	No	4	Discolouration of the skin, blue/green skin neck, cheeks + sagging of the jawline near ears + small mark on forehead)could be just trauma)
N	5	1	Scene	dark mark under the L eye on the cheek				A1		No	No	1	Eyes coloured has changes after death
O	3	0	Scene					B5	Swollen face, also R eye and area around the neck, R cheek	No	Less than half	6	Severe discolouration due to post mortem changes. Images particularly underexposed so required correction.
P	3	0	Scene					B1	It look like there is some swelling around nose and lips	No	More than half	2	Severe discolouration/skin slippage around nose, eyes, forehead, nose presenting lacerations.
QM	6	0	Scene	Moles between eyebrows, dark patch of skin below L eye			R and L lobe piercings	A1		No	Less than half	1	Nose appereas squeezed from the side, It might be due how the body was laying or pressure of the body bag.
R	5	1	Scene	Small mole above the L eyebrow, unsure if it's dirt or a mole	Scar-like feature on the L eyebrow-unsure			A1		No	No	1	
S	2	0	Scene				R and L lobe piercings	A1		No	Less than half	1	Sunken eyes
T	7	2	Scene	Multiple moles and dark acne spots on the R cheecks and temple forehead area, couple of spots also located on the L cheeck and chin	Scar on the R eyebrow + also on the L (?) + smal scar-like mark on forehead (?)			A1		No	No	1	

Appendix C- Main Study Raw Data

1.16 PM Code	1.17 Tot number of images	1.18 Teeth images	1.19 Location	1.20 Facial Marks	1.21 Facial Alterations			1.22 Decomposition changes (from Megysei, Nawrocki, Haskell 2005)	1.23 Bloating	1.24 Trauma	1.25 Obscuring matter (clothes/blood etc	1.26 Decomposition Score	1.27 Notes
	Insert total number of images available	Insert number of images showing teeth	Select scenario where the PM were taken	Skin marks	Scar/s	Tattoo/s	Piercing/s						
U	3	0	Scene	Couple of dark acne spots on L and R cheek,	spot/scar on L nose (?)		R and L lobe piercings	A1		No	No	1	
V	6	1	Scene		small scar on the center or forehead		R and L lobe piercings, double in R lobe	A1		No	Less than half	1	
W	5	0	Scene	Prominent dark skin mark (mole) on the chin, below the L lower lip border + couple of more small dark moles on the L and R cheeks		crux tattoo (fading) on the forehead		A1		No	No	1	
X	3	0	Scene	multiple dark moles pattern on cheeks, nose and foehead. In particular, large dark mole on R nasal root, R nasal body				A1		No	No	1	Zip mark on the forehead, probably body bag impression,
YT	4	1	Scene					B1		No	Less than half	2	Eyes coloured has changes after death + innatural shape - should not be considered
Z	19	0	Mortuary	Mark on the R nasal body, 2 marks on the L cheeks near eye. Couple of marks and blemishes on R cheek.	Forhead extensive possible scar, located on the L forehead	Tattoed eyebrows ?	R and L lobe piercings (?)	A1	R side of the face, involving cheekcs and jaw	No	No	1	

Appendix C- Main Study Raw Data

Table 4. Phase 2 Facial Review results. In green are highlighted the AM-PM pairs progressed to Phase 3 Comparison

2.0 Presented gender *Female(F) Male(M) Indeterminate (I)*	**2.1 PM code**	**2.2 AM code**	**2.3 Facial Review flow results** *Insert Yes (Y), No (N), I (Indeterminate)*	**2.4 Action**	**2.5 Notes** *Insert any comment regarding differences*
F	A	1	N	Not a match	facial proportions, eyebrows, face shape
F	A	2	N	Not a match	facial shape and proportions, eyebrows shape and thickness, moles in AM,
F	A	4	P	Progress to comparison	
F	A	6	N	Not a match	Facial shape, nose dimension relative to the face, eyebrows, mole PM
F	A	10	N	Not a match	Nose, mole in PM, face shape, eyebrows
F	A	13	N	Not a match	elongated face in AM, forehead mark ?, nose shape, mole in PM
F	A	8	P	Progress to comparison	
F	A	18	N	Not a match	nose position and size, moles in PM, eyebrows, teeth
F	A	14	P	Progress to comparison	
M	AA	3	N	Not a match	Age difference

M	AA	12	I	Progress to comparison	
M	AA	7	N	Not a match	Age difference
M	AA	11	N	Not a match	Ear protrusion/shape, nose and eyebrows shape, overall facial appearance
M	AA	15	N	Not a match	Age difference
M	AA	17	N	Not a match	Head shape, enlarged superior half of the face in PM, eyebrows and brow ridges
M	AA	19	N	Not a match	Age difference
M	AA	22	N	Not a match	Age difference
M	AA	23	N	Not a match	Age difference
M	AA	27	P	Progress to comparison	
M	AA	28	I	Progress to comparison	AM Could be an old image
M	AA	29	N	Not a match	Age difference
M	AB	3	I	Progress to comparison	
M	AB	7	N	Not a match	receding forehead and hairline, eyebrows, facial proportions
M	AB	11	N	Not a match	facial proportions, eyebrows, face shape
M	AB	12	N	Not a match	Ear protrusion
M	AB	15	N	Not a match	Hair, eyebrows, facial shape
M	AB	19	N	Not a match	Facial proportions, eyebrows

M	AB	17	N	Not a match	head shape, large forehead, facial proportions, elongated face
M	AB	23	I	Progress to comparison	
M	AB	22	N	Not a match	Facial shape, eyebrows, recessive hairline
M	AB	27	N	Not a match	Ear protrusion, hairline, face shape
M	AB	28	N	Not a match	Mole, head shape
M	AB	29	P	Progress to comparison	
M	AZ	3	N	Not a match	Age difference
M	AZ	7	N	Not a match	Age difference
M	AZ	11	N	Not a match	Eyebrows, ear protrusion, overall facial proportions
M	AZ	12	N	Not a match	Eyebrows, forehead, facial proportions
M	AZ	15	N	Not a match	Age difference
M	AZ	17	N	Not a match	Age difference
M	AZ	19	N	Not a match	Age difference
M	AZ	22	N	Not a match	Age difference
M	AZ	23	N	Not a match	Age difference
M	AZ	27	N	Not a match	Ear protrusion, eyebrows
M	AZ	28	I	Progress to comparison	
M	AZ	29	N	Not a match	Age difference

F	BS	1	I	Progress to comparison	
F	BS	2	N	Not a match	Eyebrows, facial features distribution
F	BS	4	I	Progress to comparison	
F	BS	8	N	Not a match	Nose, eyebrows
F	BS	6	P	Progress to comparison	
F	BS	13	N	Not a match	Facial shape, features
F	BS	14	N	Not a match	Facial shape and dimensions, forehead
F	BS	10	P	Progress to comparison	
F	BS	18	I	Progress to comparison	
F	C	25	N	Not a match	Hair colour, nose, face shape
F	C	26	N	Not a match	Nose, face shape, facial features distribution
F	C	21	I	Progress to comparison	
M	DS	3	N	Not a match	Age difference
M	DS	7	N	Not a match	Age difference
M	DS	11	N	Not a match	Age difference
M	DS	17	P	Progress to comparison	
M	DS	12	N	Not a match	Head shape, ear protrusion

M	DS	15	N	Not a match	Age difference
M	DS	19	N	Not a match	forehead, facial features distribution
M	DS	22	N	Not a match	Age difference
M	DS	23	N	Not a match	Age difference
M	DS	27	N	Not a match	Ear protrusion, face shape, forehead
M	DS	28	N	Not a match	Mole, eyebrows, nose
M	DS	29	N	Not a match	Age difference
M	E	3	P	Progress to comparison	
M	E	7	N	Not a match	Ears, facial distribution
M	E	11	N	Not a match	Age difference
M	E	12	N	Not a match	Age difference
M	E	15	N	Not a match	Hairline recessive, eyebrows, face shape
M	E	17	N	Not a match	Face proportions, eyebrows, face shape
M	E	19	N	Not a match	Eyebrows, nose, ears protrusion
M	E	22	N	Not a match	Eyebrows, features distribution
M	E	23	N	Not a match	Age difference
M	E	27	N	Not a match	Nose, face shape
M	E	28	N	Not a match	eyebrows, nose, facial distribution

M	E	29	I	Progress to comparison	
M	F	3	I	Progress to comparison	
M	F	7	I	Progress to comparison	
M	F	15	P	Progress to comparison	
M	F	11	N	Not a match	Age difference
M	F	12	N	Not a match	Age difference
M	F	17	N	Not a match	Head shape, features distribution, forehead
M	F	19	N	Not a match	Face shape, eyebrows, ears
M	F	22	N	Not a match	eyebrows, central features position, face shape
M	F	23	N	Not a match	Age difference
M	F	27	N	Not a match	eyebrows, face shape
M	F	28	N	Not a match	face shape, eyebrows, nose, mole
M	F	29	N	Not a match	Mole, eyebrows, nose
M	G	3	N	Not a match	Age difference
M	G	12	P	Progress to comparison	
M	G	7	N	Not a match	age difference
M	G	11	N	Not a match	Age difference
M	G	15	N	Not a match	Age difference

M	G	17	N	Not a match	Age difference
M	G	19	N	Not a match	Age difference
M	G	22	N	Not a match	Age difference
M	G	23	N	Not a match	Age difference
M	G	27	I	Progress to comparison	
M	G	28	I	Progress to comparison	
M	G	29	N	Not a match	Age difference
M	H	3	N	Not a match	Age difference
M	H	7	N	Not a match	Nose, eyebrows
M	H	11	N	Not a match	Age difference
M	H	12	N	Not a match	Age difference
M	H	15	N	Not a match	Facial shape, eyebrows
M	H	19	I	Progress to comparison	AM could be an old photo
M	H	17	N	Not a match	Facial shape, nose, facial proportions
M	H	22	N	Not a match	Facial proportions, nose, eyebrows
M	H	23	N	Not a match	Age difference
M	H	27	N	Not a match	Eyebrows, forehead
M	H	28	N	Not a match	Nose shape, facial shape

M	H	29	N	Not a match	Nose, eyebrows
M	I	11	P	Progress to comparison	
M	I	3	N	Not a match	Age difference
M	I	7	N	Not a match	Age difference
M	I	12	N	Not a match	Ear protrusion, nose, eyebrows
M	I	15	N	Not a match	Age difference
M	I	17	N	Not a match	Facial proportions, nose, forehead
M	I	19	N	Not a match	Age difference
M	I	22	N	Not a match	Age difference
M	I	23	N	Not a match	Age difference
M	I	27	N	Not a match	Eyebrows, nose
M	I	28	N	Not a match	eyebrows, nose, features distribution
M	I	29	N	Not a match	Age difference
M	JO	3	N	Not a match	Nose, overall feature proportions
M	JO	7	N	Not a match	hair, eyebrows, feature proportions
M	JO	11	N	Not a match	eyebrows, ears, general facial shape and feature proportions
M	JO	12	N	Not a match	Age difference
M	JO	15	N	Not a match	Age difference

M	JO	17	N	Not a match	forehead, eyebrows, facial shape, feature proportions
M	JO	19	N	Not a match	Nose, facial shape
M	JO	22	P	Progress to comparison	
M	JO	23	N	Not a match	Age difference
M	JO	27	N	Not a match	Ears protrusion, feature distribution
M	JO	28	N	Not a match	facial shape, features distribution
M	JO	29	N	Not a match	nose size, eyebrows, mole
M	K	7	I	Progress to comparison	
M	K	3	N	Not a match	nose, facial features distribution
M	K	15	I	Progress to comparison	
M	K	11	N	Not a match	features distribution, eyebrows
M	K	12	N	Not a match	Nose, eyebrows, face shape (age)
M	K	19	I	Progress to comparison	
M	K	17	N	Not a match	face shape, features distribution, eyebrows
M	K	23	I	Progress to comparison	
M	K	22	N	Not a match	Nose, general facial appearance
M	K	27	N	Not a match	feature distribution, eyebrows, ears protrusion
M	K	28	N	Not a match	face shape, features distribution

M	K	29	N	Not a match	Nose shape, eyebrows, mole
F	L	21	N	Not a match	Age difference
F	L	26	N	Not a match	Eyebrows, nose shape, facial shape
F	L	25	I	Progress to comparison	
M	M	7	P	Progress to comparison	
M	M	3	N	Not a match	Face shape, eyebrows, features distribution
M	M	11	N	Not a match	Moles, eyebrows, facial shape
M	M	12	N	Not a match	Age difference
M	M	15	N	Not a match	Age difference
M	M	17	N	Not a match	feature distribution, facial shape, hairline
M	M	19	i	Progress to comparison	
M	M	22	N	Not a match	Eyebrows, facial shape
M	M	23	N	Not a match	Age difference
M	M	27	N	Not a match	Ear protrusion, general features distribution
M	M	28	N	Not a match	Moles, facial shape
M	M	29	N	Not a match	eyebrows, facial shape
M	N	5	P	Progress to comparison	
M	N	9	I	Progress to comparison	

M	N	16	N	Not a match	Nose, eyebrows, lips
M	N	20	N	Not a match	Ears, nose, face shape
M	N	24	I	Progress to comparison	
M	O	5	N	Not a match	Eyebrows, chin
M	O	9	N	Not a match	forehead, ears, eyebrows
M	O	16	I	Progress to comparison	
M	O	20	P	Progress to comparison	
M	O	24	N	Not a match	Eyebrows, nose
M	P	9	P	Progress to comparison	
M	P	5	N	Not a match	Eyebrows, facial shape
M	P	16	N	Not a match	Nose, ears, facial shape
M	P	20	N	Not a match	facial shape, ears protrusion
M	P	24	P	Progress to comparison	
F	QM	1	P	Progress to comparison	
F	QM	2	I	Progress to comparison	
F	QM	6	N	Not a match	Age difference
F	QM	4	P	Progress to comparison	

F	QM	8	N	Not a match	Age difference
F	QM	13	N	Not a match	Nose, eyebrows, facial shape
F	QM	14	N	Not a match	Age difference
F	QM	18	N	Not a match	Eyebrows, nose, facial shape
F	QM	10	I	Progress to comparison	
M	R	9	I	Progress to comparison	
M	R	5	N	Not a match	Eyebrows, nose, asymmetry ears
M	R	16	P	Progress to comparison	
M	R	20	N	Not a match	Eyebrows, facial shape
M	R	24	I	Progress to comparison	
F	S	1	N	Not a match	Different ear
F	S	2	I	Progress to comparison	
F	S	4	I	Progress to comparison	
F	S	8	N	Not a match	Age difference
F	S	6	I	Progress to comparison	
F	S	13	N	Not a match	Nose, forehead
F	S	14	N	Not a match	Age difference

F	S	18	N	Not a match	Face proportions
F	S	10	I	Progress to comparison	
F	T	1	N	Not a match	Different facial composition
F	T	2	N	Not a match	feature distribution, facial shape
F	T	4	N	Not a match	nose, facial shape
F	T	6	N	Not a match	eyebrows, facial shape
F	T	8	N	Not a match	Age difference
F	T	10	N	Not a match	facial shape, proportions
F	T	13	N	Not a match	nose, eyebrows, facial proportions
F	T	14	I	Progress to comparison	
F	T	18	P	Progress to comparison	
F	U	1	I	Progress to comparison	
F	U	2	P	Progress to comparison	
F	U	4	N	Not a match	Eyebrows, nose
F	U	8	N	Not a match	Age difference
F	U	6	P	Progress to comparison	
F	U	13	N	Not a match	Nose, eyebrows

F	U	14	N	Not a match	Age difference
F	U	18	N	Not a match	nose, eyebrows, facial shape
F	U	10	I	Progress to comparison	
F	V	1	N	Not a match	Facial shape, eyebrows
F	V	2	P	Progress to comparison	
F	V	4	N	Not a match	facial shape, eyebrow
F	V	6	N	Not a match	eyebrows, nose, features distribution
F	V	8	N	Not a match	Age difference
F	V	10	N	Not a match	facial shape, nose
F	V	14	N	Not a match	Age difference
F	V	18	N	Not a match	facial shape, nose
F	V	13	P	Progress to comparison	
F	W	1	N	Not a match	Eyebrows, nose, mole
F	W	2	N	Not a match	nose, features distribution
F	W	4	N	Not a match	nose, mole
F	W	6	N	Not a match	teeth
F	W	8	N	Not a match	Facial shape and features distribution, forehead
F	W	10	I	Progress to comparison	

F	W	13	N	Not a match	Nose shape, features distribution
F	W	14	N	Not a match	facial shape, mole
F	W	18	I	Progress to comparison	
F	X	1	I	Progress to comparison	
F	X	2	N	Not a match	Moles, facial shape, eyebrows
F	X	4	N	Not a match	Moles, eyebrows, nose
F	X	6	N	Not a match	facial shape, nose, moles
F	X	10	N	Not a match	facial shape, moles
F	X	13	N	Not a match	eyebrows, nose, facial shape
F	X	8	P	Progress to comparison	
F	X	18	N	Not a match	Facial shape, nose dimension
F	X	14	I	Progress to comparison	
M	YT	5	I	Progress to comparison	
M	YT	9	I	Progress to comparison	
M	YT	16	N	Not a match	Nose, eyebrows,
M	YT	20	I	Progress to comparison	
M	YT	24	P	Progress to comparison	

F	Z	21	N	Not a match	facial shape, nose, checks
F	Z	25	N	Not a match	Nose, eyebrows, facial shape
M	Z	3	N	Not a match	chin, eyebrows
M	Z	7	N	Not a match	nose, checks, facial shape
M	Z	11	N	Not a match	facial shape, ears protrusion
M	Z	12	N	Not a match	Age difference
M	Z	15	N	Not a match	Age difference
M	Z	17	N	Not a match	forehead, facial shape, chin, eyebrows, nose
M	Z	19	N	Not a match	Facial shape, forehead, eyebrows
M	Z	22	N	Not a match	Lips, nose, features distribution
M	Z	23	N	Not a match	Age difference
F	Z	26	P	Progress to comparison	
M	Z	27	N	Not a match	Ears protrusion , nose, general facial shape
M	Z	28	N	Not a match	eyebrows, chin, facial shape, features distribution
M	Z	29	N	Not a match	eyebrows, mole, facial hair

Summary of matches progressed onto the Phase 3-Comparison

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Table 5- Summary of the AM-PM pairs progressed onto Phase 3 Comparison

Presented gender	2.1 PM	2.2 AM	2.3 Facial Review results	2.4 Action
(F)Female (M)Male (I)Indeterminate	PM code	*AM code*	*P (Probable) I (Indeterminate)*	
F	A	4	P	Progress to comparison
F	A	8	P	Progress to comparison
F	A	14	P	Progress to comparison
M	AA	12	I	Progress to comparison
M	AA	27	P	Progress to comparison
M	AA	28	I	Progress to comparison
M	AB	3	I	Progress to comparison
M	AB	23	I	Progress to comparison
M	AB	29	P	Progress to comparison
M	AZ	28	I	Progress to comparison
F	BS	1	I	Progress to comparison
F	BS	4	I	Progress to comparison
F	BS	6	P	Progress to comparison
F	BS	10	P	Progress to comparison
F	BS	18	I	Progress to comparison
F	C	21	I	Progress to comparison
M	DS	17	P	Progress to comparison
M	E	3	P	Progress to comparison
M	E	29	I	Progress to comparison
M	F	3	I	Progress to comparison
M	F	7	I	Progress to comparison
M	F	15	P	Progress to comparison
M	G	12	P	Progress to comparison
M	G	27	I	Progress to comparison
M	G	28	I	Progress to comparison
M	H	19	I	Progress to comparison
M	I	11	P	Progress to comparison
M	JO	22	P	Progress to comparison

M	K	7	I	Progress to comparison
M	K	15	I	Progress to comparison
M	K	19	I	Progress to comparison
M	K	23	I	Progress to comparison
F	L	25	I	Progress to comparison
M	M	7	P	Progress to comparison
M	M	19	i	Progress to comparison
M	N	5	P	Progress to comparison
M	N	9	I	Progress to comparison
M	N	24	I	Progress to comparison
M	O	16	I	Progress to comparison
M	O	20	P	Progress to comparison
M	P	9	P	Progress to comparison
M	P	24	P	Progress to comparison
F	QM	1	P	Progress to comparison
F	QM	2	I	Progress to comparison
F	QM	4	P	Progress to comparison
F	QM	10	I	Progress to comparison
M	R	9	I	Progress to comparison
M	R	16	P	Progress to comparison
M	R	24	I	Progress to comparison
F	S	2	I	Progress to comparison
F	S	4	I	Progress to comparison
F	S	6	I	Progress to comparison
F	S	10	I	Progress to comparison
F	T	14	I	Progress to comparison
F	T	18	P	Progress to comparison
F	U	1	I	Progress to comparison
F	U	2	P	Progress to comparison
F	U	6	P	Progress to comparison
F	U	10	I	Progress to comparison
F	V	2	P	Progress to comparison
F	V	13	P	Progress to comparison

F	W	10	I	Progress to comparison
F	W	18	I	Progress to comparison
F	X	1	I	Progress to comparison
F	X	8	P	Progress to comparison
F	X	14	I	Progress to comparison
M	YT	5	I	Progress to comparison
M	YT	9	I	Progress to comparison
M	YT	20	I	Progress to comparison
M	YT	24	P	Progress to comparison
F	Z	26	P	Progress to comparison

Complete List of AM case with relative quality score and total number of images

AM Case	Quality score (range)			Total images per individual AM case
	1,2,3	4,5	6	
AM1		2		2
AM2	4	2	1	7
AM3		1		1
AM4	3	2		5
AM5	6			6
AM6	1			1
AM7		2		2
AM8	5	4	1	10
AM9		6	1	7
AM10	1			1
AM11	1			1
AM12		1	6	7
AM13	1	1		2
AM14		2		2
AM15			3	3
AM16	2	2		4
AM17		4		4
AM18	3			3
AM19	2			2
AM20		4	1	5
AM21		1		1
AM22		1		1
AM23		1		1
AM24		6	1	7
AM25	1	1		2
AM26	2	3		5
AM27	1	1	1	3
AM28		2		2
AM29		1		1
Total images per score range	**33** (34%)	**50** (51%)	**15** (15%)	
Total AM images available	98			

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Table 6. Phase 3 Comparison and Phase 4 Evaluation results

PM	AM	Level of Support	AM target
A	8	No Support	14
A	14	Moderate Support	14
A	4	No Support	14
AA	12	No Support	27
AA	27	Strong Support	27
AA	28	No Support	27
AB	3	Limited Support	29
AB	29	Limited Support	29
AB	23	Moderate Support	29
AZ	28	Strong Support	28
BS	6	No Support	10
BS	18	No Support	10
BS	10	Moderate Support	10
BS	1	Limited Support	10
BS	4	No Support	10
C	21	Limited Support	21
DS	17	Support	17
E	29	No Support	3
E	3	Support	3
F	3	No Support	15
F	7	No Support	15
F	15	Moderate Support	15
G	12	Support	12
G	27	No Support	12
G	28	No Support	12
H	19	Limited Support	19
I	11	Strong Support	11
JO	22	Support	22
K	15	No Support	23
K	7	No Support	23
K	19	Limited Support	23
K	23	No Support	23
L	25	Strong Support	25
M	19	No Support	7
M	7	Strong Support	7
N	9	No Support	5
N	24	No Support	5
N	5	Strong Support	5
O	16	Limited Support	20
O	20	Support	20
P	24	Support	24
P	9	Limited Support	24
QM	10	No Support	4

QM	1	No Support	4
QM	2	No Support	4
QM	4	Support	4
R	24	No Support	16
R	9	No Support	16
R	16	Moderate Support	16
S	10	No Support	2
S	2	Support	2
S	4	No Support	2
S	6	No Support	2
T	14	Limited Support	18
T	18	Strong Support	18
U	10	No Support	6
U	1	Moderate Support	6
U	2	No Support	6
U	6	Strong Support	6
V	13	Strong Support	13
V	2	No Support	13
W	18	No Support	1
W	10	Limited Support	1
X	14	No Support	8
X	1	No Support	8
X	8	Strong Support	8
YT	5	No Support	9
YT	20	No Support	9
YT	24	No Support	9
YT	9	Moderate Support	9
Z	26	Strong Support	26

Table 7. Results of the Phase 3 Comparison Phase and Phase 4 Evaluation divided into different PM subjetcs.

3.1 PM subject	3.2 AM	3.17 Level of Support	AM target	PM-AM target matched with strong support or support	PM-AM matched with moderate or limited support	Support given to multiple AM subjects
A	8	No Support	14		X	
	14	Moderate Support				
	4	No Support				
AA	12	No Support	27	X		
	27	Strong Support				
	28	No Support				
AB	3	Limited Support	29		X	X
	29	Limited Support				
	23	Moderate Support				
AZ	28	Strong Support	28	X		
BS	6	No Support	10		X	X
	18	No Support				
	10	Moderate Support				
	1	Limited Support				
	4	No Support				
C	21	Limited Support	21		X	
DS	17	Support	17	X		
E	29	No Support	3	X		
	3	Support				
F	3	No Support	15		X	
	7	No Support				
	15	Moderate Support				
G	12	Support	12	X		
	27	No Support				
	28	No Support				

H	19	Limited Support	19		X	
I	11	Strong Support	11	X		
JO	22	Support	22	X		
K	15	No Support	23			
	7	No Support				
	19	Limited Support				
	23	No Support				
L	25	Strong Support	25	X		
M	19	No Support	7	X		
	7	Strong Support				
N	9	No Support	5	X		
	24	No Support				
	5	Strong Support				
O	16	Limited Support	20	X		X
	20	Support				
P	24	Support	24	X		X
	9	Limited Support				
QM	10	No Support	4	X		
	1	No Support				
	2	No Support				
	4	Support				
R	24	No Support	16		X	
	9	No Support				
	16	Moderate Support				
S	10	No Support	2	X		
	2	Support				
	4	No Support				
	6	No Support				
T	14	Limited Support	18	X		X
	18	Strong Support				

U	10	No Support	6	X		X
	1	Moderate Support				
	2	No Support				
	6	Strong Support				
V	13	Strong Support	13	X		
	2	No Support				
W	18	No Support	1			
	10	Limited Support				
X	14	No Support	8	X		
	1	No Support				
	8	Strong Support				
YT	5	No Support	9		X	
	20	No Support				
	24	No Support				
	9	Moderate Support				
Z	26	Strong Support	26	X		

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APPENDIX D- Inter-observer Test Results

Table 1. Comparison cases from which the interobserver study pairs were selected using a randomised selection

Comparisons case (AM-PM)	Presented gender	Decomposition (G=Green/Y=Yellow)*	Quality AM	Number given for randomisation
AM26PMZ	F	G	2	0.01898511
AM18PMT	F	G	1	0.042552731
AM4PMA	F	G	1	0.048964581
AM21PMC	F	G	2	0.09705383
AM18PMW	F	G	1	0.12023782
AM14PMT	F	G	2	0.195866104
AM1PMQM	F	G	2	0.199549282
AM10PMQM	F	G	1	0.270894997
AM25PML	F	G	2	0.338586891
AM14PMX	F	G	2	0.355385079
AM6PMBS	F	G	2	0.395833295
AM1PMX	F	G	2	0.460091959
AM10PMU	F	G	1	0.478099331
AM6PMS	F	G	2	0.545136056
AM14PMA	F	G	2	0.641603702
AM1PMBS	F	G	2	0.654561003
AM2PMQM	F	G	2	0.669686296
AM10PMS	F	G	1	0.699502343

AM18PMBS	F	G	1	0.710947977
AM8PMA	F	G	2	0.7204254
AM2PMV	F	G	2	0.733070304
AM4PMS	F	G	1	0.763901135
AM2PMS	F	G	2	0.779137969
AM1PMA	F	G	2	0.781421479
AM6PMU	F	G	2	0.805449099
AM8PMX	F	G	2	0.827748813
AM2PMU	F	G	2	0.870358887
AM1PMU	F	G	2	0.886185318
AM4PMQM	F	G	1	0.916382653
AM4PMBS	F	G	1	0.926855392
AM10PMBS	F	G	1	0.996566938
AM29PME	I	G	2	0.788159709
AM11PMI	M	G	1	0.038050297
AM17PMDS	M	G	2	0.051697431
AM9PMYT	M	G	3	0.052231462
AM24PMN	M	G	2	0.1124285
AM19PMM	M	G	1	0.1319717
AM5PMYT	M	G	1	0.150625729
AM20PMO	M	Y	2	0.157809638
AM7PMF	M	G	2	0.201195831
AM28PMG	M	G	2	0.203104657
AM9PMP	M	G	3	0.257428132
AM12PMAA	M	G	3	0.277172501
AM28PMAA	M	G	2	0.340354303
AM28PMAZ	M	G	2	0.345433609
AM13PMV	M	G	2	0.401726538
AM19PMH	M	G	1	0.547250812
AM3PMAB	M	G	2	0.573585886
AM3PMF	M	G	2	0.607664508
AM9PMN	M	G	3	0.622064797

AM19PMK	M	G	1	0.630862955
AM15PMK	M	G	3	0.636230129
AM7PMM	M	G	2	0.645976046
AM15PMF	M	G	3	0.669491427
AM19PMAB	M	G	1	0.707921044
AM24PMYT	M	G	2	0.729921402
AM16PMO	M	Y	2	0.739942224
AM27PMG	M	G	2	0.748589206
AM12PMG	M	G	3	0.75644389
AM16PMR	M	G	2	0.773786493
AM27PMAA	M	G	2	0.782170581
AM23PMAB	M	G	2	0.782492366
AM22PMJO	M	Y	2	0.811986227
AM5PMN	M	G	1	0.839684688
AM29PMAB	M	G	2	0.865957098
AM24PMP	M	G	2	0.876633578
AM9PMR	M	G	3	0.877953437
AM7PMK	M	G	2	0.885429338
AM23PMK	M	G	2	0.913909326
AM3PME	M	G	2	0.951289691
AM24PMR	M	G	2	0.969825722
AM20PMYT	M	G	2	0.982666105
*See Table 2				

Table 2. Table 1 Key

Element	Total number	Proportion required for 15 samples	%
AM quality 1 (Quality Score = 1,2,3)	18	3.8	25%
AM quality 2 (Quality Score= 4,5)	46	9.6	64%
AM quality 3 (Quality Score = 6)	8	1.7	11%

Comparison with PM subjects with fresh (G)	69	14.0	96%
Comparison with PM subjects with medium stage of decomposition (Y)	3	1.0	4%
Comparison with advanced stage of decomposition (R)	0	0	0%
F (female)	31	6	43.1%
M (male)	40	8	55.6%
I (Indeterminate)	1	0.0	1.4%

Table 3. 15 selected cases for Inter-Observer test.

Comparisons	**Presented Gender**	**Decom(G/Y)**	**Quality AM**	**Random number picked**
AM26PMZ	F	G	2	0.01898511
AM18PMT	F	G	1	0.042552731
AM4PMA	F	G	1	0.048964581
AM21PMC	F	G	2	0.09705383
AM18PMW	F	G	1	0.12023782
AM14PMT	F	G	2	0.195866104
AM1PMQM	F	G	2	0.199549282
AM11PMI	M	G	1	0.038050297
AM17PMDS	M	G	2	0.051697431
AM9PMYT	M	G	3	0.052231462
AM24PMN	M	G	2	0.1124285
AM19PMM	M	G	1	0.1319717
AM5PMYT	M	G	1	0.150625729
AM20PMO	M	Y	2	0.157809638
AM7PMF	M	G	2	0.201195831

Analysis of comparison documentation Observer 1																
Analysis of comparison documentation OW (Observer 1)	3.2 Facial mark	3.3 Facial alterations (Scars, tattoos, piercings)	3.4 Face shape/outline	3.5 Hairline/ Forehead	3.6 Eyes	3.7 Cheeks	3.8 Eyebrows	3.9 Nose	3.10 Ears	3.11 Mouth	3.12 Chin and Jawline	3.13 Facial Hair	3.14 Facial Lines	3.15 Rationale for difficult comparison	**3.16 Level of Support**	3.17 Identifying indicators visibility used for comparison
Insert the comparison case as AMxxPMxx or PMxxAMxx	Insert feature description													Select the appropriate factor from the drop-down list	Select the relevant level of support from the drop-down list	Insert the identifying indicator (e.g teeth, moles etc.)
AM26PMZ	similar pock mark on left side of forehead. similar marks at root of nose	none	similar	similar	similar infraorbital crease and lower lid bags	consistent	similar shape and density	consistent in total	consistent	similar upper lip cupids bow.	similar small prominent chin and sagging jowls	n/a	similar NLCs and marionette lines, similar forehead creases		Strong Support	marks and creases, lip and nose shape
AM18PMT	similar mark under right eyebrow - laterally	scar on forehead - line horiz at medial end of left eyebrow	similar	cannot see well on AM images	similar tilt, prominence and shape	similar prominence	similar shape and density	consistent in total	what is visible is similar on both sides	teeth match, lips are similar shape and thickness	similar	n/a	NLC in broadly similar position		Strong Support	marks, scars, nose and lip shape, teeth
AM4PMA	Pm has hairy moles on left cheek and next to ear - not visible on AM	PM nose piercing - not visible on AM	AM has longer face	cannot compare hairline, forehead appears larger in AM	broadly similar shape, PM has lower lid crease - not visible on AM	broadly similar	AM has styled and dark	AM has higher nasal root, broadly similar at tip and alae	Only visible left AM - PM ears seem smaller and with a rounder helix shape	maxillary central incisors are larger on AM, upper lip shape is different and width of philtrum is larger on PM	broadly similar	n/a	PM has mental crease - not visible on AM		No Support	teeth, eyebrows, lips, moles and ears - all different
AM21PMC	none	AM and PM ears pierced	similar	similar	similar shape and prominence	similar prominence	similar thin arched and styled	similar nasal root, pinched between eyes and bifid tip	Right ear visible on AM - similar flattened helix and pointed shape	similar thin lips with flat philtrum	similar small prom chin and sagging jowls	n/a	AM has NLCs and marionette lines - not visible on PM	AM image quality	Support	right ear, bifid nasal tip and overall morph
AM18PMW	PM has mole below R side mouth - not visible on AM	PM has old tattoo or ink or bruise on forehead - not visible on AM	broadly similar	more hair at temples on PM with lower foreheadline	PM appear deeper set	broadly similar	different hair pattern but AM more styled	PM appears deeper at root with squarer tip	cannot assess	broadly similar	broadly similar	n/a	Am has infraorbital creases - not visible on PM		No Support	mole, eyebrows, nasal shape, hairline
AM14PMT	AM has mole to left of nose - not visible on PM	none	broadly similar	AM appears higher forehead	broadly similar	broadly similar	cannot see on AM clearly	AM appears longer with more pointed tip	cannot assess	AM teeth appear larger	AM appears more pointed chin	n/a	cannot assess	AM image quality	No Support	mole chin forehead nose
AM1PMQM	Not clear on AM	none	AM has longer face	Different line at right temple	AM has smaller eyes	PM has more prominent	different pattern	AM has higher root	PM has small lobe on right ear - AM has adherent ear	PM has thicker lips. AM has crowded dental pattern		n/a	none	AM image quality	No Support	ears, teeth, hairline, eyes, nose
AM11PMI	Mole below right side of mouth, mole to left of mouth - on AM and PM	none	similar	similar	similar	similar prominence	PM has more hair between eyebrows at top of nose. Otherwise similar	similar	similar	teeth match - very distinctive	similar	n/a	none		Strong Support	moles teeth
AM17PMDS	not clear AM	none	similar	similar	similar shape and prominence	similar prominence	similar shape and density	similar	R ear very similar, left ear also	similar lips	similar	n/a	similar NLC and forehead crease	AM image quality	Support	all features, ears
AM9PMYT	not clear AM	none	similar	similar	similar shape and prominence	similar prominence	more hair between eyebrows for PM but otherwise similar	similar	right ear appears different at lobe and end of helix, left ear appears different at antihelix	broadly similar teeth and lips	AM appears more prominent chin	similar pattern under lower lip and moustache	broadly similar	AM image quality	Limited Support	ears look different but everything else looks similar
AM24PMN	none	none	similar	similar	similar shape and prominence	similar prominence	appear less styled in PM than AM - otherwise similar	similar shape	consistent on right and left	AM appears to have thicker lips. Teeth not visible in Am images	similar	similar pattern at chin and moustache	none	AM image quality	Moderate Support	ears
AM19PMM	vert glab lines, nasion line and mental crease on PM - not visible on AM. AM has second NLC not visible on PM	none	cannot compare due to age difference	cannot compare	broadly similar shape	broadly similar	PM lighter colour and less dense	PM has larger nostrils and higher nasal root	PM appears to have more fleshy lobes	AM has more defined cupids bow. PM has more prominent lower lip	PM has rounder chin - but also fatter	different moustache pattern with lighter colour	see 3.2	Time lapse	No Support	hair colour, eyebrows, nose shape and NLC pattern
AM5PMYT	freckle under right eye on AM - not visible on PM	none	AM has shorter face	different frontal hairline	AM has larger eyes	broadly similar	different patterns - thicker and joined in PM	PM has more visible nostrils, AM has more pinched nasal root	both ears are different between AM and PM	broadly similar lips, teeth do not match	AM has narrower chin	facial hair appears different at moustcahe and under lip - but not very visible on AM		PM changes/trauma	No Support	ears nose eyebrows
AM20PMO	not visible on PM	none	broadly similar	cannot assess on PM	cannot assess on PM	cannot assess on PM	appear denser and meet in PM	broasly similar	left similar	broadly similar	broadly similar	no beard hair in AM	cannot assess	PM changes/trauma	Limited Support	left ear
AM7PMF	possible scar on left cheek of AM - not visible on PM	none	broadly similar	PM bald - AM has hair	PM appear more prominent	broadly similar	PM appear more arched	PM appears narrower and different tip	right ear very different - in size, shape and detail	PM has less full lips	AM has cleft chin - PM does not	moustache on AM	forehead creases, cleft chin, nasion crease, NLC on AM - not visible on PM	Time lapse	No Support	crease patterns, ears

Table 5. Observer 1 Comparison documentation

Table 6. Observer 2 Comparison documentation

Analysis of comparison documentation Observer 2

AM26PMZ	Similar blemish on the left cheek and forehead.	Eyebrow tattoo	Similar facial proportion, but the chin appers to be different in length. Difference can be caused by gravity.	both have a high hairline, but the patterns cannot be compared.	Consistent shape and creases	Consistent shape and width but distorted by PM changes	Similar in shape and tattooed.	Consistent horizontal tilt, round nasal tip, and similar width and height.	Clef on the PM L ear, unclear on the AM. Prominant antihelix on both L ear. Disimilar earlobe position, could be caused by PM changes.	Similar lip shape and width	Similar mental crease. AM Chin appears to be longer, jawline difficult to compare, could be due to gravity.	Absent in AM, present in PM	Similar position of facial creases. Infraorbital creases stronger on PM, NLF stronger on AM. Similar forhead and chin crease	PM changes/trauma	Moderate Support	Teeth in AM not in PM.	Nothing contradicting
AM18PMT	Consistent mole position on the left jaw	acne scaring can be observed in both AM and PM	Similar facial proportion and outline	Hairline cannot be observed from Am photos, Forehead consistent in shape	Consistent shape and creases	Consistent shape and width	Brows in AM are thinner and more stylised. Scaring on the left brown is consistant.	Consistent horizontal tilt, round nasal tip, and similar width and height.	Earings in AM, earlobe piercing in PM. The shape of the left antihelix is consistant.	Similar lip shape and width	Chin and jawline similar	Absent	Similar position of infraorbital creases and NLF	None	Support	Teeth in AM and PM.	Nothing contradicting
AM4PMA	Mole on PM left cheek but absent in AM, could be masked by makeup.	Nose piercing in PM. Absent in AM	Similar facial proportion and outline	**Hair patch infront of PM left ear, but not visable in all AM photos.**	Consistent shape and creases	Consistent shape and width but distorted by PM changes	Similar in shape, but more prominant in AM. Most likely due to makeup.	Nose is slightly distorted in PM, similar in shape, but the columella sits lower in PM.	Everted left bifid antitragus in AM, not obvious in PM. Upper left lobe piercings in AM, a marking can be observed in PM. The helix is thinner in AM and appers to be a different shape. Some of the inconsistancy can be expalined by camera angle.	Lips appers to be thicker in PM. Different facial expression.	Square chin can be observed in both. Consistant chin and jawline.	Absent	NLF present in AM, difficult to assess in PM due to tissue distortion.	AM image quality	Limited Support	Teeth in AM and PM.	Ear appears different, but could be angle.
AM21PMC	no obvious facial marks	Consistent ear piercings on both AM and PM	Similar facial proportion and outline	High hairline and round forhead	Consistent shape and creases, but obscured by trauma.	Consistent shape and width but distorted by PM changes	Similar browshape	low columella, thick nasal bridge, but PM nose is distorted	Consistent thinning on the right helix and the everted antitragus.	Similar lip shape and width	Square chin can be observed in both. Consistant chin and jawline.	Absent	NLF and Chin creases in AM, tissue distortion in PM creases cannot be observed.	PM changes/trauma	Moderate Support	NA	Nothing contradicting
AM16PMW	**large mole on PM ching and neck. Not Present in AM**	Unclear marking on PM forehead, both AM and PM shows ear lobe piercing	Similar facial proportion	PM showed hairline, forehead appears wider in AM	Similar shape, but PM appears to have longer eyelashes	Cheeks apper fuller in AM, could be explained by PM change.	Different shape. [illegible]	Nasal tip bifid and downward pointing, [illegible] in PM, round and horizontal in AM. Nasal root more pinched in PM.	No obvious differences.	Mole and blemish on PM lip and not AM. Could be cosmetics	Chin more squared in PM	Absent	Lines next to mouth corner persent in AM and not PM. Difference couldbe facial expression.	Other	No Support	Teeth in AM and PM.	Nose and facial marks appears very different, could be age related? Dentition appers different, should be checked by odontologist.
AM34PMT	Poor AM image quality	Poor AM image quality	Similar	Forehead higher and wider in AM	Similar	Flatter in AM	Thicker in AM, could be cosmetics	Nasal tip downward pointing with high nasal root in AM. Horizontal nasal tip and low nasal root in PM	NA	Similar but Poor AM image quality	Chin more flat in PM	Absent	Poor AM image quality	AM image quality	Limited Support	/	Nose appears to be different.
AM1PMGM	Poor AM image quality	**Ear lobe marking in AM but not PM. Poor AM image quality**	Similar	Hair line extend downwards towards the ear in PM, not observed in AM.	Similar	Appears fuller in PM, affected by PM changes.	Thicker in AM, could be cosmetics	Thinner alar in AM	Lobe in PM, attached in AM.	Different head pose	Bifid chin in AM, similar in PM.	Absent	Similar NLF	AM image quality	Limited Support	Teeth in AM and PM.	Different ear shape
AM11PMI	consistant mole on right chin and left NLF.	none	Similar facial proportion	Covered by hair in AM	Similar	Consistent shape different camera focal length.	Similar, fuller monobrow in PM	Similar	Protruding ears in AM but PM. Camera focal length. Large in AM and PM.	Similar lip shape and width	Fuller in AM, rounder in PM.	Absent	NLF and chin creases similar	Other	Support	Teeth in AM and PM.	Nothing contradicting
AM17PMDS	no obvious facial marks	none	Similar	Similar	Similar	Similar	Similar	Similar	consistent crease on the right ear lobe	Similar	Square chin can be observed in both. Consistant chin and jawline.	Similar stubbles	Similar NLF and forehead creases	None	Support	Ear	Nothing contradicting
AM9PMYT	no obvious facial marks	none	Thinner face in AM	Similar	Similar	Appears fuller in AM, affected by PM changes	Similar shape, more monobrow in PM. Both have brow.	Similar but Low AM quality, both AM and PM have slight deviation to the left	Left ear, lobe in both, similar shape	Similar	Square chin can be observed in both. Consistant chin and jawline.	Different facial hair, but consistent area of growth	AM images are filtered	AM image quality	Moderate Support	Ear	Nothing contradicting
AM24PMN	no obvious facial marks	none	Similar but poor AM images	[illegible]	Similar	Similar	[illegible]	Similar but Low AM quality, asymmetry nostrils can be observed in both.	Left ear, lobe in both, similar shape	Thinner in AM (?)	Square chin can be observed in both. Consistant chin and jawline.	Different facial hair, but consistent area of growth	Infraorbital crease present in both	AM image quality	Moderate Support	Ear	Nothing contradicting
AM10PMM	no obvious facial marks	none	**A lit fuller in PM. Age and PM changes**	Higher hairline in PM	[illegible]	**A lot fuller in PM. Age and PM changes**	Similar pattern, hair lighter and longer in PM. Age		Similar	Similar, more downturn in PM	[illegible]	Different facial hair, but consistent area of growth	Similar NLF and forehead creases	Time lapse	Limited Support	Ear	difference in AM and PM, but nothing contradicting. Distinctive PM ear shape, but AM
AM5PMYT	AM mole on right cheek, not obvious in PM	none	Similar	[illegible]	Similar	Fuller in AM	[illegible]	Wider in AM	[illegible]	Similar, but lip pattern appears different	Square chin can be observed in both. Consistant chin and jawline	Different facial hair, but consistent area of growth	Forhead creases present in PM, absent in AM. Infra orbital crease present in both	PM changes/trauma	No Support	Ear	Different ear shape and facial creases.
AM20PMO	Mole on PM right and left cheek, chin and neck. Am image filtered.	None	PM decomp. Fuller shape in PM	[illegible]	PM decomp	PM decomp	[illegible]	[illegible]	Similar	Similar thickness, but AM images filtered and PM decomp.	Chin is more pointy in AM, difference could be shading in PM decomp	[illegible]	[illegible]	PM changes/trauma	Limited Support	/	Hairline difference, difficult comparison with decomp.
AM7PMF	no obvious facial marks	[illegible]	[illegible]	[illegible]	**Similar, but eye creases stronger in AM**	[illegible]	[illegible]	[illegible]	[illegible]	Lips thinner in PM, could be age	Similar chin, wider jaw on AM, could be age	Different facial hair, but consistent area of growth	[illegible]	AM image quality	No Support	Facial creases	Different facial creases that cannot be explained by age, cosmetic or PM changes.

Table 7. Observer 3 Comparison documentation

3.1 PM	3.2 AM	3.3 Facial mark	3.4 Facial alterations (Scars, tattoos, piercings)	3.5 Face shape/outline	3.6 Hairline/ Forehead	3.7 Eyes	3.8 Cheeks	3.9 Eyebrows	3.10 Nose	3.11 Ears	3.12 Mouth	3.13 Chin and Jawline	3.14 Facial Hair	3.15 Facial Lines	3.16 Rationale for difficult comparison	3.17 Level of Support	3.18 Identifying features	3.19 Notes
A	4	Moles located in the lower left cheek in PM, not in AM + PM with visible large mole near left nasal alae not present in AM		Similar facial contour. PM eyes located away from the midline, Difficult to assess the rest of the proportions and features.	Similar in shape and height. Brow ridge look generally more proted on the AM			PM with R eyebrow more visible than L. slightly arched shape, very sparse hair resulting in light eyebrows with not a well defined shape. Medial has noticeably longer hair and more density than the lateral side. AM very peculiar shape with arched thicker medially and very thin laterally. general shape of eyes and eyelids is different between AM and PM. PM with closed eyes, appear less protruded. with a shallow upper and lower lid. AM has a more sunken appearance, and a well defined superior palpebral crease.	Different orientation make comparison challenging, only general appearance can be observed. PM with a shorter and wider nasal body, larger nasal base deviated towards right. AM longer nasal mody and straight nasal base, quite symmetric	Not comparable	NA (due to a smiling face in all AM pictures)	Not comparable		L and R nasolabial fold visible in AM (mostly due to smiling?), not visible in PM. PM with L and R inferior palpebral creases, not visible on AM (possibly due to makeup?)		No Support	Moles	
C	21	Differences: moles pattern not matching?		Similarities: skin colour, relative positions of the eyes, mouth and eyebrows. Not comparable: The rest cannot be assessed due to head position.	Similar forehead relative height and width, shape. Differences: hair colour at the roots with similarities when looking a the hair tips in PM. Could be explained as dye colour.	Not comparable		Similarities: eyebrow shape and thickness. Tilt of the medial side. Not comparable: The rest cannot be assessed due to image quality.	Similarities: nasal root Not comparable: Rest cannot be assessed.	Not comparable	Similarities: Holistic similar shape, some evidence of dry lower lip in both AM and PM Not comparable: Rest cannot be assessed.	Not comparable		Differences: Marked R and L nasolabial folds in AM, not present in PM. Marked R and L buccal creases. Aforementioned folds and creases visible in AM are NOT visible in PM. Only nasion creases are visible in AM and in PM.	None	Limited Support		
DS	17			Similarities: facial shape, proportion of the features	Similarities: baldness pattern, lateral hair growing, sideburns around the ears	Similarities; / dep set of eyes, superior palpebral furrow	Similarities: defined cheeks	Similarities: brow ridges from frontal and lateral/ eyebrows shape, pattern, size, length relative to eyes, density of hair	Similarities: nasal root width and dept from frontal and lateral, nasal body length, nasal base, dimension and shape of nostrils and alae, columella	Similarities: all inner feature of the R ear are consistent, Differences: slight difference in overall shape can be explained by looking at the head suture post autopsy thats tretch the skin around the head and ears	Similarities: shape and dimension of lower and upper lips, including vermilion border look consistent- slight difference in position of the mouth	Similarities: chin and jawline shape and outline	Similarities: grey shade on the chin where facial hair are growing on the chin is visible on the AM picture, area covered is consistent	Similarities: single frontal line, nasion crease, superior palpebral crease, infraorbital crease, nasolabial fold, shallow mentolabial sulcus consistent in shape and position	None	Support	Ears	
F	7	no similarities		no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities		No Support		
I	11	Similarities: Various facial marks observed on cheeks and nose and one very visible facial marks below the R mouth corner and above the L mouth corner on the nasiolabial fold. Consistent in both AM and PM		Similarities: The PM image suffer from a barrel distortion- adjusted with photoshop. Similar distribution of facial features	Similarities: hair colour, hair texture an density, hairline on the R and L side visible from frontal view Not comparable: forehead hairline covered by hair in AM	Not comparable: other eyes features due to eyes being closed in PM	Similarities: cheek from frontal view	Similarities: shape of the eyebrows, length of the hair, texture, colour, density towards the midline and less density towards the lateral line/ intercanthal distance, angle of the eyes Differences: conjoined left-right eyebrows in PM, could be due to trimming, however in AM is visible that there are hair in the centre	Similarities: nasal root width, nasal body length, nasal tip shape and orientation, nasal base, nasal nostril, alae , columella	Not comparable: also PM suffer from barrel distortion so ears appear flat rom a frontal view	Similarities: dimension upper and lower lip with upper being thinner, cupids' bow shape, lip fissure shape, tori of the lower lip.	Similarities: even if AM suffer from distortion, the shape of the chin and jawline is consistent	Similarities: no facial hair in both pictures however PM clearly shaved (grey colour above upper lip and below lower lip), AM looks younger so no facial hair growing visible from image	Differences: couple of inferior palpebral in PM, not visible in PM. Pm has barely visible infraorbital creases however it could be the age difference in images		Strong Support	Facial marks	age difference, barrel distortion for camera distance in PM
M	19	no similarities		no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities	no similarities		No Support		
N	24	Facial mark under R eye on the cheek in PM, not observable in PM but quality in AM not the best		Overall similar	Straigther in AM	difficult to assess	Similar shape	Thicker eebrows in PM, thinner in AM also diffferent in length	Slightly wider in AM	Bigger Lobe in AM, overall shape some simlarities	fuller lips in AM	difficult to assess due to beard in AM	Differen facial lines even if different style, PM not having the same side facial hair and sideburns	n/a	n/a	No Support		

O	20			Not comparable: facial shape altered by post mortem swelling	Similarities: forehead hairline, L lateral hairline, hair texture and colour, in particular thin sideburns / forehead is of similar height		Not comparable: cheeks areas swollen due to PM changes/	Similarities: thickness of the eyebrows, lateral L hair density and texture, lateral position relative to the L eye. Not comparable: Due to orientation of the face tilted toward the back it is difficult to assess the [illegible] all the features can be assessed	Not comparable: due to the different head position and swelling of the nose most of the nasal features cannot be assessed	Similarities: strong similarities overall shape of L ear, helix shape, unattached lobe dimension and position, scaphoid fossa shape, flat antitragus, intertragic notch, concha tragus. Not comparable: R ear, L crus of the helix not completely visible	Similarities: overall mouth shape, relative dimensions of upper and lower lips, vermilion border	Not comparable: jawline suffer from swelling so comparison is not possible	Similarities: visible hair above the upper lip (partially covered by blood), some similarities in the growing patter of the hair above the upper lip is observed onto the AM. Differences: Some facial hair on the chin observed in PM, not observed in AM, but could be due to trimming	Not comparable: due to the facial swelling facial lines can emerge or the existent ones be hidden		Support	Ear	Ear with strong similarity
QM	1		No visible R ear piercing in PM, otherwise visible in AM	Some similarities in proportion of the facial feature, but different shape. Similarities in position of the eyes, nose and mouth.	Baby hair present near the right ear in AM, absent in PM. Forehead hairline is different, high hairline in AM and bell-shaped in PM. High forehead in PM, lower in height in AM.			[illegible] PM and AM [illegible]. Different right eyebrow, AM straight relatively [illegible]. Different upper lid.	Similar cheek shape. [illegible] nasal body.	Overall ear different. INAM Defined [illegible]	[illegible]	Similar chin and jawline. No cleft crease in PM.		Mentolabial sulcus present in AM but not in PM. Different right inferior palpebral crease shape, with AM being more pronounced on the lateral side and PM on medially and centrally. Difference might be explained due to pose being slightly different. No Right nasolabial fold in PM.	Different head pose	No Support	Right ear	
T	14	Differences: Prominent mole visible on AM L side of the nose near the ear, not found on PM. Acne pattern on R and L cheeks/chin on PM not visible on AM, but can be due to post production filters(?).	Differences: Scar-like mark on PM forehead not visible on AM (?)	Differences: overall shape of the head with a more squared chin in PM; distribution of facial features different, PM with more distant eyes, different position of the nose	Differences: forehead height and width, AM higher and wider than PM			Similarities: similar distance L-R eyebrow. Differences: shape, thickness, texture and length of hair on the medial side. Vertical end position of the medial eyebrow/ lateral brows relative to lateral/medial canthus. Difference in intercanthal distance with AM having closer eyes.	Similarities: Nasal outline similar shape in length. Similar nasal tip, but image is slightly overexposed so tip is not well visible. Nasal base in symmetry and shape; Similar size of the nostrils. Differences: root width, with PM being wider. Nasal body near the root is wider but otherwise similar. Nasal base in PM looks wider.		Similarities: philtrum and distance upper lip to base of the nose. Similar mouth opening shape. Differences: overall fullness AM thinner lips. Upper lip has a similar shape and fullness, Lower lip looks slightly different, with PM being fuller. Not comparable: difficult to assess some elements due to makeup on/quality of the image. Cupid's bow present on PM, unsure if present in AM.	Differences: between pictures - could be the pose/lighting? ; stronger jawline in PM		L and R inferior palpebral creases in PM, not visible in AM but could be due to post production filter - skin has been smoothed out)		Limited Support		
T	18	Similarities: acne pattern on L and R cheeks/chin. On PM a visible facial marks on the L mandible near the jawline, it is found only in the 3/4 AM pictures, but it is really faded, could be a false.	Similarities: Scar-like mark on forehead; scar-like marks on R lateral end of the eyebrow of PM looks like is present in AM	Similarities: Overall shape of the face (slight difference in orientation) seems consistent. Distribution of the facial features;	Similarities: forehead relative height and brow ridges prominence visible even though images don't have the same orientation. Not comparable: Forehead line covered in AM by an head piece.			Differences: more defined in AM, with thinner eyebrows and less hair density. PM are thicker from medial to lateral sides with some overgrown hair. The differences might be relative to AM having makeup on/drawn eyebrows and also well trimmed. There is an hair gap of L eyebrow towards the lateral side in PM, not clearly visible on AM. Similarities: there are noticeably longer hair towards the midline in AM and PM. There is a resemblance of shape (curved).	Similarities in cheek shape and prominence. Nose has similar shape - despite facial orientation differences, length and width are consistent. Nasal root same width and shape from a frontal view. Nasal body has the same creases/enlargement on the R and L side towards the root. Consistent nasal tip in shape and prominence. Nasal base; alae and nostrils.	Not comparable	Difficult to assess mouth due to different expression. Similar shape of upper and lower lips. Skin mark on the philtrum concavity, visible on PM - could be found in AM but could be an image distortion. Upper lip cupid's bow consistent, similar fullness. Lower lip shape. Lower lip PM with a median sulcus, only found in AM 1 where there is no lipstick. Teeth image PM showing lower and upper rows of teeth [illegible] general shape consistency of teeth observed in the AM (13,12,11,221,22)	Overall chin shape is similar (squared shape, with a slight prominence observable in both AM and PM).		Similar R and L infraorbital creases - however more marked in PM (could be the use of flash and better quality of AM images)		Strong Support	Facial marks, Scars, Teeth	
W	18	Different	Different	Some similarities	Different	Different	difficult to assess	Different	Different		Different	Different		Different		No Support		
YT	5	Differences: Dark facial mark under R lower eyelid found on AM cheek, not found in PM		Similarities: overall head shape. Differences: distribution of facial features	Similarities: hair colour, texture and brow ridges. Differences: forehead width and hairline and shape	Not comparable: eyes due to PM changes		Similarities: similar eyebrows in thickness, similar lateral end of eyebrows. Differences: conjoined eyebrows in PM, longer hair, thicker and longer hair on the medial end of the eyebrows in PM	Similarities: overall nasal [illegible] columella. Differences: [illegible]	Not comparable: Frontal view does not allow for analysis of the ear but the lower portion of the L ear where the lobe is appear more protruded and with a different shape if compared to AM	Differences: shape of upper and lower lip fullness, thinner upper lip and a fuller lower lip in PM [illegible]. Not comparable: [illegible] covered by facial hair in PM	Not comparable: presence of facial hair on the chin in PM	Differences: long and full facial hair in PM in both above the upper [illegible]	Differences: frontal lines in PM and nasolabial creases [illegible]	None	No Support		
YT	9			Similarities: general proportions of the face, length of the face distance between features	Similarities: straight forehead hairlines, relative height and lateral side hairline, as well as area near the L ear		Similarities: cheeks frontal view	Similarities: straight shape of the eyebrow, texture and colour, lack of density at the lateral end in both AM and PM, position relative to eyes. Differences: hair growing between the medial ends, not visible in AM but could be due to trimming	Similarities: Nasal root width, nasal body length and width, 3/4 view PM a bend in the nasal bridge is visible - also observed in PM image lateral, nasal tip shape from lateral view, nostrils and alae, columella shape	Similarities: images have not the same orientation (3/4 R AM and LR PM), however similar lobe attachment and shape, posterior auricular furrow, antitragus. Not comparable: the rest of the features and L ear cannot be compared due to head position.	Similarities: distance upper lip border columella, cupid's bow, dimension, shape and fullness of upper lip in relation to lower lip	Similarities; jawline shape/ chin squared shape and width from frontal view	Similarities: facial hair above the lip similar shape under the columella (texture in PM is slightly more intense), colour, area of facial hair below the lower lip is consistent. Differences: PM continuity of facial hair above upper lip with side and below the mouth and chin (only chin in AM): this could be related to different grooming practice	Not comparable: Quality of AM is low and also skin in the images has been smoothed out. In PM some folds frontal lines are visible		Moderate Support		
Z	26	Similarities: Matching position and size of facial marks above the R eyebrow on the forehead; nose blemish on the nasal body; facial marks on the L cheek		Similarities: skin colour, general distribution of the facial features despite swelling of the face	Similarities: Width and length of the forehead, consistent L forehead hairline not covering hair in pictures.			Similarities: eyebrow shape, it looks tattooed on PM [illegible]. Position relative to the eyes, thickness and distribution	Not comparable L cheek swollen, R cheek only visible from frontal view	Similar	Similarities: flat philtrum, upper lip with shape and cupid's bow. Dimensions and fullness of the lower relative to upper lips.	Similarities: chin, prominence from frontal view; Not comparable: jawline cannot be assessed from lateral view	Differences: PM with short facial hair around chin and jawline, very little growing and uneven. Not observed in AM. This is explained by individual presenting as female in AM images	Similarities: multiple R and L inferior palpebral creases, nasion crease, more marked in AM. R and L nasolabial fold but visible in PM as well. R and L periorbital creases		Strong Support	Facial marks	

Table 8. Observer 1,2,3 level of supports for the 15 cases analysed

Observer 1		
AM	PM	Level of Support
26	Z	Strong Support
18	T	Strong Support
4	A	No Support
21	**C**	**No Support**
18	W	No Support
14	**T**	**No Support**
1	QM	No Support
11	I	Strong Support
17	DS	Support
9	YT	Limited Support
24	**N**	**Moderate Support**
19	M	No Support
5	YT	No Support
20	**O**	**Limited Support**
7	F	No Support

Observer 2		
AM	PM	Level of Support
26	Z	Moderate Support
18	T	Support
4	A	Limited Support
21	C	Moderate Support
18	W	No Support
14	T	Limited Support
1	QM	Limited Support
11	I	Support
17	DS	Support
9	YT	Moderate Support
24	N	Moderate Support
19	M	Limited Support
5	YT	No Support
20	O	Limited Support
7	F	No Support

Observer 3		
AM	PM	Level of Support
26	Z	Strong Support
18	T	Strong Support
4	A	No Support
21	C	Limited Support
18	W	No Support
14	T	Limited Support
1	QM	No Support
11	I	Strong Support
17	DS	Support
9	YT	Moderate Support
24	N	No Support
19	M	Limited Support
5	YT	No Support
20	O	Support
7	F	No Support

Table 9. Comparison of results among 3 observers.

							Is it a match?			Level expressed			Disagreements between observers		
PM	AM	Observer 1 (O1)	Observer 2 (O2)	Observer 3 (O3)	AM target	Correct (0=No ; 1=Yes)	O1	O2	O3	O1	O2	O3	O1-O2	O2-O3	O3-O1
A	4	No Support	Limited Support	No Support	14	0	0	1	0	0	1	0	1	0	0
C	21	Support	Moderate	Limited Support	21	1	1	1	1	3	2	1	1	1	**2**
DS	17				17	1	1	1	1	3	3	3	0	0	0
F	7	No Support	No Support	No Support	15	0	0	0	0	0	0	0	0	0	0
I	11				11	1	1	1	1	4	3	4	1	1	0
M	19	No Support	Limited Support	Limited Support	7	0	0	1	1	0	1	1	1	0	1
N	24	Moderate Support	Moderate Support	No Support	5	0	1	1	0	2	2	0	0	**2**	**2**
O	20	Limited Support	Limited Support	Limited Support	20	1	1	1	1	1	1	1	0	0	0
QM	1	No Support	Limited Support	No Support	4	0	0	1	0	0	1	0	1	1	0
T	18				18	1	1	1	1	4	3	4	1	1	0
T	14	No Support			18	0	0	1	1	0	1	1	1	0	1
W	18	No Support			1	0	0	0	0	0	0	0	0	0	0
YT	9				9	1	1	1	1	1	2	2	1	0	1
YT	5				9	0	0	0	0	0	0	0	0	0	0
Z	26	Strong Support	Moderate Support	Strong Support	26	1	1	1	1	4	2	4	1	**2**	0

Key	
0 = NO SUPPORT 1=LIMITED SUPPORT 2=MODERATE SUPPORT 3=SUPPORT 4=STRONG SUPPORT	0 = NO SUPPORT (No) 1 = POSITIVE LEVEL OF SUPPORT (Yes)