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MORPHOLOGY OF THE FACE AS A POSTMORTEM PERSONAL IDENTIFIER

PhD Thesis

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List of abbreviations

AM – antemortem

PM – postmortem

DVI – Disaster Victim Identification

ICRC – International Committee of Red Cross

3D – three-dimensional

2D – two-dimensional

CCTV – Closed-Circuit Television

PCA – Principal Component Analysis

DLA – Dynamic Link Architecture

EBGM – Elastic Bunch Graph Matching

FK2DPCA – Fuzzy Kernel Two-Dimensional Principal Component

EIG – Extended Gaussian Image

ICP – Iterative Closes Point

ICNP – Iterative closest-normal point

RoPS – Rotational Projection Statistics

EER – Equal Error Rate

I3DFSR – Intrinsic 3D facial sparse representation

CSDC – Collective Shape Difference Classifier

2.5D – two-and-half dimensional

CCA – Canonical Correlation Analysis

S*in* – *sinister*/left

Dex – *dexter*/right

MELRM – Mixed Effect Linear Regression Model

Landmark definitions

Definitions of 3D landmarks

Landmark	Definition
Selion	The point of maximal curvature of the mid-line nasal profile curve at its nasal root end. (Katina, et al., 2016)
Pronasale	The crossing of the mid-line nasal profile and alar curve. (Katina, et al., 2016)
Subnasale	The point of maximal curvature on the mid-line curve at the base of the nasal septum. (Katina, et al., 2016)
Alare dex./sin.	The point of maximal curvature along the alar curve (Katina, et al., 2016)
Alare crest dex./sin.	The point of maximum curvature on the alar curve where this meets the paranasal area. (Katina, et al., 2016)
Labiale superius	The crossing of the upper lip and mid-line philtrum curves. (Katina, et al., 2016)
Labiale inferius	The crossing of the lower lip and mid-line lower lip curves. (Katina, et al., 2016)
Sublabiale	The point of maximal curvature in the mid-line curve as it passes through the mentolabial sulcus. (Katina, et al., 2016)
Gnathion	The crossing of the mid-line chin and mandible curves. (Katina, et al., 2016)
Exocanthion dex./sin.	The crossing of the lateral ends of the lower and upper eye lid curves. (Katina, et al., 2016)
Endocanthion dex./sin.	The crossing of the medial ends of the lower and upper eye lid curves. (Katina, et al., 2016)
Fonto-zygomatic dex./sin.	The most lateral point on the frontozygomatic suture. (Lessard, et al., 2011)
Chelion dex./sin.	The point of maximum curvature at the lateral end of the labial seal curve. (Katina, et al., 2016)
Otobasion Inferius dex./sin.	The final point at the preauricular end of the ear rim curve. (Katina, et al., 2016)
Otobasion supeprior dex./sin.	The point of attachment of the helix in the temporal region. It determines the upper border of the ear insertion. (Farkas, 1994)
Tragion dex,/sin.	The point of maximum curvature at the superior end of the tragus curve (Katina, et al., 2016)
Nasion	The point where the brow ridge curves meet the superior extension of the mid-line nasal profile curve (Katina, et al., 2016)

Definitions of 2D landmarks (Farkas, 1994)

Exocanthion (ex R., ex L.)	Outer corner of the eye
Endocanthion (en R., en L.)	Inner corner of the eye
Alare (al R., al L.)	The most lateral point on each alar contour
Gnathion gn	The most inferior midline point on the mandible
Sides of philtrum (ph R., ph L.)	The most lateral part of subnasal depression where the philtrum margins meet the upper lip vermilion border
Centre of the Cupid´s bow lp (lip tubercle)	Centre of the shape created by the upper lip vermilion border within the philtrum peaks

List of full-text publications

Caplova Z, Obertova Z, Gibelli DM, Mazzarelli D, Fracasso T, Vanezis P, Sforza C, Cattaneo C. The Reliability of Facial Recognition of Deceased Persons on Photographs. *Journal of Forensic Sciences* 2017, 62(5):1286-1291.

Caplova Z, Compassi V, Giancola S, Gibelli DM, Obertova Z, Poppa P, Sala R, Sforza C, Cattaneo C. Recognition of children on age-different images: Facial morphology and age-stable features. *Science and Justice* 2017, 57(4):250-256.

Caplova Z, Gibelli DM, Poppa P, Cummaudo M, Obertova Z, Sforza C, Cattaneo C. 3D quantitative analysis of early decomposition changes of the human face. *International Journal of Legal Medicine* 2017, doi: 10.1007/s00414-017-1647-x. [Epub ahead of print]

Caplova Z, Obertova Z, Gibelli DM, De Angelis D, Mazzarelli D, Sforza C, Cattaneo C. Personal identification of deceased persons: An overview of the current methods based on physical appearance. *Journal of Forensic Science* 2017, DOI:10.1111/1556-4029.13643 [Epub ahead of print]

Abstract

The human face carries some of the most individualizing features suitable for the personal identification. Facial morphology is used for the face matching of living. An extensive research is conducted to develop the matching algorithm to mimic the human ability to recognize and match faces. Human ability to recognize and match faces, however, is not errorless and it serves as the main argument precluding the visual facial matching from its use as an identification tool.

The human face keeps its individuality after death. Compared to the faces of living, the faces of deceased are rarely used or researched for the face matching. Different factors influence the appearance of the face of the deceased compared to the face of the living, namely the early postmortem changes and decomposition process. On the other hand, the literature review showed the use of visual recognition in multiple cases of identity assessment after the natural disasters.

Presented dissertation thesis is composed of several projects focused on the possibility of personal identification of the decedents solely based on the morphology of their face. Dissertation explains the need for such identification and explores the error rates of the visual recognition of deceased, the progress of facial changes due to the early decomposition and the possibility of utilization of soft biometric traits, specifically facial moles.

Lastly, the dissertation presents the use of shape index (s) as a quality indicator of three different 3D scanners aimed towards the most suitable method for obtaining facial postmortem 3D images.

Outline of thesis

Following dissertation thesis titled “MORPHOLOGY OF THE FACE AS A POSTMORTEM PERSONAL IDENTIFIER”, as well as described research, had arisen from the problematic identification of deceased migrants, which is currently an ongoing process in Italy. Previous years showed that usual means of identification are not applicable due to the nonexistent information for the comparison. Therefore, the attention had to be paid to less accurate but often occurring data, such as a simple antemortem photograph.

The literature review indicated the need of such a research, especially focused on the deceased, as very little could be found on this topic. Visual identification from the face and the facial photographs are somehow taken for granted, despite the fact that errors of visual recognition of familiar and unfamiliar persons are known. Most of the publications dealing with visual recognition and identification focus only of living faces. Similarly do technical publications developing facial recognition and matching algorithms. However, in theory, every recognition/identification method used for the living could be potentially employed for the deceased.

The dissertation thesis is divided into three chapters. Chapters are written to broadly cover background and all existing topic-related literature, identifying missing aspects and present topic-related research.

The first chapter “Forensic identification of the deceased”, explains the need and means of forensic identification, its application during disasters, differentiates primary and secondary identification methods, then focuses on visual recognition of human face and describes the recognition of faces of deceased, as well as the factors which influence such a recognition.

The second chapter ”Forensic identification of the living” lists all the identification methods which were used or researched for the identification of living person based only on the appearance of the face and body, describes possibilities of comparison of images of the face and presents the use of mole on the face as an identification feature.

The third chapter focuses only on the 3D scanning of the faces of the deceased as an alternative to the classical photography. The chapter identifies the most suitable 3D scanning method applicable in the unusual conditions typical for the research of the deceased, and employes Shape index (s) as 3D scan quallity indicator.

The conclusion of all three chapters is then summarized.

Aim of the thesis

The research and the thesis in general aim to outline the current practice of personal identification from the human face applicable on deceased. Multiple sub-research projects, which were carried out during the last 3 years, focus on the morphology of the face and soft biometric traits as potential identification elements, especially when antemortem and postmortem features are compared.

In particular, the thesis aims toward:

a) Investigating the current practice of identification of deceased when no primary identification means are applicable.
b) Point out the incorrect utilization of such methods by identifying their error rates, which leads to highlighting the need for more research on the topic.
c) Test the human ability to recognize and pair images of deceased people, and to compare trained and untrained participants.
d) Discuss and research the factors hindering facial recognition and identification of deceased with focus on quantification of early decomposition of the human face.

e) Point out the possibilities of morphological face recognition and identification of living people, which could be potentially utilized for dead.

f) Investigate the objectivity of morphological atlas for morphological evaluation and face matching of living.

g) Test, whether facial moles (soft biometric trait) are useful in face matching of age different images.

1. Forensic identification of the deceased

Forensic identification of the deceased is a legal determination of the identity based on the verified scientific matching of an antemortem (AM) and postmortem (PM) data. Generally, the higher number of matching AM/PM information means the greater possibility of a true match. The personal identification requires a holistic approach and verification by multiple identification methods. However, not all AM/PM data matches have the same discriminating power.

The identification of human remains has legal and humanitarian implications. The discussion about the potential rights and interests of the deceased emerged recently into the humanitarian actions. Several authors stated that despite the fact that the deceased cannot express the wish after death, for instance, the wish of a certain type of burial according to the customs of their religion, it does not mean not having any (Wilkinson, 2002) (Smolensky, 2009). The main argument to oppose is the fact the deceased cannot control the violations of wishes; the deceased possess their “own kind of dignity” but not the human rights. This justifies the responsibilities of living people towards the dead, and identification of the deceased is one of them (de Beats, 2004). The families of the deceased have the right to mourn, hold a funeral, to bury and cremate decedents as well as to participate in the investigation of death (Grant, 2016). The rights of the deceased and the responsibilities of living towards the dead is indeed an interesting discussion, although the subjective influences can be seen in opinion among people of different religion (Begherzadeh, 2016).

Despite this, the identification, death registration, and burial are the foremost matter of the national law of each country (Grant, 2016). The identification of the deceased is important for the legal matters of the remaining family – for instance, the inheritance procedure. The current rules and laws applicable to the personal identification of decedents can be found in the law of armed conflict and even if aimed at the application during and aftermath the conflict situations, the same rules apply, for example, in case of current deaths of international migrants (Grant, 2016).

The forensic personal identification is performed by various forensic experts. Generally, the more soft tissue is present; more pathologists are involved; the skeletonized remains should be the domain of the anthropologist (Cattaneo, 2007). However, the aid of forensic anthropologist when assessing sex, age or ancestry of skeletonized remains is not fully used in routine cases; forensic pathologists are preferred instead although they may not have experience with the osteological material (Cattaneo, 2007).

Different methods apply in the forensic identification of human remains depending on the state of preservation. Overall, methods can be divided into two overlapping groups (1) methods applied if soft tissue is present and (2) methods applied if the only skeletal tissue is present.

Forensic identification in case of the presence of the soft tissue focuses on the comparison of latent prints (fingerprints, rarely ear prints or lip prints), identification from the physical appearance, pathologies or medical intervention, trauma, iris pattern and body modifications (e.g. tattoos) (Thompson & Black, 2006). Comparison of dental data and DNA fingerprinting are methods applicable to both intact and decomposing bodies and skeletal remains.

When only skeletal remains are present, the construction of the biological profile consisting of age, sex and stature estimations, description of skeletal pathologies and trauma or cranio-facial approximation can aid the identification of the deceased. Sex is estimated morphologically by rating sexual characteristics of the adult skull and pelvis; pelvis being the most reliable; or metrically from the measurements of bones. The sex of the fetal and subadult skeletal remains is difficult to estimate due to the fact that sexually skeletal different traits develop with sexual maturation later in the life. The age of individuals is estimated in the age range – for young individuals using epiphyseal closures, tooth development and eruption or metric of the bones; for adults, for example, by the morphological rating of the surface of a pubic symphysis, sternal end of ribs, the auricular surface of ilium or less reliable sutures of the skull. Pathologies such as bacterial diseases, metabolic disorders, tumor lesions, osteoarthritis, healed fractures can be observed on skeletal remains as well as other antemortem and perimortem trauma and some medical interventions. Stature is estimated metrically from long bones using population-specific equations. (Ortner, 2003) (Meindl & Lovejoy, 1985) (Brooks & Suchey, 1990) (White & Folkens, 2005) (Phenice, 1969) (Aufderheide & Rodriguez-Martin, 2011) (Schaefer, et al., 2008).

The identification of human remains in single cases and in cases of disaster differ – in a single case the comparison of single postmortem and single or multiple antemortem data is required; while in the case of mass disaster multiple postmortem data are being matched to the multiple antemortem data. Forensic identification of the victims of mass disasters, therefore, requires a different approach – so-called mass disaster management.

1.1. Disaster Victim Identification

Simply said, the mass disaster is a sudden or progressive event, man-made or natural, that causes a great damage and loss of lives (Jain & Rajoo, 2009). The International Disaster Database reported 13 610 disasters in the last 20 years (1997- 06/2017) with various numbers of total deaths (Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir, 2017). Among the most destructive were natural disasters – earthquakes and tsunami (2010 Haiti with 222 570 dead, 2004 Indonesia with 165 708 dead), storms (2008 Myanmar with 138 366 dead, 1998 Honduras with 14 600 dead), extreme temperatures (2010 Russia with 55 736 dead, 2003 France with 19 490 dead) and floods (1999 Venezuela with 30 000 dead, 2013 India with 6054 dead) (Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir, 2017). Such disasters often overwhelm systems which care and identify deceased. Therefore the planning, training, and coordination play an important role and multiple organizations are involved in the mass disaster management – for instance, Pan American Health Organization, World Health Organization, and International Committee of the Red Cross (Morgan, et al., 2009). The mass disaster management deals with methods of body recovery, body storage, identification of dead bodies, risks of infectious diseases and provides support to families and relatives. As the collection of postmortem and antemortem data is overwhelming in terms of the amount of collected information, several online and offline schemes were developed. Regularly updated Disaster Victim Identification (DVI) Guide by Interpol addresses the issue of DVI team setting and management of DVI operations; and offers antemortem and postmortem schema for easier data collection (INTERPOL, 2014). The International Committee of the Red Cross (ICRC) created AM/PM database electronic tool for managing information on human remains and on missing people. The tool also offers the basic automatic matching of AM and PM data (International Committee of the Red Cross, 2013).

The mass disaster management issues the recommendations and the best practice for the identification of the deceased. Morgan et al. (2009) mainly addressed the identification of dead bodies by matching physical features and clothes as visual recognition of cadavers or their photographs is the simplest form of identification, however known to be prone to error. The DVI Guide (INTERPOL, 2014) on the other hand, recommends avoiding the identification based only on photographs and rather employ the primary identification methods – fingerprint analysis, comparative dental analysis and DNA analysis. The personal descriptions and the clothing are secondary methods of identification which may act as support to the primary means but are not sufficient as means of identification (Interpol, 2013).

1.2. Primary and secondary means of identification

Primary identification methods – matching AM/PM dental data, fingerprints and DNA samples are highly discriminating. Other identifiers such as unique physical and medical traits are called secondary identification methods (International Committee of the Red Cross, 2013).

Primary means of identification

The development of DNA analysis revolutionized the forensic identification. Any human remains if a sample for comparison is obtainable, nowadays can be potentially identified. DNA can be extracted from the soft tissue (blood or buccal swab) or skeletal material. The DNA analysis is less expensive, faster and more sensitive since it was first performed and, therefore, DNA analysis might be routinely used to aid the identification of single cases as well as the victims of mass disasters. The method is based on the comparison of two or multiple DNA profiles. DNA matching is the most accurate when used for the comparison with close family members – children and parents. Different parts of human DNA can be utilized – short tandem repeats located on autosomal chromosomes, mitochondrial DNA for matching with a maternal line of the deceased, short tandem repeats of Y chromosome for matching with a paternal line or single nucleotide polymorphism in cases of degraded DNA (International Committee of the Red Cross, 2009). DNA profiles are compared to the reference samples, the statistical inference is drawn and a likelihood ratio is calculated (Akhteruzzman, et al., 2015).

Forensic identification by analysis of fingerprints or palm prints is performed if AM reference prints exist. Reference prints are fingerprints taken for the identification purposes (for example when issuing the biometric passport or for immigration and asylum records) or are left as latent prints on personal belongings (INTERPOL, 2014). Two major types of features used in the fingerprint matching are local and global features. Local features, for instance, the minutiae, contain the information of a local area only. The global features (such as the number, type, and position of singularities, spatial relationship, and geometrical attributes of ridge lines, size and shape of the fingerings) are characterized by the attributes that capture the global spatial relationships of a fingerprint (Maltoni, et al., 2009).

In case of the existence of antemortem dental records, forensic dentistry contributes to forensic identification by comparing AM and PM data. Antemortem dental records can be obtained after the person underwent the dental examination or treatment; and can be in form of written clinical notes, radiographs, plaster casts of dentition and photographs (Hill, et al., 2011). So-called dental profiling can also help in the cases when no antemortem data are present. The presence/absence of teeth, the shape, size of crown and root, bone peculiarities, morphology and pathology of pulp chamber, dental restorations and other pathologies are used to create the dental profile (Stavrianos, et al., 2008).

Depending on the cause of the disaster and the preservation state of human remains, the primary methods are used in combination with the secondary means of identification. In the 1990s and early 2000s, the cost of the DNA analysis remained high. Therefore, in numerous cases, the dental and fingerprint comparison played important role in the forensic identification. In 1994 M/S Estonia ferry sank in Baltic Sea and 14% of passengers (989 in total) were rescued alive, 92 bodies of deceased were recovered. Sixty percent of victims were identified based on dental data as comparison of fingerprints was not possible due to non-existing AM data (Soomer, et al., 2001). The similar disaster happened in 1997 in the Mediterranean Sea, when the ship carrying migrants sank. Bodies were recovered after 7 months from the sea. Identification was possible in 49 of 52 cases using AM/PM data matching of physical appearance, clothing, and dental data. DNA samples were taken from all the recovered bodies but were not used in the identification process (Introna, et al., 2013).

The bombing of the US-Embassy in Nairobi in 1998 caused a massive damage of the buildings and the death of 211 people. Comparison of AM/PM fingerprints was used and successful in the identification of 3% of the deceased, DNA was used only in 2 cases (Kalebi & Olumbe, 2006).

The identification aftermath the Bali bombing in 2002 was performed in 60% of cases by a comparison of dental data within the first weeks; later only by using DNA (Lain, et al., 2003).

The massive earthquake in the Indian Ocean in December 2004 caused the Tsunami in South-East Asia, killing over 230 000 people in different countries. Reports from the city of Galle in Sri Lanka, Phuket in Thailand and from Indonesia were published describing the identification procedures. From 1500 Victims of Tsunami who died in the train in Galle, Sri Lanka 400 were unidentified and buried in the mass grave. The rest was identified using a combination of photographs and dental data; DNA samples were taken but not used (Rohan, et al., 2009). One year after the Tsunami, 1474 of victims in Indonesia were identified – 79% by dental data, 9% by fingerprints and 0.5% by DNA comparison (James, 2005). In Thai city Phuket 91% of victims were identified using dental data, 7% by fingerprints and 0.2% by DNA (Tsokos, et al., 2006).

As DNA testing became more available later in the 2000s, it started to be routinely used in the forensic identification of deceased.

Aftermath the firestorm in Victoria, Australia in 2009, DNA comparison was successfully used for the identification of 67 out of 163 victims (Hartman, et al., 2011).

However reliable and specific primary identification methods are, it is important to mention their limitations. First of all, the existence of antemortem data for comparison is necessary. DNA samples with high discrimination power are samples from the deceased found on personal effects or from the closest relatives – parents, children, and siblings (Alonso, et al., 2005). In case of a high number of victims, the problem of false positives emerges when comparing DNA sample of siblings (Brenner & Weir, 2003). DNA samples are easily degraded – incorrect storage and transport can cause the decomposition of the blood or sampled tissue (Hartman, et al., 2011) as well as decomposition process of the human remains itself (Alonso, et al., 2005). Genetic identification of semi-burnt bodies is possible and reliable; but some DNA tests (e.g. autosomal short tandem repeat analysis) are successful only sporadically on severely burnt remains (Schwark, et al., 2011).

Dental identification is massively used and successful method. Teeth are physical characteristics that endure the decomposition process. Among problems occurring in the dental identification are the longtime period between AM radiographs and the death, and morphological changes of the jawbone due to the resorption of the alveolar ridges after extraction/fallout of the teeth. Prolonged heat affects the position of the tooth in the mouth and may destruct the tooth crown. Differing quality of AM data may influence the identification process – the inconsistency in the dental treatment nomenclature or insufficient information about treatments (Stavrianos, et al., 2008) (Lain, et al., 2003) (Richmond & A, 2007) (Vazquez Villa, et al., 2015).

Similarly, some countries do not keep fingerprint records due to the security policy; moreover, the fingerprints are obtainable only from unburnt and not skeletonized human remains (Soomer, et al., 2001) (Akhteruzzman, et al., 2015).

Secondary means of identification

Secondary identification methods, including personal description, medical findings, and clothing, serve to complement the primary identification means. While in the past the identification based solely on the secondary means was not recommended as it is not sufficient and may be unreliable; recently the importance of the secondary identification means is being recognized (INTERPOL, 2014). DNA technology has become more common in the personal identification, but together with fingerprints and dental identifications are negligible when no data for comparison exist. Therefore, secondary means have to be employed in the process of identification.

The first group of secondary means of identification is represented by medical records, medical implants, marks of past surgeries and healed injuries and fractures. Antemortem and postmortem radiographs, CT and MRI scans can be matched, as well as the CT scan of deceased can aid the sex determination of burnt bodies (O´Donnell, et al., 2011) (Sidler, et al., 2007).

A point-by-point comparison of corresponding medical antemortem radiographs of any area of the body can potentially be employed for the purpose of personal identification.

The successful cases of personal identification by comparing vascular groove patterns of calvarium (Messmer & Fierro, 1986) (Rhine & Sperry, 1991), septation and lobulation of the frontal sinuses (Campobasso, et al., 2007), morphology and metrical analysis of frontal and maxillary sinuses (Camariere, et al., 2005) , combination of frontal sinus and the pattern of nasal septum (Taniquchi, et al., 2003), other cranial features, including Wormian bones and patterns of cranial sutures (Jayaprakash, 1997) can be found; and features of the vertebral column visible on head radiographs have also been used (Khana, et al., 2002).

As with radiographs, the identification by CT or MRI scanning uses morphological and metric comparisons of postmortem and existing antemortem data (Dedouit, et al., 2007). Single case studies demonstrated successful positive identification using CT scans of the head (Smith, et al., 2002) by matching the bony details of frontal and sphenoid sinuses, ethmoid and mastoid air cells, sagittal cranial suture, and the torcula; or by using the size and shape of parietal and temporal bones, orbits, and the shape of the skull base (Lino, et al., 2013). The possibility of comparison between antemortem and postmortem images acquired by two different radiographic modalities - conventional X-ray and CT data was explored for frontal sinuses

(Pfaeffli, et al., 2007). The study showed that it is possible to reconstruct the same projection from postmortem CT data for comparison with antemortem conventional X-ray image.

The positive identification can be obtained from antemortem radiographs of prostheses and metal plates by its location, morphological comparison, and bone remodeling. Medical implants with the unique serial numbers such as metallic knee and hip prostheses, or metal plates and the properties of intraocular lens implants can confirm the identity (Simpson, et al., 2007) (Murray & Caiach, 1998) (Isaacs, et al., 1997).

Personal effects and jewelry are as well considered to be the secondary identifiers. The unique appearance and engraved name are useful in the personal identification. However, as they can be borrowed or stolen, they cannot be used as a single identifier (Blau & Hill, 2009).

Very rarely in DVI, the identification based only on the secondary identifiers without any support of the primary identification methods is used. In 2015 five victims of a helicopter crash in Malaysia were identified only by strong secondary identifiers, and the bodies were released to relatives without awaiting the DNA comparison results (Khoo, et al., 2016). The only female victim was identified by exclusion method; five other men by matching AM information obtained from relatives to PM findings – car key, deformity of the foot, worn bangle, tattoo and traditional Malay clothes.

1.3. Other possibilities of identification

In cases in which the above mentioned primary and secondary methods are not applicable due to the lack of antemortem data, other means of identification needs to be engaged to aid the establishment of the identity of unknown decedents. The use of images and physical appearance of deceased persons has become more important, since the available antemortem information for comparisons may consist only of physical descriptions and photographs. Conversely, the appearance of the human face and body is not usually listed as a secondary identifier of the decedents, even if the human face and body hold information about the identity, age, sex, and ethnicity. The human face, in particular, is widely used for the personal identification of living persons (for instance eyewitness recognition, or the assessment of images by experts in criminal proceedings of eyewitness identification). Moreover, a high percentage of non-putrefied bodies are routinely identified by relatives within the first two days after death by visual identification of their faces (The Justice Project, 2007) (Hanzlick & Smith, 2006).

Similarly, tattoos, birthmarks, moles or scars (soft biometrics) are individualizing features appearing on the skin, therefore are considered as secondary identifiers.

The following overview includes parts of the literature review of identification methods based on physical appearance which was authored and published by the author of this thesis as:

Z. Caplova, Z. Obertova, D. Gibelli, D. De Angelis, D. Mazzarelli, C. Sforza and C. Cattaneo, "Personal identification of deceased persons: An overview of the current methods based on physical appearance," Journal of Forensic Sciences, 2017 (Caplova, et al., 2017).

The review provides a summary of current methods of assessment of the human face and body that have been applied or studied for the identification of unknown decedents (as opposed to living individuals). It comprises of articles published in the last 20 years (January 1996-May

2017), altogether 21 publications were considered relevant. Selected publications were divided into categories according to the utilized method – visual identification, identification based on specific facial/body areas, identification using biometrics and dental superimposition (Caplova, et al., 2017). The summary of all considered publications is presented in Table 1.

Table 1 A summary of all considered publications (Caplova, et al., 2017)

Publication	Context	Method used	Feature	Result
Chaikunrat et al. (2011)	• Mass disaster victim identification	• Primary means • Visual identification	• Physical appearance	• 32.2% of the cases identified visually • Exact error rates are not stated • Low in specificity despite of its moderate cost, easy to use-no special skills needed
Tsokos et al. (2006)	• Mass disaster victim identification	• Primary means • Visual identification	• Physical appearance	• Visual identification is highly erroneous in advanced state of decomposition without any supportive evidence
Soomer et al. (2001)	• Mass disaster victim identification	• Primary means • Visual identification	• Physical appearance	• Visual identification was used in 95% of cases • Error rates are not stated

Morgan et al. (2006)	• Mass disaster victim identification	• Primary means • Visual identification	• Physical appearance	• Decomposition hindered visual identification • Used in 0.3% of cases in Thailand • Greatly dependent on environmental conditions • No error rates are stated
Kalebi and Olumbe (2006)	• Mass disaster victim identification	• Primary means • Visual identification	• Physical appearance	• Visual identification was sufficient in 95% of cases • Other means were used for identification fingerprinting (3%), DNA testing (2%), and forensic odontology (1%)
Caplova et al. (2017)	• Scientific research	• Visual recognition	• Physical appearance	• No difference between students and professionals when matching postmortem images of faces • Recognition rates too low to be reliable • The nose attracts the most attention
Utsno et al. (2004)	• Scientific research	• Comparison of size and morphology	• Postmortem lip prints of embalmed bodies	• No changes in size observed • Morphological changes present • Effect of opened/closed mouth • Clear lip print can be obtained only less than 24h after death
Hadi and Wilkinson (2014)	• Scientific research	• Superimpositi on	• Resilience of facial creases of normal and bloated faces	• Transverse nasal creases, horizontal forehead creases and vertical glabellar lines remain relatively stable

Beautier et al. (2011)	• Mass disaster victim identification	• Unknown	• Tattoo	• Tattoos were easily detected and were of great value for identification
Matoso et al. (2013)	• Single case report	• Comparison of AM/PM description	• Tattoo	• Description of tattoo of burned body aided positive identification
Birngruber et al. (2011)	• Single case report	• Superimposition	• Tattoo	• AM and PM photograph matched and identity could be verified
Starkie et al. (2011)	• Scientific research	• Infrared photography	• Tattoo	• Green and Black ink pigments are easy to visualize on decomposing skin, red pigments are less responsive
Bolme et al. (2016)	• Scientific research	• Biometrical matching using algorithms	• Face and iris	• The iris and face deteriorate quickly, only 8.5% and 0.6% of all collected postmortem images of face and iris could be successfully matched
Sauerwein et al. (2017)	• Scientific research	• Data collection	• Face and iris	• Usable facial and iris data could be obtained for first three days during spring and summer • In winter, facial images could be obtained for 40 days on average, and iris images for 28 days.
Trokielewicz et al. (2016)	• Scientific research	• Matching algorithm	• Iris	• More than 90% of postmortem iris images could be successfully matched 5-7 hours after death and 13.3% to 73.3% 22 hours after death

Trokielewicz et al. (2016)	• Scientific research	• Matching algorithm	• Iris	• Biometric iris match with 13% error rate was found 60 hours after death • Occasional match could be found up to 17 days after death
De Angelis et al. (2007)	• Scientific research	• Dental superimposition	• Dentition	• Preliminary protocol for quantitative evaluation of dental superimposition of photographs and dental casts
Miranda et al. (2016)	• Single case report	• Dental superimposition	• Dentition	• Burned remains were positively identified • Combination of scoring of match between AM selfie and PM photograph, technique of comparison of smile line (canine to canine) of the maxillary anterior teeth and superimposition of two photographs
Silva et al. (2015)	• Single case report	• Comparison of AM/PM data • Superimposition	• Dentition	• Information obtained only by observing smiling photographs together with superimposition helped to confirm identity of deceased
Silva et al. (2008)	• Single case report	• Direct comparison • Superimposition • Analysis of upper and lower incisal edges	• Dentition	• Simple and low-quality AM data (smile photographs) allowed positive identification

Wu and Forrest (2010)	• Single case report	• Dental superimposition	• Dentition	• 3D CT reconstructed scan was used for AM/PM dental superimposition • 3D scans are easily acquired and overcome the difficulties with changes in head position • Limitations are the lack of definition at object margins and artefacts from metallic fillings

1.3.1. Visual identification of deceased

Very often the terms “visual recognition” and “visual identification” are not distinguished in the forensic literature (Caplova, et al., 2017). Face identification or visual identification is the simplest form of the personal identification of the deceased and living; and however unreliable, it is used in the practice.

The opinions about reliability of the visual identification vary - some studies reported its low reliability and high risk of misidentification (Speers, 1977) (International Committee of the Red Cross, 2009), while others demonstrated a good success rate of correct identification during mass disasters. The verification of the success rates by other means of identification were not stated in the publications (Padmitilaka, 2005) (Soomer, et al., 2001). For the purpose of the review, the terms visual identification and recognition were kept as they appeared in original publications, as it is not clear whether any scientific validation of simple visual recognition was performed to support “visual identification” (Caplova, et al., 2017).

In routine situations for instance of home deaths, the recognition and identification of decedents are performed visually by a relative or an acquainted person by viewing the body.

In some countries, such as the U.S.A., the viewing of the body of a decedent by relatives is considered to be an acceptable and sufficient method of identification. Depending on the jurisdiction, the visual recognition and identification by relatives can be also performed from photographs of the remains. No studies of the reliability of recognition from postmortem photographs in comparison to the viewing of the body directly have been done so far.

Many recent studies focus on understanding the differences between the processes of recognition of familiar and unfamiliar living faces, which also need to be considered when dealing with the visual recognition of faces of the deceased.

Despite the high error rates of the facial recognition, visual identification has been used in mass disasters, such as the Thailand tsunami (Tsokos, et al., 2006) (Chaikunrat, et al., 2011). The exact error rates are not stated by (Tsokos, et al., 2006). During the early period of the investigation after the disaster, most of the cases were identified by physical appearance and the photographs of the dead bodies. It was the only comparative material available and from the total number of identified victims the visual identification was successfully used in 32.2% of cases (Chaikunrat, et al., 2011).

Visual identification was also one of the methods used for the identification of the victims of already mentioned shipwreck in the Baltic Sea in 1994 (Soomer, et al., 2001). The remains were in relatively good condition and the physical description and visual identification were used in 95% of the cases also due to the fact that none of the victims had antemortem fingerprints on file and only 60% had antemortem dental records. The error rates of the visual identification were not stated in the publication. DNA samples were taken but the analysis was not used mainly because of its cost.

Some authors stress the importance to attempt the visual identification from human remains or photographs during mass disasters; others caution that the applicability of the method. In such situations, the visual recognition is greatly dependent on environmental conditions since for example, hot climate makes it almost impossible after 24-48 hours (Morgan, et al., 2006).

Visual identification by unfamiliar persons based on antemortem photographs is highly erroneous - such situation can happen if the visual identification by relatives is not possible, as in cases of international visitors during mass disasters and currently in cases of dead migrants. In particular, the post-mortem changes can occur few hours after the death depending on the environmental conditions. Even the initial postmortem changes as corneal clouding, slackness of the jaw, pallor, and loss of muscle tone changes the appearance of the deceased (Wilkinson, 2014). More research is needed in order to understand the change of the facial features after death and to select useful and applicable features that can be observed on non-putrefied or slightly putrefied faces of the deceased (Caplova, et al., 2017).

If the identification is based solely on the comparison of facial images, it is often restricted to images taken shortly before the burial and they may not be comparable to the available antemortem photographs regarding the position of the head or the visibility of features (Caplova, et al., 2017). The DVI Guide by Interpol (2013) addresses the photographic documentation of victims. Two overlapping photographs of upper and lower body, full frame of the head, any pathologies and photographs of the teeth are recommended. However, the recommendations of photographic documentation and the protocol are not detailed enough, and practice may differ (Caplova, et al., 2017). The 3D scanning of faces of deceased may be a user-friendly alternative to the traditional 2D photography, providing the solution to the restrictions caused by non-standardized photography for comparisons with antemortem images. Similarly, as for living people, any 3D scan of the face of the deceased can be rotated to mimic the antemortem photograph or to expose any individualizing facial features (Caplova, et al., 2017).

The use of the visual identification has been doubted because it only relies on the human ability to compare and recognize faces, which so far had not been fully explained by the existing scientific methods (Zhao, et al., 2003).

Interestingly, photographs of the face of the deceased are shown to families in order to obtain positive identification in routine cases (e.g. home deaths) and positive recognition in cases of mass disasters. The images of injured or moderately putrefied faces may undergo modification to minimize the destruction (Prag & Neave, 1997) as well as the craniofacial reconstruction can be performed from skeletonized remains (Clement & Ranson, 1998). In both cases, the main aim is to produce the living facial representation. Several publications present the manual of the craniofacial reconstruction and postmortem sketching (Taylor, 2000) (Gibson, 2007) (Wilkinson, 2008).

This approach, though, still relies on the human ability to compare and recognize faces. Similarly to the identification of living faces, the categorization of facial features with the aid of morphological atlas could potentially be used for deceased. Different morphological classification of facial features for living persons was proposed by different authors (Ritz-Timme, et al., 2011) (Rosing, 2008) but none of the methods has been accepted as a standard for the identification. The rating and categorization of morphological facial features may be considered as more objective when assisted by morphological atlases, but recent studies showed high inter- and intra-observer mismatch percentages (Ritz-Timme, et al., 2011) (Caplova, et al., 2017). This approach of classification of facial features was not tested on deceased yet (Caplova, et al., 2017). The DVI postmortem data collection form by Interpol (2014) includes a section for the external description of the body with multiple options for instance for hair and eye color. For other facial features, such as the mouth, chin, lips, and neck, the form allows only an open-end description of a distinctive feature. In these cases, the use of visual aids (as morphological atlas) for the description of distinctive facial features may allow more consistent collection of the data; and may prompt the examiners to pay attention to features with which morphological assessment they may not have had experience in the past (Caplova, et al., 2017). On the other hand, Broach et al. (Broach, et al., 2017) recently tested the commercially available facial recognition software for the personal identification of deceased. The publication, the first of its kind, aimed to simplify the disaster victim identification by software matching of a high number of antemortem and postmortem 2D images. Broach et al. (2017) used photographs of living people and simulated the facial injury by moulage of the mild, moderate and severe stage. Each no-moulage image was then compared to the library of moulage photographs using the recognition algorithm of commercially available iPhoto software (by Apple). The recognition match was reached in 42% to 49% with mild and moderate moulage, and in 31% to 49% in cases of severe moulage depending on the quality of photographs. Even if the presented study used simulated postmortem images, the result showed that AM/PM face matching may be used as a recognition tool when dealing with the larger amount of deceased (Broach, et al., 2017)

Although the visual recognition has been used for the personal identification of the deceased, a little research about its reliability and applicability has been undertaken; and no standardization and validation of the method was performed. The standardized postmortem photographic guidelines or employment of 3D scanning technology can overcome basic limitations of the face recognition (such as low visibility of individualizing features or different head angles) (Abate, et al., 2007). Similarly, the use of standardized facial feature classification could decrease the error rates of visual recognition; however, high inter-observer differences were observed (Ritz-Timme, et al., 2011). High intra-observer errors may be caused by a different understanding of definitions of facial features by each observer, as well as insufficient descriptions of the length and width of facial features which are often the issues in morphological atlases (Caplova, et al., 2017).

Such preliminary face matching, if used, should not be based solely on one´s ability to recognize faces.

1.3.1.1. Human ability to recognize faces

Face recognition is generally described as a usage of the face to identify a familiar individual; face identification as naming the person and face recall as a description of the face from the memory (Roth & Bruce, 1995). Recognition of faces is an innate human ability which is influenced by many factors. Differences between the recognition of familiar and unfamiliar faces, recognition of photographs and video records and the recognition of faces of deceased had been studied. The human ability to recognize faces had been debated to be special and unique. Various arguments had been used to support this idea – its prodigiousness - one can recognize transformed and inverted faces; or easily spot the human face among other stimuli (Cohen Levine, 1988).

Even if the faces of different people carry the same features (nose, mouth, eyes) and the same configuration, humans are able to spot the familiar faces in the crowd in a fraction of a second.

Variety of information is learned from the human face by a simple look – approximate age, sex, ethnicity, identity and even the current mood. Moreover, humans are able to process the visual information in the poor illumination conditions, with changing viewpoint and changing facial expressions. The neural processing of faces had been studied and several areas of the brain involved in the face recognition are known. The creation of the automatic face recognition algorithms based on neural networks simulating the human recognition ability, however, still remains challenging (O´Toole, 2005).

Two different theories of the face recognition were researched – the holistic considering the face as a whole configuration, and the feature based focusing mainly on facial features. In the beginning of the face recognition research, the holistic approach was preferred; later overtaken by the support of the feature-based approach (Tanaka & Farah, 1993). Currently, it is still not fully understood how humans recognize faces.

The fact that the human face is hardly recognized when turned upside down than other objects is supporting the holistic theory (Yin, 1969). Moreover, the inversion of mouth and eyes only ("Thatcher illusion") is left unnoticed during the recognition of inverted image (Thompson, 1980). Similarly, naming the famous person on the photograph becomes more difficult when the upper and lower part of the face belongs to two different people (Young, et al., 1987).

On the other hand, when participants of the test were asked to describe the unfamiliar face they have used particular facial features (Shepherd, et al., 1981). Others argue that facial features are processed independently and when facial features on the image are manipulated and exchanged, the person becomes unfamiliar and recognition low (Bradshaw & Wallace, 1971). Not all the faces are recognized with the equal accuracy - more unusual features there are on the unfamiliar face, the higher is the recognition accuracy (Light, et al., 1979).

The number of perceptual strategies of scanning and encoding the human face in the process of recognition is infinitive. The pattern of the eye scan can be demonstrated by various tests – tracking of the eye movement, masking particular facial features, alternation of facial features, or observing the order in which people describe faces (Ellis, et al., 1979). The first observations suggested a top-to-bottom perceptual scan (Smith & Nielsen, 1970), later the preference of inner features arisen (Luria & Strauss, 1978). Inner features, such as eyes and the mouth, are involved in the communication and are most likely to attract the most attention. The experiment by Eliis at al. (1979) showed that while inner facial features play important role in the recognition of familiar faces, no differences in recognition accuracy of the unfamiliar face from inner and outer facial features were found.

The developmental research in the 1970s showed that young infants prefer outer outlines of the faces and as they grow older they start to prefer the inner features (Maurer & Salapatek, 1976). However, the recent studies suggest that children of the age of 7 years old use internal facial features over the external and they process the faces in the same way adults do (Bonner & Burton, 2010). This can be explained by the fact that the ability to recognize faces is driven by the genetic influences and the experience – babies are born with the face discrimination abilities and the experience plays a role in the recognition accuracy (McKone, et al., 2009).

The age, sex, ancestry and interpersonal differences were found to play an important role in the face perception and the accuracy of the face recognition of familiar and unfamiliar faces.

"The other race effect" phenomenon is causing the lower recognition accuracy when recognizing faces of individuals of different ancestry (O´Toole, 2005). As face memory tests are used for the diagnosis of for example mental prosopagnosia, it is important that the ethnicity matches to different testing populations. The effect of ethnicity is subtle but clear on the face processing even in the healthy participants (McKone, et al., 2011). It is not fully understood whether "the other race effect" is caused by memorial or perceptual processes. Recently, the link between the strong "other race effect" and lower accuracy of unfamiliar face recognition was pointed out. People who are performing poorly in the recognition of unfamiliar faces of the same ancestry perform poorly when recognizing faces of different ancestry, as it rather relies on the perceptual process than the memory (Megreya, et al., 2011).

The recognition of the faces is affected by the presence of the second face. The presence of two target faces reduces the recognition accuracy. The effect is stronger when two faces are placed close to each other. The effect can have a great importance in the eye-witness recognition procedure, when several subjects may be presented at the same time (Megreya & Burton, 2006).

Females are generally outperforming males when recognizing facial emotions and at non-affective face recognition (McClure, 2000) (McBain, et al., 2009). Performance of simple recognition, however, depends on the strength of the visual signal (for example the difference between two photographs). The males require the strong signal to reach the same accuracy level as females. Females excel in the recognition of faces of both sexes. The finding also has clinical implications – for instance, the women with schizophrenia tend to be less socially impaired by the disease (Usall, et al., 2001).

The influence of sex on the recognition of faces with different facial expression was studied (Hofmann, et al., 2006). The results showed that the processing time in opposite-sex face recognition is lower and females can recognize male expression-different faces faster compared to expression-different female faces; and vice versa. The finding supports the evolutionary perspective which suggests that more attention is paid to the identity of a potential mate.

The recognition of familiar and unfamiliar faces are two different processes; involving different cerebral hemispheres, and showing different error rates (Cohen Levine, 1988).

Recognition errors of unfamiliar and familiar faces

Recognition of unfamiliar faces is often studied for the forensic implications. The high error rates of recognition of unfamiliar had been shown in multiple publications, reporting on average 20-30% errors. Different error rates of the unfamiliar matching depend on the performed experiments. Recognition of person on photographs after viewing the video showed an error rate of 30%; the comparison of a target photograph to the line-up of photographs 20% error. The accuracy decreases when the target is compared with multiple numbers of faces (Bruce, et al., 1999).

Recently, unfamiliar face matching may be performed from low-quality images from CCTV cameras. The accuracy of such recognition is poor, also in comparison to the recognition of the familiar person in the same conditions (Burton, et al., 1999). The recognition remains poor even if using the high-quality photographs and broadcast quality video (Henderson, et al., 2001).

The comparison of ID-photographs of living face of an unfamiliar person is routinely performed at the border control. Therefore the experts carrying out such examinations have to be better in recognizing faces. Wilkinson and Evans (Wilkinson & Evans, 2009) suggest that training and experience in the facial analysis improve the reliability and accuracy of facial comparisons. In the experiment conducted by Hollingsworth (Hollingsworth, 2014) volunteers evaluating eyebrows reached higher recognition accuracy by 6% with previous training compared to evaluators without. On the other hand, in different experiment trained passport officers perform with low accuracy when matching unfamiliar faces compared to untrained observers (White, et al., 2014) – on average 10% error when matching the person to photo; and 30% error when matching the photo to photo.

The existence of so-called super-recognizers was suggested to oppose the idea of training improving the recognition accuracy – people naturally good in recognition tend to proceed with a career in which facial recognition (Hollingsworth, 2014). Super-recognizers can recognize unfamiliar faces after many years, the task which is difficult for “average” recognizers (Russell, et al., 2009).

In contrast to difficulties in the recognition of unfamiliar faces, humans are better in the recognition of familiar faces. The observer´s accuracy increase with the familiarity of matching the subject. The recognition of familiar faces is not influenced by degradation of the face (for example pixelization of the image or low quality) (Bruce & Young, 1986).

Ellis et al. (1979) point out the differences of feature preference between familiar and unfamiliar faces. While inner facial features are more likely to attract attention when recognizing familiar faces; in case of unfamiliar faces the various feature saliences balance one another.

Majority of the research of the face perception and recognition is dealing with faces of living. However, when recognizing faces of deceased for the purpose of personal identification, different environmental and decomposition conditions play a role. Following subchapter, which was published and authored by the author of this thesis; focus on error rates of facial recognition of deceased from photographs.

1.3.1.2. Reliability of facial recognition of deceased persons on photographs

Z. Caplova, Z. Obertova, D. M. Gibelli, D. Mazzarelli, T. Fracasso, P. Vanezis, C. Sforza and C. Cattaneo, "The Reliability of Facial Recognition of Deceased Persons on Photographs," Journal of Forensic Sciences, 2017 62(5):1286-1291.

In the past years, the task of identification has been more and more delegated to technology (e.g. DNA) and quantification. Even if the relatives of the deceased are known they may not be able to provide a suitable DNA sample for comparisons. However, in many cases for instance death of migrants from less developed countries, at least their antemortem photographs obtained from families or found on their ID documents they carried are available for comparison, which may aid visual identification by a third person. Aftermath of the mass disasters the visual comparison of antemortem and postmortem photographs is not a simple one-to-one comparison, but rather comparison of many postmortem and many antemortem images (Caplova , et al., 2017).

The task of recognition by facial images is somehow taken for granted; for example, identification of the living by a ID picture on behalf of customs or police personnel; or even identification of a cadaver on behalf of authorities who are confronted with comparing the face of a well-preserved body with the photograph from a picture ID (Caplova , et al., 2017) .

Considering the extensive use of recognition from picture IDs for living persons, and the literature on identification of living persons based on images (Halberstein, 2001) (Porter & Doran, 2000) (Vanezis & Brierley, 1996) it may be tempting to identify deceased persons by comparing their face with photographs when it is only antemortem material available. But the applicability of a visual recognition of deceased persons by comparison of antemortem and postmortem facial images has not been examined yet, and therefore may easily lead to erroneous results (Caplova , et al., 2017) .

Although identification/recognition of a dead well-preserved body by someone who knew the person well in life is more or less standard in many European countries and the USA before autopsies; visual identification of deceased persons by relatives in the aftermath of mass disasters has been shown to have an error rate of about 30% (Speers, 1977) (Morgan, et al., 2006). The recognition and identification of victims by relatives is commonly used despite its high error rate and the recognition of unfamiliar faces may be even more error-prone. However, the rate of incorrect recognition of unfamiliar faces of living persons has been shown to be on average around 30%, similar to that undertaken by relatives (Speers, 1977)

This pilot study aimed to explore the ability of observers (professionals and students) to recognize and match unfamiliar faces of living and dead persons and to identify those facial morphological traits most frequently used in recognition (Caplova , et al., 2017).

Material and methods

Forty-one students (20-55 years old) of Arts and Natural Sciences participated and anonymously completed a questionnaire. Five professionals aged 35 to 70 years from The Section of Legal Medicine of the University of Milan with forensic experience in the personal identification and facial recognition completed the questionnaire (Caplova , et al., 2017).

The questionnaire contained photographs of living and deceased faces arranged into 19 line-ups in four categories combinations:

1 dead versus 5 dead (8 line-ups)

1 living versus 5 dead (2 line-ups)

1 dead versus 5 living (7 line-ups)

1 living versus 5 living (2 line-ups) (Caplova , et al., 2017).

The comparison of antemortem or postmortem photographs only was chosen to explore the effect of the change of the position of the head, lighting, distance and the age difference on recognition. Images were obtained from the database of photographs and autopsy cases of the Section of Legal Medicine at the University of Milan in Milan (Italy) and the University Center of Legal Medicine Geneva-Lausanne in Geneva (Switzerland) (Caplova , et al., 2017).

The images of Caucasian males differing in lighting, head orientation, the presence of facial hair and age of the depicted person had been collected from real-life scenarios and haven't been modified. Only pictures without signs of putrefaction were used. The photographs of individuals selected for any line-up resembled each other in order to make the recognition procedure more realistic. An example of the line-up is illustrated in Figure 1 (Caplova , et al., 2017).

The observers were asked to decide if given facial photograph corresponds to one of five photographs in a line-up, select it and to identify most useful facial feature used for recognition. There were no time restrictions for completing the task and no list of facial features to choose from was offered. The given facial photograph always corresponded to one of the photographs in the line-up.

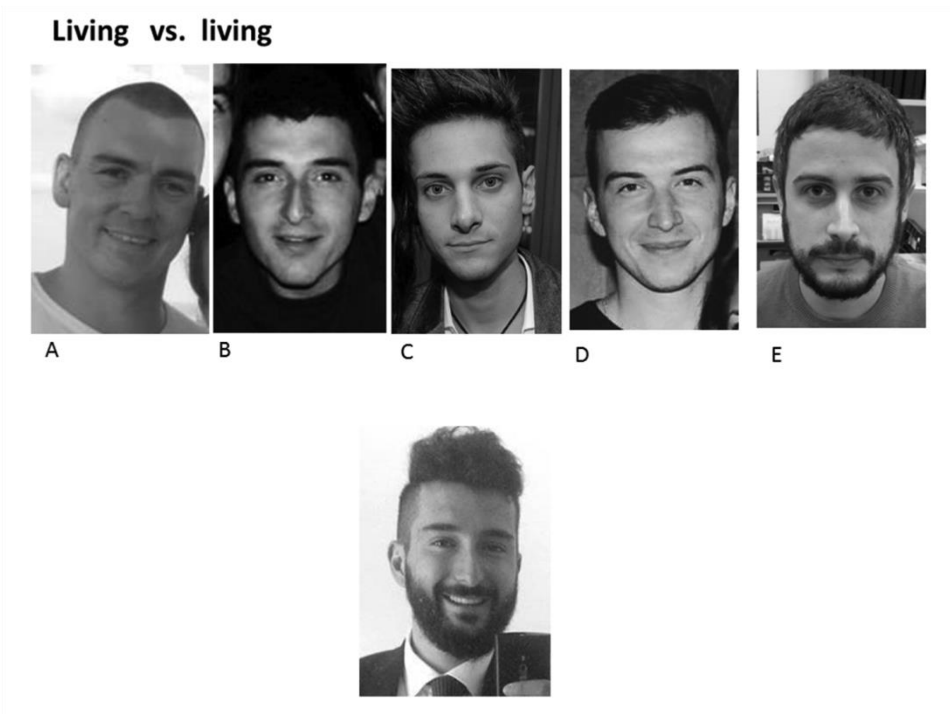

Figure 1 An example of a line-up (correct answer B) (Caplova , et al., 2017)

Statistical evaluation

The number of correct and incorrect answers, as well as the most useful facial feature, was noted. Microsoft Excel 2010© was used for descriptive statistics (median, minimum, maximum).

Normal distribution of data was tested (Anderson-Darling Normality Test Calculator version 6.0 (Otto, n.d.)), and Mann-Whitney U Test was used to compare the difference in preference of certain facial feature of correct and incorrect answers of students and professionals. Chi-Squared test was employed to test if the observed rate of correct answers significantly differs from the expected accuracy (Preacher, 2001). Due to the small number of images in the other two categories, only dead vs. dead and dead vs. living groups were used in the statistical analysis.

Results

Figure 2 and Figure 3 illustrate the distribution of correct answers by line-up category for students and for professionals. As can be seen, the accuracy varied depending on the line-up set up. The overall median accuracy of students was 78.1%, with a minimum of 12.2% and a maximum 100% of correct recognition. The overall median accuracy of professionals was 80.0%, with a minimum of 20.0% and a maximum of 100% (Caplova , et al., 2017).

The highest percentage of correct answers was observed when facial images of 1 dead and 5 dead persons were compared (100% by professionals), and when facial images of 1 dead and 5 living persons were compared (91.5% by students). Generally, the comparisons of 1 living with the line-up showed lower correct rate than the comparisons of 1 dead with lines-up.

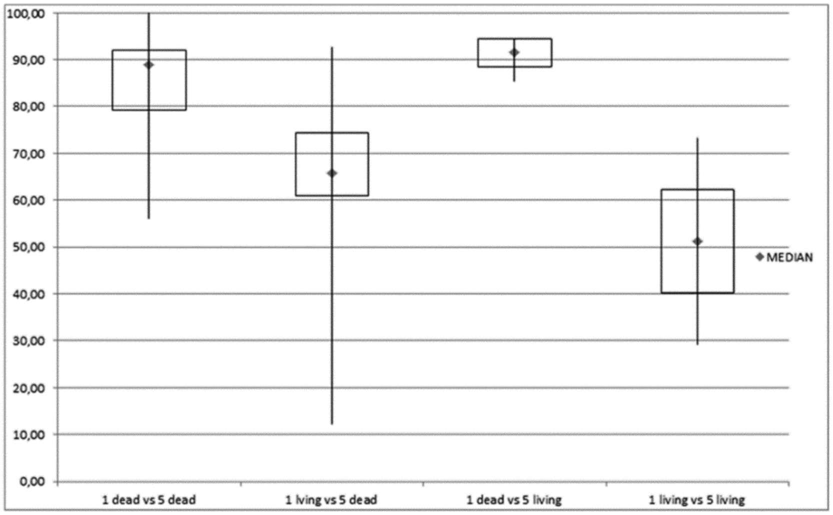

Figure 2 Median accuracy of students (Caplova , et al., 2017)

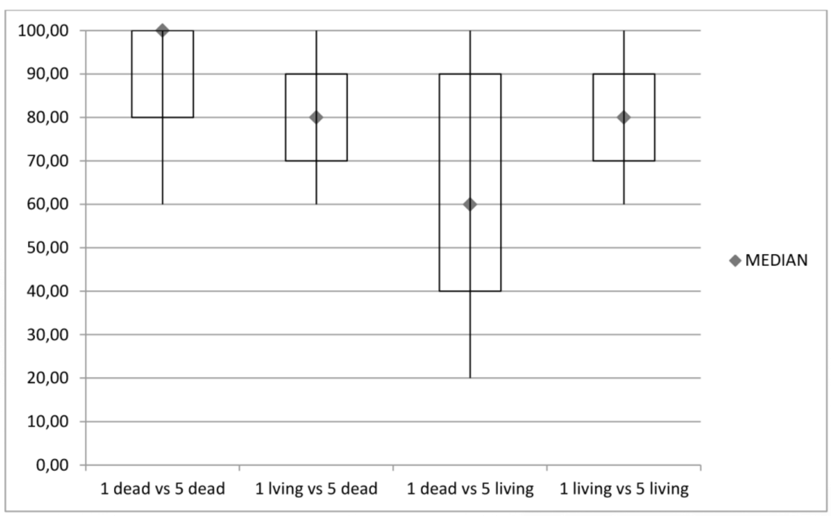

Figure 3 Median accuracy of professionals (Caplova, et al., 2017)

Table 2 presents the three most used facial features for correct and incorrect recognition of each of the four image categories and for students and professionals.

Table 2 The most used facial features for recognition

Students	Correct			Incorrect		
1 dead vs. 5 dead	Nose	Face shape	Mouth	Nose	Mouth	Eyebrows
1 dead vs. 5 living	Nose	Eyebrows	Face shape	Nose	Mouth	Face shape
1 living vs. 5 dead	Nose	Mouth	Skin	Nose	Ears	Eyes
1 living vs. 5 living	Mouth	Eyes	Ears	Face shape	Chin	Eyes
Professionals	**Correct**			**Incorrect**		
1 dead vs. 5 dead	Nose	Mouth	Eyebrows	Nose	Eyebrows	Mouth
1 dead vs. 5 living	Nose	Beard	Eyes	Mouth	Face shape	Eyebrows
1 living vs. 5 dead	Nose	Ears	Eyebrows	Nose	-	-
1 living vs. 5 living	Mouth	Nose	Face shape	Face shape	-	-

When correctly answered, the nose was considered as the most useful facial feature for both groups (36.9% for students, 29.0% for professionals). When incorrectly answered, the nose was considered as the most useful feature by students (45.1%), but mouth by professionals (21.0%) (Caplova , et al., 2017).

The second and the third most common answers (mouth and face shape) did not depend on the correctness of the answer of students. On the other hand, professionals considered mouth and eyes/eyebrows as the second and third most useful when answering correctly; and face shape and eyebrows when answering incorrectly (Caplova , et al., 2017).

The difference between the most common feature used for recognition of categories, in which at least one postmortem facial image was present and the only living category was noted. Observers paid more attention to the nose when postmortem image was present, as opposed to any other facial feature except nose when only antemortem images were present (Caplova , et al., 2017).

No significant differences in the distribution of used facial features between correct and incorrect answers of both students and professionals features were found (Mann Whitney test, p>0.05); and distribution (%) of the most useful facial features for recognition is illustrated in Figure 4 (Caplova , et al., 2017).

The correct observed recognition rate was then compared to the theoretical chance of selecting any image (in the 1 to 5 set-up being 20%) using a chi-squared test. The test revealed that the latter was greater than by chance expected at the statistically significant level of > 0.05 for all categories analyzed by both students and professionals (Caplova , et al., 2017).

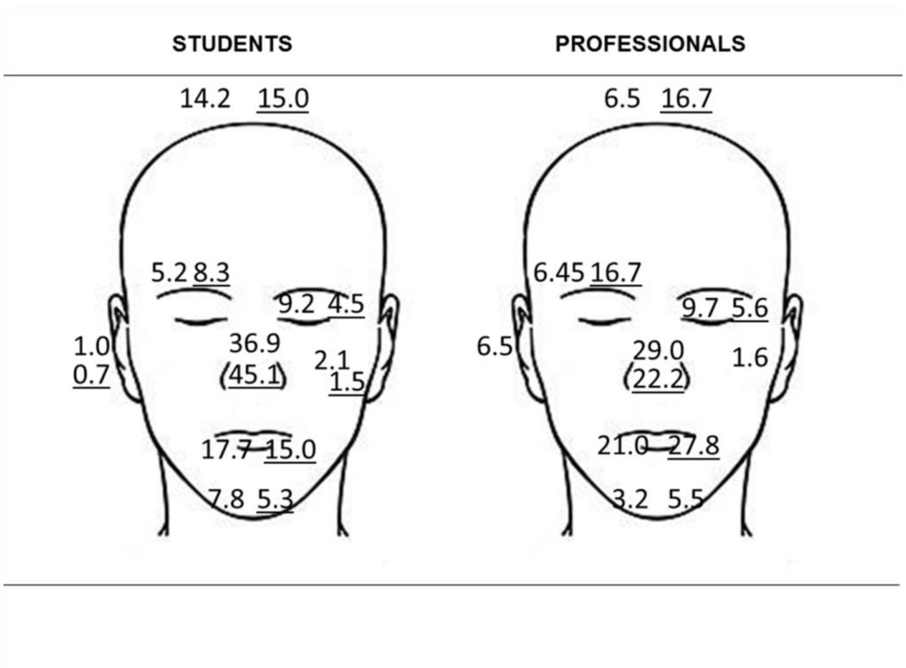

Figure 4 Graphical demonstration of the percentage of correct and incorrect (underlined) answers for students and professionals by used facial feature (Caplova , et al., 2017)

Discussion

Median recognition accuracy up to 100% was reached depending on image set-up. Moreover, the recognition was not driven by chance. The results showed that comparison of unfamiliar faces of living and deceased could be potentially used as an initial recognition method, even performed by the third person. However, this is only a pilot study pointing out the issues of facial recognition of deceased and more research is needed to establish to what level and under what circumstances this method would be applicable (Caplova , et al., 2017) .

No significant differences in correct rates of students and professionals were found. In an experimental setting, which may differ from real life scenarios, the recognition did not seem to be affected by the head position, distance to the camera of righting. The recognition of living, especially when the observation was done by students, seemed to be affected by age changes of the depicted person. The participants of this study selected nose as the most useful facial feature for face recognition. Several previous studies, however, showed that the nose does not play an important role for perceiving faces (Shepherd, et al., 1981) (Bruce, 1988). The differences between prior studies and this pilot study might be caused by the fact that previously only frontal images of living people were used, while in this case, head positions of living and deceased people differed (Caplova , et al., 2017).

Interestingly, the nose was selected as the most useful facial feature in cases of incorrect answers. Luria and Strauss (Luria & Strauss, 1978) pointed out that while nose seems to attract the most visual attention, it is not useful for the recognition of the face.

The nose was selected as the most useful facial feature even the presence of potentially individualizing features, such as scars, discolorations or teeth. Even though those features were rarely considered, compared to students, professionals seemed to pay more attention to them.

The lowest recognition rates of students (12.2%) and professionals (20.0%) were observed when a photograph of the living man with the mustache was compared to the line-up of 5 deceased men with a full beard. Similarly, low correct recognition rates (29% for students, 60% for professionals) were recorded when the facial image of living man with a mustache was compared to line-up consisting of four men with no facial hair and one man with a mustache.

On the other hand, the presence of full beard in AM and PM compared photographs resulted in the correct recognition of 78.5% by students and 100% by professionals.

The simple experiments allowed making an interesting implication about the possible application of the comparison of unfamiliar faces for the personal identification.

1.3.1.3. Limitations of use of images of the deceased

Different limitations come in place when dealing with the images of faces of deceased in comparison to faces of living individuals. The effect of the pose and illumination remains but the changing facial expressions disappear. Moreover, the early postmortem changes and following body decomposition change the appearance of the face.

Similarly to recognition/identification of living people, the use of 3D technology minimizes the limitations of the different head pose. Three-dimensional (3D) image is characterized by three dimensions – width, height and depth; model can be rotated and seen from all views.

The progress of early decomposition was the interest of the author; hence the following chapter contains methodology, results, and conclusion from publication authored by the author of this work, namely:

Z. Caplova, DM. Gibelli, P.Poppa, M.Cummaudo, Z.Obertova, C.Sforza, C.Cattaneo, 2017. 3D quantitative analysis of early decomposition changes of the human face. International Journal of Legal Medicine doi: 10.1007/s00414-017-1647-x. [Epub ahead of print]

1.3.1.3.1. Quantitative analysis of early decomposition changes

The process of body decomposition in different environmental conditions is well known and described (Hayman & Oxenham, 2016) (Galloway, et al., 1989) (Haglund & Sorg, 2001). Despite that, the early decomposition process affecting the human face was studied and described only recently (Wilkinson & Tillotson, 2012).

Wilkinson and Tillotson (2012) investigated the facial decomposition for better prediction of the appearance of the living. Color change, dehydration, swelling and insect activity was observed and recorded in 3D at the Anthropological Research Facility in Knoxville, USA. The predictable pattern of early decomposition was described: (1) dehydration of eyes and orbital shrinkage, (2) bloating of cheeks, mouth and nose, (3) no change in volume in upper and midface, and (4) compression of tissues along the midline of the face (Wilkinson & Tillotson, 2012). The experiment was conducted outside – bodies were exposed to changing temperature and weather conditions.

A similar experiment of tracking facial decomposition of a single cadaver as reported by Wilkinson and Tillotson (2012) was conducted, but in different environmental conditions. The usual way of storage of deceased was chosen – unchanging temperature of 4 degrees Celsius. Additionally, the study focused on the quantification of the changes in the face due to the decomposition using 3D-3D superimposition and calculation of Root Means Square Values (RMS). The approach was used by Gibelli et al. (2016) for the estimation of the sameness of two time-different 3D scans of the same person. The method quantifies the differences between two 3D scans for the purpose of identification using Root Means Square (RMS) point-to-point distance. The RMS as the indicator of differences between 3D scans has been used in previous studies regarding, for instance, facial symmetry (Codari, et al., 2017), but not for the quantification of early decomposition changes.

Material and methods

Three-dimensional scans of the face of a cadaver of a single donor (female 63 years old suffered from metastasized lung cancer) were obtained over the period of 2 months in accordance with the Mortuary Regulation of the Section of Legal Medicine in Milan, Italy. The donation was possible through the donation program PANDORA (Programma Anatomico di Donazione Cadaveri a Scopo di Ricerca Antropologica e Biomedica) permitted by local legislation (DPR 10.09.90 n° 285, art. 44) (Caplova, et al., 2017).

The environmental conditions were stable during the whole period of the study - the cadaver of the donor was stored in a body bag at a constant temperature of 4° C. The environment changed only for the short time needed to acquire 3D scans and for sporadic didactic purposes. Thirty-six scans of the face and head, supported by wooden support before each scanning, were acquired using the SenseTM 3D scanner (3D Systems) over a period of two months (Caplova, et al., 2017).

Facial landmarks marked by one operator on each scan were used for correct orientation of 3D scans, namely *Tragion* (right/ left); *Otobasion Inferius* (right/ left); *Nasion*; *Subnasale* and *Gnathion* (Katina, et al., 2016) as defined in the section "Landmark definitions". Then the final superimposition was performed using entire surfaces of both scans in order to reach the least point-to-point difference. The procedure was automatically completed by the VAM® software (Canfield Scientific, Inc) (Caplova, et al., 2017).

Chromatic analysis by the "Color Surface by Distance" option of VAM® software was employed to visualize and qualitatively evaluate the decomposition changes of the face. The color map of distance differences between two aligned and superimposed 3D scans was created as an output of the chromatic analysis; together with Root Means Square (RMS) calculation, Minimum, Maximum, Mean and Standard deviation. Data for 35 comparisons were obtained, always comparing the first scan to the scans obtained in the subsequent days (Caplova, et al., 2017).

After the test of normality of data (Anderson-Darling Normality Test, $p>0.05$), the linear correlation of RMS and time from death was calculated (MS Excel).

Results and discussion

The chosen method allowed the successful visualization, qualitative description and quantitative analysis of the early decomposition changes of the face. Recorded Root Mean Square values (RMS), Mean values and Standard Deviations are presented in Table 3 and Table 4 (Caplova, et al., 2017).

Table 3 Mean values (mm), Standard Deviations (SD; mm) and Root Mean Square (RMS; mm) for each superimposition of the 3D scans (Caplova, et al., 2017).

Scan	RMS	mean	SD	Scan	RMS	mean	SD
Day 2	0.94	-0.20	0.90	Day 25	1.68	0.28	1.66
Day 3	0.90	0.02	0.90	Day 28	1.73	0.46	1.67
Day 4	1.53	-0.46	1.46	Day 29	2.20	-0.42	2.16
Day 8	1.30	-0.40	1.24	Day 30	1.69	-0.36	1.65
Day 9	1.38	0.30	1.35	Day 31	1.73	-0.38	1.69
Day 10	1.66	-0.51	1.58	Day 32	1.80	0.49	1.73
Day 11	1.51	0.38	1.47	Day 38	1.79	-0.28	1.76
Day 14	1.57	0.54	1.47	Day 39	1.86	-0.50	1.79
Day 15	1.63	-0.27	1.60	Day 42	2.06	0.50	2.00
Day 16	1.39	0.25	1.37	Day 43	2.04	0.48	1.99
Day 17	1.45	0.33	1.41	Day 44	1.98	-0.42	1.93
Day 18	1.71	-0.31	1.68	Day 45	1.76	-0.28	1.74

Day 21	1.56	-0.40	1.51	Day 51	2.18	0.26	2.14
Day 22	1.53	-0.39	1.48	Day 56	2.21	0.56	2.13
Day 23	1.72	0.50	1.65	Day 58	2.30	-0.59	2.22
Day 24	1.48	0.07	1.48				

Table 4 Average Root Mean Square (RMS) distance by weeks (in mm) (Caplova, et al., 2017)

week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8
1.17	1.55	1.53	1.65	1.85	1.94	1.97	2.25

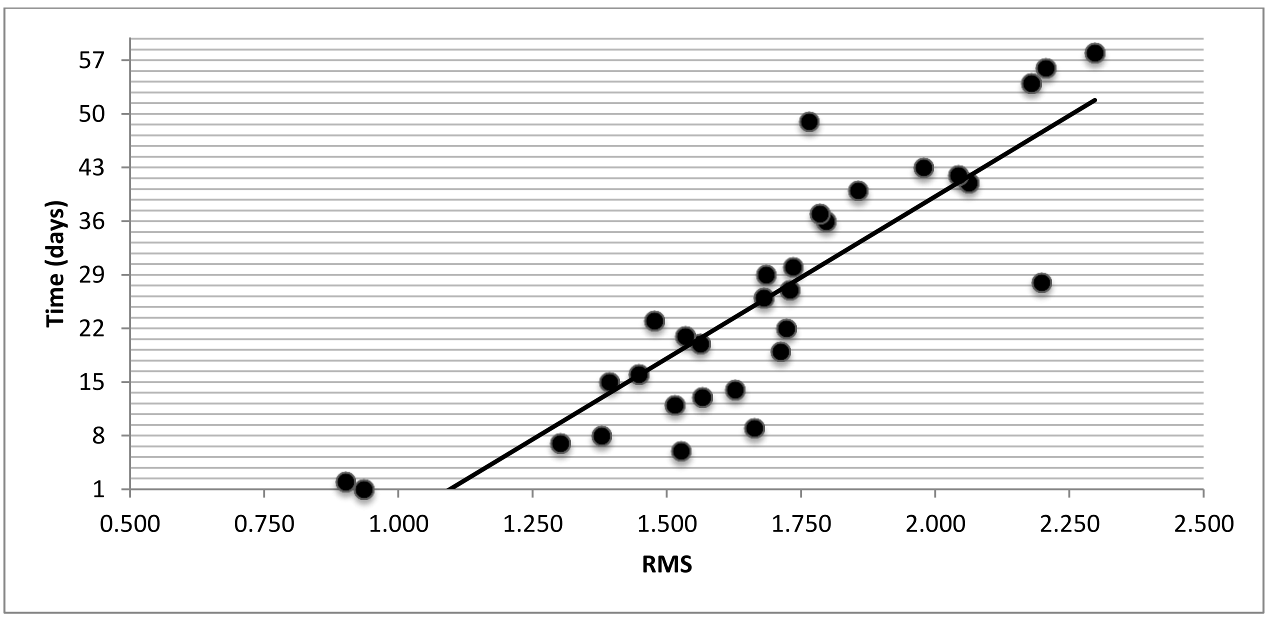

Figure 5 Linear correlation between RMS (mm) and time from death (in days) (Caplova, et al., 2017)

Table 5 Results of qualitative observation of early decomposition of the face (Caplova, et al., 2017)

	Bloating	Dehydration
Week 1	Temples Corners of mouth and eyes Cheeks next to ears Area under chin	Forehead around *glabella* Cheeks next to nose Left/Right eye
Week 2	Forehead Temples Corners of mouth and eyes Cheeks except under eye area and line of mandible Area under chin	Forehead around *glabella* Left cheek next to nose Left/Right eye
Week 3	Cheeks except under eye area and line of mandible Area under chin Cheek next to right ear Corners of mouth and eyes	Forehead around *glabella* Left cheek next to nose Left/Right eye
Week 4	Cheeks except under eye area and line of mandible Area under chin Temples Forehead	Forehead around *glabella* Left cheek next to nose Left/Right eye
Week 5 -8	Progress of the previous changes	Progress of the previous changes

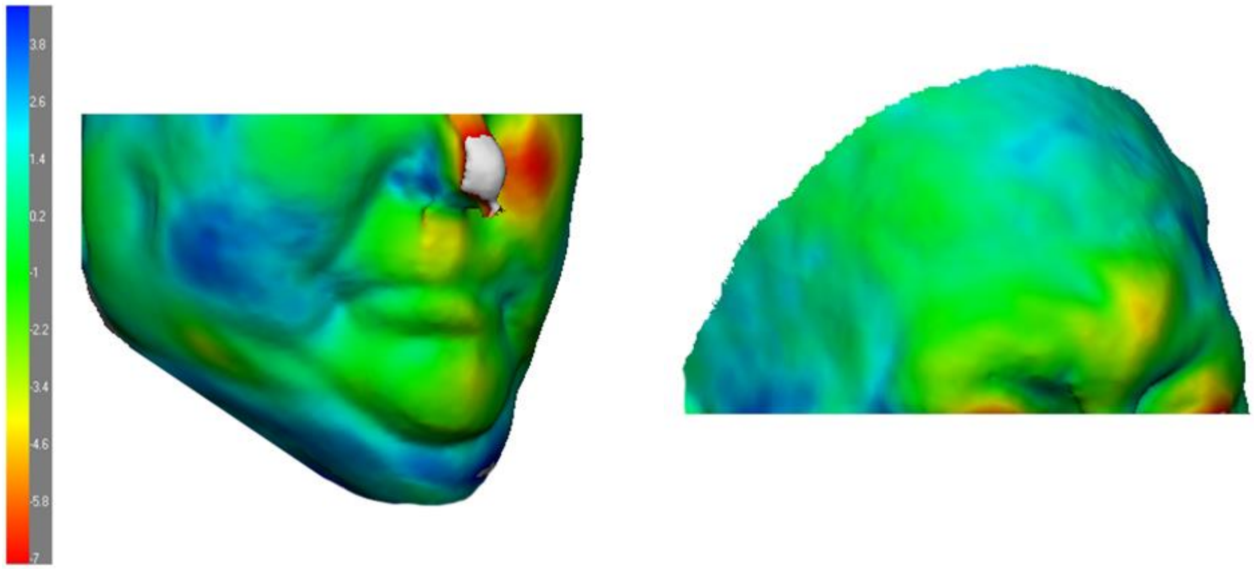

Figure 6 Upper and lower parts of the faces with chromatic maps of early decomposition changes on 7th week after death in comparison to 3D scan obtained shortly after death (Caplova, et al., 2017)

The decomposition changes described by Wilkinson and Tillotson (2012) showed the common pattern for all observed cadavers in the used environmental conditions. The comparable changes (bloating and dehydration) were qualitatively tracked on the donor body in different and controlled conditions. The insect activity and related decomposition changes did not occur (Caplova, et al., 2017).

Dehydration and bloating were differentiated by colors on chromatic map – green color represents minimal differences, blue shades represent bloating and yellow and red shades represent dehydration (Fig.6). Bloating was detected on the lateral parts of the face such as the area under the chin, cheeks next to the ears, temples, corners of the eyes and mouth; while dehydration around the facial midline– forehead around the glabella, eyes, and cheek next to the nose. The area under the eyes and the mandible line did not show any detectable changes (Caplova, et al., 2017). The changes observed in both cases (Caplova, et al., 2017) (Wilkinson &

Tillotson, 2012) were (1) shrinkage of the orbits due to dehydration of the eyes; (2) bloating of the lateral regions of the face – temples, cheeks next to the ears; (3) swelling around orbits – corners of eyes; (4) shrinkage of area around glabella and chin; (5) shrinkage of cheeks – on left side of the nose; (6) no change in volume in upper face. No lower and upper lip shrinkage and major changes of the jaw were detected. As the position of the head after dead caused distortion of the nose, any documented changes were not linked to early decomposition, and therefore were not described and reported (Caplova, et al., 2017).

The observed decomposition changes were in the agreement with those by Wilkinson and Tillotson (2012); but the timing and the progress of the changes differ - the timeframe of two months resulted in bloating and dehydration, but not in skeletonization as in case of (Wilkinson & Tillotson, 2012).The effect of different environment is obvious, and possibly the effect of the health conditions and related medical treatment before the death of the donor seem to play a role. For example, in the present case, the subject underwent courses of antibiotics and chemotherapy which have limited the bacterial proliferation and therefore hampered the decomposition (Caplova, et al., 2017).

The novel approach of quantification of the early decomposition changes by assessing RMS point-to-point values for each facial superimposition showed a high correlation (r = 0.863) with time passed since death. The gradual increase of the average RMS distance can be seen week by week (Tab. 4). The results as well confirmed the slow decomposition rate. The differences in the RMS values reflect the early decomposition changes which were observed qualitatively by color maps (Caplova, et al., 2017).

The average weekly RMS values stated in Table 4 showed that for the 7 observed weeks after death the values were lower than the values for the same person comparison reported by Gibelli et al. (2016). Gibelli at al. (2016) reported an average RMS value of 2.10 mm and mean distance value of 0.44 mm (min 0.01 mm; maximum 0.94 mm) for superimposition of the face of the same person using the same methodology; average RMS 4.47 mm and mean distance value 1.68 mm (minimum 0.02 mm; maximum 5.09 mm) in the case of superimposition of facial 3D scans of different persons.

1.3.2. Identification based on specific facial/body areas

The morphological and metric assessment of the ears, lips, and facial shape has been widely applied for the personal identification of living (Hooogstrate, et al., 2001) (Porter & Doran, 2000) (Vankatesh & David, 2011). Only two studies explored the possibilities of the identification of the deceased were found (Utsno, et al., 2004) (Hadi & Wilkinson, 2014).

Utsno et al. (Utsno, et al., 2004) report the use of lip prints for personal identification of the deceased. Lip prints of embalmed donated cadavers during the first 24 hours after death were examined in order to determine the process and the effect of the shrinkage and enlargement on the morphological patterns of lip prints. No significant changes in size were observed, which authors linked to the fact artificial preservation of tissue which slowed the decomposition process. Morphological changes were present and possibly caused by variations in the facial artery distribution and by the chemical effect of formalin used to fix the cadavers. Lip impressions were affected by whether the mouth was open or closed. The results of the study suggest that clear and identifiable lip prints can be obtained if taken less than 24 hours after death. The farther comparison of AM/PM lip print was not performed.

The applicability of facial creases for identification was studied by Hadi and Wilkinson (Hadi & Wilkinson, 2014). Several challenges come in place when studying facial creases - they are mobile in nature and image for comparison has to be of similarly high quality to obtain a meaningful comparison. In order to establish the applicability of comparisons for personal identification of unknown decedents, Hadi and Wilkinson (Hadi & Wilkinson, 2014) studied the resilience of facial creases during the bloating of seven donated bodies. Results showed the transverse nasal creases, horizontal forehead creases and the vertical glabellar lines remained relatively stable. These creases were selected as the reference points for superimposition of creases of the normal and bloated faces. This initial research suggests that some facial creases may be resilient enough after death, especially in areas with thinner skin, while areas with thicker skin, such as the cheeks undergo changes relatively fast and are therefore not reliable for the purpose of a personal identification.

The ears have often been emphasized as a highly suitable biometric feature for personal identification because of their minimal changes over time and with changing facial expression (Iannarelli, 1989) (Dinkar & Sambyal, 2012). In recent years there have been claims that ears may be used for identification of the deceased but no studies on the reliability of such comparisons have been published so far (Caplova, et al., 2017).

Following the research on living people (Malone, 2014) (Singh, et al., 2015), Krishan and Kanchan (Krishan & Kanchan, 2016) suggested the use of middle phalangeal hair for the personal identification of deceased. The presence of hair on the middle phalanges could aid the identification in combination with other morphological characteristics of the hand by simple comparison with antemortem photographs. However, the authors present no case or study of a successful application of the proposed method (Caplova, et al., 2017).

1.3.3. Biometrics

Individualizing features including tattoos, moles, and scars are soft biometrics, which can help the identification of the deceased. Tattoo matching is used in criminal cases of living suspects. The presented tattoo is searched in the database and tattoo's class labels are matched (McCabe & Newton, 2007). Automatic tattoo matching and retrieval system was developed (Lee, et al., 2008) (Jain, et al., 2009) but its applicability for matching and identification of postmortem tattoos has not been tested yet (Caplova, et al., 2017).

The major benefit of tattoo matching is its stability in the early decomposition process which does not influence its visibility; in some cases, the skin slippage may enhance the colors of the tattoos (Simpson & Byard, 2008). Tattoos can persist in water for a short time and are visible on the superficially burned skin (Simpson & Byard, 2008). Radiographic examinations can locate removed or modified old tattoos created with the metallic ink (Clarkson & Brich, 2013). However, the skin discoloration of the deceased can cover up tattoos. The direct application of hydrogen peroxide solution at 3% concentration can visualize such tattoos, but the method is destructive (Haglund & Sperry, 1993). The infrared imagining of postmortem tattoos is useful in visualizing green and black colors, while red ink is less responsive to infrared photography (Starkie, et al., 2011).

The use of tattoos for the identification of the deceased is widely established – preserved tattoos helped to identify victims of Asian tsunami in 2004 (Beautier, et al., 2011), description of a tattoo and the superimposition of antemortem and postmortem photographs of tattoo aided the positive identification in single cases in Brazil and Germany (Matoso, et al., 2013) (Birngruber, et al., 2011).

Several other cases of the identification of deceased from present tattoos were reported in the media in the last few years. In February 2016 a partially decomposed body of an unknown man floating in the Pacific Ocean near San Diego was identified by relatives who recognized sketches of two tattoos recreated by a forensic artist (FOX 5 San Diego, 2016). Similarly, the identity of a man floating in a river in Sydney was established after his tattoos were recognized by a friend, and the identity was then confirmed by fingerprint comparison (Benny-Morrison & Levy, 2015).

Moles and birthmarks are considered as individualizing features, however, their use for personal identification hasn´t been researched for the dead so far.

A few studies of living people have shown that moles and birthmarks appearing also in other parts of the body can aid the identification. Black et al. (Black, et al., 2014) (Black, et al., 2014) studied the presence, position, and incidence of scars and moles on the dorsum of the hands. Studies suggested that one strong linear scar is a strong individualizing feature, while the pattern formed by multiple small scars is of considerable importance. The presence of nevi is not common on the dorsal surface of the hand, therefore, could be potentially useful for the personal identification. Three separate cases of positive identification of living persons by comparison of photographs of scars on hands were presented by (Jain & Park, 2009) and one case of the use of nevi was published (Jackson & Black, 2014). Similarly to the identification of living people, these methods could be of use for the identification of the deceased but the postmortem changes of the skin, scars, and nevi have to be taken into consideration (Caplova, et al., 2017).

The possibility of utilization of PM/AM biometric matching has been the interest of several scientific groups (Bolme, et al., 2016) (Sauerwein, et al., 2017) (Trokielewicz, et al., 2016) (Trokielewicz, et al., 2016). Except for the use of the postmortem fingerprint matching, the research focused on facial biometrics – iris and face. Bolme et al. (Bolme, et al., 2016) captured iris and face during outdoor decomposition of 12 donated bodies until biometric data was distorted or missing due to the decomposition process. The evaluation of the collection, detection, and use of data was performed and even if data were collectible, the matching and therefore the personal identification was not possible. The iris and face were shown to deteriorate quickly, only 8.5% and 0.6% of all collected postmortem images of the face and iris could be matched to images taken right after the death. The effect of the weather and temperature was observed during the data collection as well - temperature was the main factor hindering the data collection during the spring and summer. With daily temperatures ranging between 15 and 29 degrees Celsius, the usable facial and iris data could be obtained on average during the first four days. Higher temperatures in summer (up to 33 degrees Celsius) caused faster decomposition and the usable data were able to be obtained for an average of 2 days. On the other hand, in winter with temperatures ranging between -8 and 13 degrees Celsius, usable facial images could be obtained on average for 40 days, and iris images for 28 days. (Bolme, et al., 2016).

Similar study of postmortem iris matching was presented by Trokielewicz et al. (Trokielewicz, et al., 2016) (Trokielewicz, et al., 2016) who tested four different iris matching algorithms on photographs of iris taken 5-7 hours, 11-15 hours and 22 hours after death on a deceased kept at 6 degrees Celsius. Over 90% of the images could be successfully matched 5-7 hours after death. The percentage of correct matches decreased with time passed after death - 13.3% to73.3% 22 hours after death, depending on the algorithm used. The match was found even up to 60 hours after death, with an error rate of 13% (Trokielewicz, et al., 2016). The study suggests that successful iris match could be obtained up to 17 days after death (Trokielewicz, et al., 2016).

1.3.4. AM/PM dental superimposition

Antemortem photographs of smiling people may be provided as the only antemortem data for the identification of the deceased. Direct morphological comparison of photographs of the teeth, the superimposition, and analysis of the incisal outline of the anterior teeth are commonly applied and scientifically validated comparison techniques (Silva, et al., 2015).

De Angelis et al. (De Angelis, et al., 2007) studied the superimposition of teeth visible in photographs and dental casts for possible postmortem identification. Their study provides a preliminary protocol for quantitative evaluation of dental superimposition which had been successfully applied in the forensic practice. The technique proposed by De Angelis et al. (De Angelis, et al., 2007) was used to score the match between AM self-photograph and PM photograph together with a technique for comparison of smile line (canine to canine) of the anterior teeth, which resulted in the identification of unknown burnt remains (Miranda, et al., 2016).

The technique was successfully applied in other single cases. Missing upper left central incisor visible from the frontal antemortem image in combination with the above-mentioned superimposition method helped to confirm the identity of the deceased (Silva, et al., 2008).

A three-dimensional CT reconstructed scan can be used to overcome the difficulties of the non-matching position of the head on antemortem and postmortem photographs (Wu & Forrest, 2010).

However, the use of the most recent antemortem photographs is necessary since the target person may undergo prosthetic and orthodontic treatment, which may alter potentially individualizing features (for instance diastema). Therefore, the use of smiling photographs for identification has its limitations (Silva, et al., 2012).

Summary

The physical appearance of a person displays numerous individualizing features, both metric and morphological, which can aid the forensic identification. There is a need to establish techniques and protocols to successfully apply such features for the personal identification. Various identification methods concerning deceased persons are listed in the overview. The existing literature so far has mainly focused on personal identification based on the appearance of living individuals despite the fact that the demand for the forensic evaluation of facial images of deceased has been rising. As DNA or fingerprints comparisons may not always be applicable, it is essential to explore other means of personal identification of unknown decedents (Caplova, et al., 2017).

Different parts of the human face are carrying individualizing features which are useful for the personal identification (Hooogstrate, et al., 2001) (Lee, et al., 2008). In real life scenario, it may be difficult to obtain antemortem lip or ear prints for comparison and the use of such methods is therefore limited and used only for specific cases. Similarly, the direct comparison of facial creases may aid the identification, but the changes of each feature due to decomposition process needs to be considered before the comparison of AM and PM appearance of the face. Even early postmortem changes influence the face, therefore the comparison could be relevant only shortly after death (Caplova, et al., 2017).

The biometric matching of iris depends on the visibility of iris on photographs and therefore on the decomposition rate which differs depending on the temperature of the environment. Moreover, antemortem images for comparison have to be of high quality. Other soft biometric characteristics, such as moles, can be removed for cosmetic or medical reasons. In addition, age-related changes of the scar tissue and moles may modify their appearance and the size, and therefore only recent images can be used for personal identification (Bond, et al., 2008). Similarly to facial features, the decomposition process may influence the visibility and appearance of soft biometrics, but so far little research on this topic was conducted (Caplova, et al., 2017).

Dental superimposition allows successful application of this method and identification of deceased when only smiling photographs are available, considering the decomposition and heat resistance of the human dentition and the existence of the standardized method of dental superimposition (De Angelis, et al., 2007).

1.4. Chapter summary

The identification of human remains is an important procedure with multiple legal and humanitarian implications. Different methods are employed in the holistic approach of forensic identification to assure the true match. While some identification methods are very reliable and recommended, their use is not always possible. Especially in cases of mass disasters, such as current deaths of migrants in the Mediterranean Sea, the lack of comparative data necessary for utilization of primary identification methods challenge the successful identification of victims.

In theory, the same recognition/identification methods which were studied and used for the living could be applied for the deceased. Despite that, the identification of deceased either relies on the visual recognition with high errors or on primary identification methods with higher cost or requirement of specific antemortem data for comparison.

The human face offers multiple individualizing features, which are used for the recognition and identification of living, but research in the field of the facial recognition/identification of deceased is still very limited. In particular, the applications of recognition software and algorithms on facial images of deceased are rare.

As many identification methods are studied, tested and used for faces of living people, the second chapter focuses on current identification techniques developed for this purpose.

2. Forensic identification of living

The identification of living people, similarly to the identification of deceased, is an establishment of one's identity. Identification of living individuals is as important as of the deceased and is equally challenging. Comparison of fingerprints and DNA profiles is widely used for the living as the most reliable identification methods. Moreover, nowadays the focus lies on the faces of living individuals due to the latest extensive development of video and photo technology which found a place in our everyday life. The need of identification of living is not solely the matter of a criminal investigation, but also the issue in cases of missing children or border security controls.

As previously mentioned, any identification method studied or used for the living could be potentially used for the dead. Following chapter lists multiple applications of the appearance of the human face for the forensic identification of living.

The human face is in focus of other various studies dealing with, for example, emotional and health status or attractiveness, as this information as well can be read from the human face.

The study of the beauty has been emerging lately – the perception of the beauty and the symmetry of the face is an important topic in plastic and orthognathic surgery. However, the interest in a facial beauty is not new – sculptors and painters used the "golden standard" for creating the perfect faces in their work since the ancient times. Different studies related to the correlation of the "golden standard" and beauty perception (Shell & Woods, 2004), facial proportions of beautiful faces in different populations (Dawei, et al., 1997) (Sforza, et al., 2007), cross-cultural beauty judgments (Thakera & Iwawaki, 1979) (Cross & Cross, 1971) or the preference of beautiful faces by newborns (Langolis, et al., 1987) were conducted.

As the face is symmetric around its sagittal plane, the influence of any deviations in the symmetry on the perception of its beauty was studied (Mealey , et al., 1999) (Kowner, 1996)

(Perrett, et al., 1999). The asymmetrical face can be seen in patients with neuromuscular disease, for example with facial neuromuscular dysfunction. The research focuses on the evaluation of the degree of asymmetry (Codari, et al., 2017) or the evaluation of the progress of chosen therapy (Manikandan, 2007) .

In the past, the research of human faces was performed exclusively in 2D (Jones, et al., 2001) (Powell & Rayson, 1976) but with today's technological improvement the use of 3D scanners and models is becoming more common (Abboud, et al., 2017) (Hartmann, et al., 2007). The employment of the 3D scanning offers many advantages over the classical photography (2D); some of which are described in the following chapters.

The human face holds information about the identity of the person and it is used for the forensic personal identification of deceased. The following sections deal with the other use of human faces in the forensic identification research involving living individuals, as more attention is paid to them; and as written previously, potentially any method of identification and recognition of the face of living could be used for the face of the dead.

2.1. Identification methods

The facial identification of living individuals can be performed by biometric comparison of the morphology of specific facial parts (e.g. lips or iris) or morphologically and metrically from the whole face. As the quality of photographs increased with the technological improvements, the personal identification can be performed from 2D or 3D images. In the last 30 years the decrease in the cost of photographic equipment, difficulty and time needed for taking the photographs caused the widespread of photographic and video cameras in the research, security and importantly, in everyday life. The easiest way to take a picture is by mobile phone and it is estimated that 4 billion people in the world own a phone with built-in camera and taking approximately 1.2 trillion photographs in 2017 (Perret, 2016). Similarly, the recent three-dimensional (3D) technology overcomes several limitations of the classical photography, and therefore, it found its place in the research of the human faces.

Despite this, in some cases, for instance of eyewitness identification, the presence of the target individual may be necessary.

2.1.1. Eyewitness identification

Eyewitness identification is a specific form of the facial recognition and therefore the simplest form of personal identification based on the appearance of the human face. The errors of the eyewitness identification are known to be high, and the misidentifications cause the wrongful conviction of innocent people. However, the justice systems still rely on the eyewitness identification as it is the simplest process and many eyewitnesses do recognize the culprit correctly. Several factors play important role in the incorrect identification – time passed between exposure to a culprit and the identification, or the stress which can cause over 30% of incorrect eyewitness identifications (Bindemann, et al., 2002). Environmental conditions of the process itself such as duration, lighting, obstruction, and distance were found to play an important role as well (Valentine, et al., 2003). The accuracy of eyewitness identification had been correlated to general ability to recognize faces – higher the ability, higher the probability of correct eyewitness identification (Morgan, et al., 2007). The age of the witness also plays a significant role, as young children and elderly people perform less accurately in comparison to young adults (Coxon, 1997).

The eyewitness identification can be performed live or by use of the video. It was believed, that the individuals in the line-up should match to the description of the culprit, rather than to the appearance of the suspect (Luus & Wells, 1991). Darling et al. (2008) however, didn't find any improvement using a description-matching strategy and no improvement when using video records.

Interestingly, the eyewitness identification and visual recognition/identification of deceased are similar, if not the same methods based only on the human ability to recognize faces. While eyewitness identification seems to be accepted by the jurisdiction system despite its known high misidentification rates; the visual recognition of deceased is recommended to be avoided.

2.1.2. Specific facial parts

Several facial areas and facial features attract attention because of their individuality. The use of facial parts of living faces for the identification has been more accepted compared to faces of deceased. While only a few publications testing the possibilities of identification of decease from the morphology of their facial parts can be found (Chapter 1.3); more extensive research has been conducted on faces of living. In general, same methods applied for identification of faces of living from their facial parts can be used for deceased, however postmortem changes and decomposition play important role changing the appearance of the deceased.

Direct or image-based comparison of ears, lips or iris can aid the personal recognition and identification of living. Those identification methods of the living are similar to previously described identification methods of deceased, however, are undergoing more extensive research.

Ears

The use of ears is based on the fact that ears do not change radically with aging and facial expressions. The first method using the biometry of ears was developed by Iannarelli in 1989 (1989). The Iannarelli system contained 12 measurements obtained from photographs of the ears. Since that, many other attempts at creating automatic recognition systems can be seen, reaching recognition rate 80 - 100%: comparison of curves and edges, Principal Component Analysis (PCA) based algorithms in a combination with the use of whole face, Iterative Closest Point (ICP) algorithm applied to 3D scans of ears, geometrical method of feature extraction, or the use of neural networks for outer ear comparison (Chang, et al., 2003) (Burge & Burger, 1998) (Chen & Bhanu, 2007) (Yan & Bowyer, 2007) (Choras, 2004) (Abdel-Mottaleb & Zhou, 2005) (Moreno, et al., 1999).

Lips

The other facial feature studied for the recognition and identification of the living are lips – the study of the lip prints (cheiloscopy) or the lip features obtained from photographs. Study of lip prints dates back to 1900s (Sivapathasundharam, et al., 2001) and until 1960s such studies appear sporadically. Later in 1970, when the individuality of each lip print was confirmed (Renaud, 1973), the first classification system was created (Tsuchihashi, 1974). Lip prints are unique and stable over time; moreover, they recover when they undergo alternation caused by illness or trauma (Tsuchihashi, 1974).

Biometrical studies extracting features of lips form 2D photographs present different approach: biometric identification by lip outline or the combination of color features and geometrical parameters can be used (Gomez, et al., 2002) (Choras, 2008).

Iris

The pattern of the iris is as well highly individual and remains stable in the adulthood. The biometric recognition of iris uses photographs of eyes for the pattern by spatial filters, comparison cumulative-sum-based grey change analysis or multichannel Gabor filtering and wavelet transform (Ma, et al., 2003) (Azizi & Pourreza, 2009) (Zhu, et al., 2000).

2.1.3. Morphological and metrical comparison

Comparison of the whole face is the key to successful holistic identification and can be performed in two different ways – morphologically or metrically. The most basic morphological evaluation can be completed with help of morphological atlas or by superimposing two facial photographs. The metrical analyses include anthropometry/photo-anthropometry or employment of various mathematical algorithms both in 2D and 3D.

Following sub-chapters offer a review of some of the methods used in the comparison of faces of living.

2.1.3.1. Morphological Atlas

Classification of morphological features of the face in order to create the "morphological profile of the face" is the idea behind the use of any morphological atlas. A morphological atlas is an aid tool, for example, for objective evaluation of superimposition of two images. The most recent morphological atlas was developed for females and for males by Ohlorogge et al. (2009) and Aßmann, et al. (2007). The feasibility of male atlas as a preliminary step to personal identification was tested by exploring the intra- and inter-observer error on 900 photographs of males (aged 20-31 years old) (Ritz-Timme, et al., 2011). The mismatch percentage reaching 39% highlighted the subjectivity of the approach. Even if the atlas should decrease the subjectivity of a morphological classification, the inter- and intra-observer error remains high. The atlas may, therefore, be used as an initial screening tool, but not as an identification tool (Ritz-Timme, et al., 2011).

Morphological classification could be of help also in cases of missing children. The face of the child changes with growth; such changes, however slower and less dramatic, continue during adulthood (Bishara, et al., 1998) (Sforza, et al., 2010). Therefore the applicability of atlases in case of age different photographs of children was tested (Caplova, et al., 2017).

As the article is authored by the author of this dissertation, the following chapter contains parts of the work published as (Caplova, et al., 2017):

Z. Caplova, V. Compassi, S. Giancola, D.M. Gibelli, Z. Obertova, P. Poppa, R. Sala, C. Sforza, C. Cattaneo, "Recognition of children on age-different images: Facial morphology and age-stable features," *Science and Justice,* 2017.

The main aim was to test whether a morphological atlas of facial features can be used as a tool for improving the observer subjectivity in the categorization of facial features, and thus aid personal recognition; and to examine whether and which morphological features of the face are assessed by the observers as stable over time, and the potential usefulness of such features for the recognition of missing children on age-different images (Caplova, et al., 2017).

Material and methods

The Anthropological Atlas of Female Facial Features (Ohlrogge, et al., 2009) and the Anthropological Atlas of Male Facial Features (Aßmann, et al., 2007) were used for the categorization of facial features in 110 age-different images of 16 Italian subjects (13 females and 3 males). A series of age different good-quality photographs of the face in frontal or slightly lateral view was collected with the consent. Table 6 summarizes the age distribution of the photographs provided by each person (Caplova, et al., 2017).

The evaluation of features on age-different images with an Anthropological Atlas was used to assess the inter-observer agreement and to test, which facial features were perceived as being stable over time by all observers (Caplova, et al., 2017).

Six observers with a degree in biology or medicine completed the test. Each observer received a copy of The Anthropological Atlas of Male Facial Features (Aßmann, et al., 2007) , a copy of The Anthropological Atlas of Female Facial Features (Ohlrogge, et al., 2009), the series of facial images and answer sheets (Caplova, et al., 2017).

The observers were asked to classify all observable facial features based on the illustrations and descriptions found in the Atlases. Each Atlas includes descriptions, drawings and photographic examples of 43 facial features for males and 45 facial features for females (Caplova, et al., 2017).

For the purpose of the study, only facial features visible from frontal images were evaluated (34 facial features). The photographs were divided into two groups: 1) Individuals A-H (58 facial photographs in total), and 2) individuals K-R (52 facial photographs in total; Table 6). Each group was evaluated by three different observers. There were no time restrictions for completing the test (Caplova, et al., 2017).

The division of photographs was performed in order to make the study feasible in terms of the time the observers needed to devote to the evaluation – each observer needed to evaluate 34 features on 58 photographs in the first group (1972 in total); and on 52 photographs in second group (1768 in total) (Caplova, et al., 2017).

The categorization of facial features was compared between the observers (inter-observer error), and between the age-different images of one subject (stability of features). Mismatch percentages were calculated by facial feature for a sample of three pairs of observers for the series of 25 age-different photographs of two females and two male subjects (Caplova, et al., 2017).

Table 6 Sample description of the age and sex of each subject, who provided facial photographs (Caplova, et al., 2017).

Image Series	SEX	AGE OF THE PHOTOGRAPHS	Image Series	SEX	AGE OF THE PHOTOGRAPHS
A	F	10ys. 13ys. 15ys. 17ys. 19ys	**K**	F	10ys. 13ys. 14ys. 15ys. 16ys. 17ys. 18ys
B	M	11ys. 12ys. 14ys. 16ys. 19ys	**L**	M	13ys. 14ys. 15ys. 17ys. 19ys
C	F	14ys. 15ys. 17ys. 18ys. 19ys	**M**	F	10ys. 11ys. 13ys. 14ys. 20ys
D	F	10ys. 12ys. 13ys. 14ys. 15ys. 16ys. 18ys	**N**	F	10ys. 11ys. 14ys. 16ys. 18ys. 19ys
E	M	12ys. 13ys. 14ys. 15ys. 16ys. 17ys. 20ys. 21ys	**O**	F	14ys. 15ys. 16ys. 17ys. 18ys
F	F	3ys. 4ys. 5ys. 6ys. 7ys. 8ys. 9ys. 10ys. 11ys. 12ys. 13ys. 14ys. 15ys	**P**	F	10ys. 12ys. 14ys. 16ys. 18ys
G	F	2ys. 3ys. 4ys. 5ys. 6ys. 7ys. 8ys. 9ys. 11ys. 13ys	**Q**	F	10ys. 12ys. 16ys. 17ys. 18ys. 19ys
H	F	10ys. 11ys. 13ys. 15ys. 19ys	**R**	F	3ys. 4ys. 5ys. 6ys. 7ys. 8ys. 9ys. 10ys. 11ys. 12ys. 13ys. 14ys. 15ys

Results

Differences in the categorization were observed. Table 7 illustrates the agreement/disagreement in the categorization of a single photograph by three observers.

The classification patterns on a single image, as well as for age-different images of one person varied - none of the patterns was the same for all three observers (Caplova, et al., 2017).

Table 7 Example of the categorization pattern of facial features in one photograph provided by three observers (Caplova, et al., 2017)

	EVALUATION		
FACIAL FEATURE	Observer 1	Observer 2	Observer 3
Head shape	Wedge	Pentagon	Wedge
Frontal height	Average	High	High
Frontal breadth	Broad	Average	Average
Frontal hairline	Convex	Straight	Straight
Eyebrow height	Average	Slight. Curve	Slight. Curve
Eyebrow density	Bushy	Bushy	Bushy
Eyebrow shape	Slight. Curve	Slight. Curve	Slight. Curve
Mono-brow	None	Present	None
Upper eyelid-eyebrow distn.	Average	Average	Average
Upper eyelid	Visible	Visible	Visible
Inner eyebase	Wide	Average	Average
Lid axis	Straight	Straight	Straight
Nasal root	Narrow	Average	Narrow
Nose bridge length	Long	Average	Average
Nose bridge breadth	Broad	Average	Average
Nose bridge process	Symmetrical	Downwards broader	Symmetrical
Nose tip shape	Bulbous	Bulbous	Round
Nose tip cleft	Not clefted	Not clefted	Not clefted
Nasal breadth	Broad	Average	Broad
Philtrum height	Average	Average	Low
Philtrum depth	/	Shallow	Shallow
Philtrum shape	Divergent	Divergent	Parallel
Upper lip notch	/	Straight	Wavy
Labial breadth	/	Average	Broad
Mouth corner	/	Straight	Slightly up
Upper vermillion	/	Thin	Thin
Lower vermillion	/	Average	Thin
Chin shape	Pointed	Pointed	Pointed
Chin height	Height	Average	Height
Chin transition	Transition	No transition	No transition
Chin dimple	Absent	Absent	Absent
Ear protrusion	Close fitting	Slightly pronounced	Slightly pronounced
Transition head neck	Neck clearly	Neck clearly	Neck slightly

	narrowed	narrower	narrower
Pronunciations of cheek bones	Strongly pronounced	Strongly pronounced	Strongly pronounced

The mismatch percentage of classification was calculated by facial feature for three pairs of observers for the series of 25 age-different photographs of two female and two male subjects (Table 8) (Caplova, et al., 2017).

The overall mean inter-observer mismatch percentage was 45.6%. The mean mismatch percentage for 11 features describing size was 53%, while the mean mismatch percentage for 19 features describing shape was 41%. The result showed that the nose tip cleft was the only feature which reached the complete classification agreement among observers and also was evaluated as stable over time in all age-different images (Caplova, et al., 2017).

Table 8 Percentage (minimum, maximum, mean) of miss-match between three observers evaluating line-up of photographs of two female and two male subjects.

Feature	**Minimum**	**Maximum**	**Mean**	**Category**	
Head shape	52%	64%	58.00%	shape	
Frontal Height	36%	64%	50.00%	size	
Frontal breadth	52%	80%	66.00%	size	
Frontal hairline	44%	92%	68.00%	shape	
Eyebrow height	36%	44%	40.00%	size	
Eyebrow density	8%	44%	26.00%	shape	
Eyebrow shape	12%	36%	24.00%	shape	
Mono-brow	4%	36%	20.00%	shape	*
Upper eyelid-eyebrow dist.	12%	48%	30.00%	size	
Upper eyelid	24%	44%	34.00%	shape	
Lid axis	28%	48%	38.00%	shape	

Nasal root	56%	64%	60.00%	size	
Nose bridge length	56%	100%	78.00%	size	
Nose bridge breadth	20%	64%	42.00%	size	
Nose bridge process	8%	36%	22.00%	shape	
Nose tip shape	20%	72%	46.00%	shape	
Nose tip cleft	0%	0%	0.00%	shape	*
Nasal breadth	28%	52%	40.00%	size	
Philtrum height	20%	48%	34.00%	size	
Philtrum depth	32%	84%	58.00%	size	
Philtrum shape	32%	72%	52.00%	shape	
Upper lip notch	40%	72%	56.00%	shape	
Labial breadth	52%	88%	70.00%	size	
Mouth corner	64%	80%	72.00%	shape	
Chin shape	28%	68%	48.00%	shape	
Chin transition	44%	68%	56.00%	shape	
Chin dimple	8%	28%	18.00%	shape	*
Ear protrusion	28%	48%	38.00%	shape	
Transition head neck	32%	40%	36.00%	shape	
Pronunciations of cheek bones	52%	84%	68.00%	shape	*

*Presence of “absent” category

The mismatch percentages for individual facial features ranged from 0% to 100%. The features were grouped into three categories based on low, medium and high mismatch percentages among observers (Table 9). The lowest mismatch percentages were recorded for facial features that included the category of the element being absent and described shape: the nose tip cleft, the chin dimple and the mono-brow (Caplova, et al., 2017).

Table 9 Categorization of facial features based on the mismatch percentage among observers (Caplova, et al., 2017)

LOW Min 0% - Max 48% (mean 25% and lower or 5 best performing)	Eyebrow shape Mono-brow Nose bridge process Nose tip cleft Chin dimple	
MEDIUM Min 20% - Max 72% (mean 26%-59%)	Frontal Height Upper eyelid Nose bridge breadth Nose tip shape Philtrum depth Upper lip notch Chin transition Transition head neck Upper eyelid-eyebrow dist.	Eyebrow density Lid axis Eyebrow density Nasal breadth Philtrum shape Chin shape Ear protrusion Philtrum height Head shape
HIGH Min 44% - Max 100% (mean 60% and higher or 5* worst performing)	Frontal breadth Frontal hairline Labial breadth Pronunciations of cheek bones (Nasal Root)	Nose bridge length Mouth corner

On average, the mismatch percentages were higher for features describing size than for those describing shape, which may be due to insufficiencies in categorization and descriptions of features relating to size (Caplova, et al., 2017).

2.1.3.2. Photo-anthropometry and superimposition

Photo-anthropometry (also called photogrammetry) is an application of a classical anthropometry to the images. Both can be defined as obtaining "spatial measurements of (facial) features as well as distances and angles between (facial) landmarks" (Ali, et al., 2012). Photo-anthropometry (and anthropometry as well) deals with facial measurements along with measurements of other body parts. It is successfully applied in the forensic and medical research or design of products and equipment (Roelofse, et al., 2008), (Hurwitz, et al., 1999), (Chi-Yuen Hung, et al., 2004).

In comparison to the morphological atlas, which qualitatively describes facial features in terms of shape, length, and width; the photo-anthropometry describes the morphological features quantitatively. Photo-anthropometry may be used to compare the measurements taken from the 2D image to dimensions of the real person, or to compare the measurements of the two different images. Measurements of a real person are obtained using caliper; measurements of the digital (or digitized) images are obtained using computer software such as tpsDig (Rohlf, 2017), Digimizer (MedCalc Software, 2016) or Adobe Photoshop CC (Adobe Systems Incorporated., 2016). Compared to the classical anthropometry, photo-anthropometry has many advantages – it allows repetition of measurement and quick collection of a large amount of data. On the other hand, the used photographs have to be of a good quality sufficient for the landmark placement (Kleinberg, et al., 2007)

Anthropometry and photo-anthropometry are widely used and successfully applied in many fields; however, the application in the personal identification has been questioned. Following publications are ordered depending on the year of publication.

On one hand, the effective application of video-to-real photo-anthropometry in three cases was described by (Halberstein, 2001), on the other hand, (Kleinberg, et al., 2007) conducted the study to test the value of the photo-anthropometric comparisons. By comparing measured distances and proportions of one video image versus 10 photo images, the conclusion that photo-anthropometric comparison is of a limited use in obtaining personal identification, even in nearly ideal conditions, was drawn. Too many factors contributed to the differences between two compared images – e.g. image quality, facial mimicry or a weight gain.

Similarly, (Moreton & Morley, 2011) studied photo-anthropometrical proportion comparison of the high-quality facial images of the same person taken in the controlled conditions at different angulations (0° to 40° horizontally; -10° to +20° vertically) resulting in the finding that positioning of the camera influence all measured vertical and horizontal facial proportions. The distance from the camera, lighting, and resolution of the image also influenced the measurements. The variability between the measurements of images of the same person was as high as in case of inter-personal comparison (Moreton & Morley, 2011).

Kleinberg and Siebert (2012) derived measurements between selected landmarks on the face and combined them into feature vectors to statistically determine if identification is possible. Fifty-nine distance ratios measured between 24 landmarks represented the feature vector and mean absolute difference (the summarization of absolute values of each face ratio vector subtracted from the same ratio of a second face, smaller difference indicates the smaller difference between faces); Euclidian distance and Cosine Θ distance were used for the comparison. The study showed that from three utilized methods, Cosine *Θ* distance equation using *Z*-normalized values offered the largest separation between True positive and True negative matches. However, the discrimination power was not sufficient for distinguishing individuals (Kleinberg & Siebert, 2012).

Several other studies, e.g. (Davis, et al., 2010), failed to provide a less erroneous method of the comparison of photo-anthropometric measurements of 2D images. Table 10 offers the summary of described photo-anthropometric methods.

Different methods of comparison of 2D images exist and are described in the following chapter.

Table 10 Summary of photo-anthropometric methods

Authors	Method	Result
Halberstein (2001)	video-to-real photo-anthropometry	The effective application in three cases.
Kleiberg et al. (2007)	photo-anthropometry of 1 video image versus 10 photo images, comparison of distances and proportions	Limited use for personal identification.
Moreton and Morley (2011)	photo-anthropometrical proportions of high-quality images in different angulations	The position of the camera influenced all proportions; the variability of the same person was as great as in inter-personal comparison.
Kleinberg and Siebert (2012)	measurements were derived and combined to feature vector; mean absolute difference, Euclidian distance and Cosine *Θ* distance used for comparison	Cosine *Θ* distance offered the largest separation between true positive and true negative, however not sufficient enough for identification.
Davis et al. (2010)	software-assisted photo-anthropometric facial landmark identification system using 37 linear and 25 angular measurements across the two viewpoints (profile and frontal)	The method is unreliable unless multiple distances and angular measurements from both viewpoints were included in an analysis.

2.1.3.3. Comparison of 2D images

Apart from the photo-anthropometry, other methods can be utilized for the comparison of two 2D images. The limitations emerging from the static 2D picture (position of the head and mimicry) make such comparisons unusable in some cases, and therefore, may seem less reliable. However, the comparison of 2D images, which may also be 2D images captured by the video camera, is important and crucial in everyday crime investigation. Application of Closed-Circuit Television (CCTV) cameras is the reality in today´s world – an average Londoner is captured 300 times per day and an average American citizen 75 times per day (Yolanda, 2016).

No time trend of development or preference of a certain method could be found - it can be seen that certain method were utilized in 1990s similarly as in late 2000s. Therefore, the following publications are grouped based on the used method/algorithm.

Photo-superimposition is a simple method of morphological comparison. Two facial images are superimposed onto each other and the morphological "fit" of facial features is evaluated. The technique has been mostly used to compare images captured by CCTV camera and 2D photographs. The methodology of video-photo 2D superimposition of 46 real crime cases submitted for the examination was described (Vanezis & Brierley, 1996). Once the images were overlaid based on the selected landmarks, one image was wiped across the other in different directions to directly examine the match of facial contours. As the visual evaluation is dependent on the quality of images, the examination showed that 22% of video recordings were of insufficient quality. The positive identification could be reached in 18% of the comparisons, exclusion in 5%, and no conclusion in 29% of the cases. Probable or possible identification could be obtained in 47% of comparisons. In cases of positive identification, the comparison focused mainly on individualizing marks or anomalies – ears, scars or moles, in combination with other facial features. Several limitations were pointed out – compared images must be of the same head orientation, high-quality equipment is needed, and it is necessary to distinguish between the real facial contour and artifact (Vanezis & Brierley, 1996).

Computer algorithms, appearing to be more accurate, were developed for the facial recognition from 2D images.

Statistical active shape and appearance modeling is a method of matching statistical models of appearance to the images (Cootes, et al., 2001) which was applied to human faces. Statistical appearance model of the face is generated by combining the model of shape variation and model of texture variation (colors) from the training set of images with marked corresponding points of main facial features. The correlation between the shape and texture is used to generate appearance model. Cootes el at. (2001) used a set of 400 facial images with 68 marked points, generating an appearance model which required 55 parameters to explain 95% of the observed variations. The new image was then compared and matched to the learned model. Peacock and Goode (2004) tested the recognition performance of the algorithm on images taken in varying conditions resulting in the true match in 58% of cases.

Other algorithms are based on Principal Component Analysis (PCA) which is used to compute set of "eigenfaces" – vectors produced by analysis. Kim et al. (2002) tested PCA on a dataset of photographs of 40 individuals with different facial expressions. Fifty percent of the images were used as a training dataset, other 50% as test images. The effectiveness was confirmed by low average error rate reaching 2.5%. More recent studies (Javed, 2013), (Zeng, et al., 2015) test the use of PCA for the recognition and personal identification; its improvement and lower error rates in combination with other methods.

Tome et al. (2013) proposed the use of morphological regions of the face instead of matching the whole face and reports discriminative power of different facial regions (PCA based) in three comparisons – (1) mugshot (police photograph taken after the arrest) versus mugshot; (2)

mugshot versus CCTV and (3) CCTV versus CCTV. Inner traits of the face (nose, eyebrows, and eyes) showed better performance in a mugshot controlled scenario; the discriminative power of forehead region is better than of full face in case of mugshot versus CCTV; and lastly, all mentioned regions outperform the whole face matching in CCTV versus CCTV comparison.

The use of another method – Gabor wavelets is not limited to facial recognition only – applications for facial landmark location (Lim, et al., 2000), tracking (McKenna, et al., 1997), head pose estimation (Kruger & Sommer, 2002) and others are known. Two most used Gabor methods for face matching are Dynamic Link Architecture (DLA) and Elastic Bunch Graph Matching (EBGM) (Duc, et al., 1999), (Wiskott, et al., 1999). The recognition accuracy of Gabor based algorithms is reported to be between 88–100% (Shen & Bai, 2006).

Jenkins and Burton (2008) proposed the image averaging to improve the recognition rates of the FaceVACS online implementation on website MyHeritage – the algorithm authors didn't have control over. Firstly authors assessed its accuracy on real-world images to 54% and then improved the recognition to 100% by creating the average face for each participant.

Recognition rates from 80% to 100% were presented by Gordon (1992) using a different method of image comparison. In his study, depth and curvature features were extracted from range images and vectors were calculated. The similarity is measured by comparison of Euclidean distances of vectors in the feature space.

The need for the reliable recognition method from 2D images brought the commercialization of several systems, which had been tested by Face Recognition Vendor Test (Grother & Ngan, 2014). Test reports lower error rates compared to systems of previous years; systems work well in the controlled conditions, in which they outperform humans; but the recognition decreased in uncontrolled conditions. The test showed that the recognition rates of automatic algorithms seem to be sufficiently low, but on the other hand, the different head orientation on two compared images still seemed to be the main obstacle. Thus, the employment of the 3D images in the facial recognition was a logical step towards the improvement of the comparison of the human face.

The first studies incorporating 3D into 2D/2D facial recognition used only 2 images of the face and a morphable model to create the 3D face model of every individual in the database (Huang, et al., 2002). Then 7700 syntactic 2D face images of 6 subjects under different pose and illuminations were generated to train the recognition system for 2D/2D matching. Ten face components (features) were extracted and used for the recognition by Support Vector Machine, returning the recognition rates around 98% for faces rotated up to ±36°.

Hesher et al. (2003) used range images, which capture shape variations independently from illumination variables, generated from 3D meshes and used PCA for the recognition. The range image is "an array of depth values from each triangle of the mesh into 2D image plane" (Hesher, et al., 2003). Range images seem to be an effective way of facial recognition, but the robustness of the chosen PCA was not sufficient to deal with the noise of the 3D scans.

The summary of publications dealing with 2D/2D facial image matching is presented in Table 11.

Table 11 Summary of 2D/2D image comparison publications

Vanezis and Brielrey (1996)	video-Photo superimposition of 46 real crime cases; match evaluated morphologically using wipe-across method	Positive identification of 18% of cases, exclusion in 5%, no conclusion in 29%, probable or possible identification in 47%. Around 22% of used videos were of a poor quality which influenced the identification.
Cootes el at. (2001)	statistical active shape and appearance modeling	Fifty-five parameters can explain 95% of the observed variation. 13% of tested images failed to converge to a satisfactory result.
Peacock and Goode (2004)	statistical active shape and appearance modeling	The true match was obtained in 58% of cases.
Kim et al.	Principal Component Analysis (PCA)	The low average error rate of 2.5% was

(2002)	on dataset of photographs of 40 individuals with different facial expressions	reported.
Javed (2013)	Principal Component Analysis (PCA) tested on photographs with multiple people	The correct recognition rate for a photograph with more than 10 people was 80%; with 10 people 87%, 2 persons was 93% and single person 99%.
Zeng et al. (2015)	Fuzzy Kernel Two-Dimensional Principal Component (FK2DPCA) tested on YALE database	FK2DPCA method is more stable and efficient than PCA.
Tome et al. (2013)	PCA based matching of morphological regions comparing mugshots and CCTV videos in different combinations	Inner traits of the face (nose, eyebrows, and eyes) showed better performance in mugshot/mugshot scenario; the discriminative power of forehead region is better than of full face in case of mugshot/CCTV; all mentioned regions outperformed the whole face matching in CCTV/CCTV comparison.
Duc et al. (1999)	Elastic Bunch Graph Matching (EBGM)	The combination of elastic deformation and weighting the nods according to their significance improves the recognition compared to other methods.
Wiskott et al. (1999)	Elastic Bunch Graph Matching (EBGM) on gallery of 250 photographs	Very high recognition rate when comparing frontal images, 84% comparing right with a left profile, 57% left with right, when comparing half profiles – the recognition dropped.
Jenkins and Burton (2008)	averaging the multiple images of the same person, using commercial algorithm with no control	Averaging improved the recognition rate from 54% to 100%.
Gordon (1992)	comparison of distance of vectors of depth and curvature features by comparing Euclidean distance measure in scaled feature space	Recognition rates from 80% to 100%.
Huang et al. (2002)	Support Vector Machines and 3D Head Models	Recognition rates around 98% for faces rotated up to +/- 36°.
Hesher et al. (2003)	PCA on range images created generated from 3D meshes	Range images seem to be effective but chosen PCA was not sufficient to deal with the noise of 3D meshes.

2.1.3.4. Comparison of 3D images

Variation in the head orientation, among other factors, significantly increasing errors in 2D/2D comparisons led to use of 3D face models. 3D scanning has a number of advantages – it retains information about the geometry of the face and therefore new approaches rely on the shape rather than the color and texture; scans are not influenced by changing lighting conditions, and can be rotated which overcomes the limitation of the head orientation and alignment. 3D face recognition is an alternative to the conventional 2D face recognition approaches (Abate, et al., 2007), (Heseltine, et al., 2004). While the head position limitation is minimized with the utilization of 3D scanning, the limitation of different facial expressions remains.

Currently, four different approaches to the 3D face recognition can be identified – (1) holistic approach using the whole face (Mohammadzade & Hatzinakos, 2013); (2) local feature-based approach, which focus on those facial features changing the least with the changing facial expressions (Chua, et al., 2000), (3) the third approach uses a model of 3D facial expressions that can be applied to any face shape (Chang, et al., 2006), and the last (4) approach transforms the 3D face shape into the expression-invariant representation (Bronstein, et al., 2005).

This chapter offers a brief overview of some of the methods applied and used for 3D/3D face recognition ordered base on the used method.

Similar or the same algorithms used in 2D/2D recognition are used for 3D/3D recognition; as well as 3D anthropometry is used in medical and biomedical research (Zhang & Molenbroek, 2004), (Olds, et al., 2013), (Olds, 2004).

Early use of 3D for facial recognition emerged in the 1980s but the spread of the 3D scanning technology made it more available and used since 1990s.

In the 1990s the facial recognition research focused on different curvature match. In the early 2000s the local feature-based approach emerged, and in the last 10 years, the research focused on methods combining several features of the face as well as the recognition based on the whole face (holistic approach).

Tanaka et al. (1998) addressed the problem of 3D face recognition with a correlation-based approach built on the analysis of maximal and minimal principal curvatures. By extraction of convex-concave points with the high curvature value they constructed the Extended Gaussian Image (EGI) which represented the face. The similarity between faces was measured by Fisher´s spherical correlation (which measures the similarity between two vector sets), reaching correct match in 44% of cases. The method was reported to be robust to the presence of glasses, hair or change of hairstyle.

Nagamine et al. (1992) used 3D facial sectioning – vertical, horizontal and circular. Curves of those intersections contain distinctive features such as nose and mouth. The match of two patterns was evaluated by Euclidian distance. The recognition rate and error rate were evaluated; the vertical section at –20 and +20 degrees from the central region showed 100% recognition and 0% error rate. Similarly, the recognition rate of 100% was achieved using circular section near both corners of eyes. The shape of the most successful sections is similar to the profile, and therefore the study confirms the profile silhouette to be the most reliable for face matching.

Local feature approach is based on the fact that the shape of the face is changing with facial expressions, but some regions stay unchanged. Chua et al. (2000) used Point Signature to align two 3D faces, extracted rigid parts of the face which are not influenced by the changing facial expressions and used them in the recognition process. Rigid facial parts were identified from aligned 3D scans as points with the nearest distance by a defined threshold. Authors tested the method with an accuracy of 78–93%.

Chang et al. (2006) suggested the use of a combination of match scores from overlapping regions around the nose to overcome the facial expression problem of the 3D facial recognition. The landmarks were automatically detected based on the curvature type – nose tip as a peak region, eye cavities as a pit region and nose bridge as a saddle region. Then the pose of 3D scans was standardized by aligning each scan to the standardized 3D face model. Three different surfaces were extracted from around the nose tip – surfaces overlapped but included different portions of the face. Iterative closes point (ICP) method was applied to each of the surfaces and each of the three nose regions individually achieved 95–96% recognition rate in a neutral expression. Authors proposed that using a smaller part of the face may improve the facial recognition accuracy.

A novel technique using 4D data was presented by Papatheodorou and Rueckert (2004). The 4D data combined the geometric information from the 3D scan and the texture map from the 2D image using Iterative Closest Point algorithm (ICP). The calculation of the distances between points of two superimposed faces expresses their similarity. The method was tested on a database of 4D images of 70 subjects, each recorded in 13 different angles and facial expressions. The correct recognition of 98.40–100% was achieved in the frontal view; 66.60–93.60% in 45° view; 68.85–86.88% for smiling faces and 95–100% for 20° *x*-axis tilt. The same test was performed on 3D data without 2D texture. The combination of the 3D geometry and 2D texture improved the recognition rate in comparison to using of 3D only.

Mohammadzdzade and Hatzinakos (2013) presented Iterative closest-normal point (ICNP) method, which is similar to ICP and finds the closest corresponding point between the faces (holistic approach). The method can overcome the problem of different facial expressions. Firstly, the tip of the nose was detected on 3D scans with different facial expression using PCA, then sphere radius of 100 mm centered at nose was cropped, the noise was removed using 2D

Wiener filtering and Hotelling transformation technique was used for the correct pose of the face. Similarly, the expression-neutral reference face was created; and the reference point on the reference face was found for every corresponding point on the input face. The input face was then rotated and translated to reduce the distance between corresponding points, which assures better alignment and more accurate results. The process of rotation and translation was repeated until the sum of squared differences between the current rotation matrix and the identity matrix was less than a set threshold. The method reached verification rate of 99.6%.

The construction of the expression invariant face by isometrically embedding the surface into a low-dimensional space with convenient geometry was described by Bronstein et al. (2005). A fully automatic prototype of the 3D face recognition system based on the expression-invariant representation of facial surfaces which automatically crops, smooths and subsamples 3D scans; locates eyes, nose tip, and nose apex; performs multidimensional scaling and canonization and surface matching, was created. The method was tested on the dataset of 220 faces of 30 subjects resulting in good recognition accuracy, especially in the case of great expression differences. Authors highlighted the process of canonization can "hide" the true identity of the person, which is currently a problematic issue in the biometrical security. The canonization changes the appearance of the face and cannot be undone; therefore the true identity is hidden. A similar approach of canonization was presented by Lao et al. (2000) who performed the recognition by calculating the mean differences in depth, which was sufficient even without the use of any 2D features.

Fully automatic recognition system based on the recognition of local features was created (Guo, et al., 2016). The algorithm locates the nose tip, crops and normalizes the 3D face and detects key points. Key points are dependent on the specific shape of the 3D face and can differ. Rotational Projection Statistics (RoPS) is used for the feature matching, as well as for the face registration. The automatic system achieved high identification rate of 99.4% for faces with a neutral expression, and 94.0% for non-neutral faces.

As 3D face keeps its geometry, the geometrical analysis can be performed. The most popular is Principal Component Analysis (PCA), the same as used for the 2D/2D recognition. Aeria et al. (2010) improved the recognition of 3D scans modeled in a PCA space and uses Euclidean and Mahalanobis distance as similarity measure with the accuracy of 97.8% and 94.8%. Decomposed Euclidean distances outperformed the undecomposed Mahalanobis distances, which are often used and preferred in the facial recognition.

Combination of the 3D face recognition systems based on Fisher surface method was described by Heseltine et al. (2004). Well-known methods of recognition developed for 2D images had been successfully applied for the 3D recognition (PCA and Linear discriminant analysis). The combination of 184 dimensions from 16 surface spaces on the sample of 1770 3D face models reduced Equal Error Rate (EER; the point at which false acceptance rate is equal to false rejections rate) to 8.2%.

Zhang et al. (2012) described a different method which homeomorphically mapped 3D scans of faces into the 2D face lattice invariant to the pose change. The use of discrete conformal mapping allowed the preservation of geometrical information by finding the correspondence between every vertex on the 3D surface and 2D site. For image recognition, authors employed eigenface algorithm and tested method on three different datasets. Results showed that proposed method was not robust against the facial expression change, but it improved the robustness to head pose variations compared to other studies and methods tested on the same datasets.

A similar approach was chosen by Guo et al. (2012) – their study presents multi-pose 3D recognition by intrinsic 3D facial sparse representation (I3DFSR) algorithm. The algorithm, similar to (Zhang, et al., 2012), mapped each 3D scan of the face onto the 2D lattice, interpolated them and converted them into the 2D facial attribute image. Comparison and recognition were achieved by sparse representation based classification algorithm. Method, tested on three different databases, showed the increased rank-one identification compared to other methods tested on the same dataset.

Collective Shape Difference Classifier (CSDC) is technique achieving the recognition rate of 98.22% with nearly real-time speed (Wang, et al., 2008). 3D scans are aligned; a sign difference shape map is obtained from aligned scans and encoded Haar-like features algorithm.

Haar-like features, widely used for real-time face recognition, are based on the Haar wavelets developed by Viola and Jones (2001). An algorithm sums up intensities of pixels at a specific location (e.g. eyes) and calculates differences between sums. The difference is then used for a categorization of sections of each image. Differences of multiple images are compared to set a threshold of likeness. The most discriminant features are used to build three CSDCs which are fused to obtain the verification score. The technique is described as robust on faces with a large missing region; however, it can fail when the area of the nose is missing because it is used for correct alignment.

A deformable model approach, described by (Kakadiaris, et al., 2007), combines the descriptiveness of the 3D data and a computational efficiency of the 2D data. Fully automatic recognition system aligns 3D scans and measures the difference between them with a high degree of expression invariance and a high accuracy. The distance measure is based on Haar Metrics and Pyramid Metrics. The model achieved high recognition rate (99% rank-one rate).

Table 12 summarizes all the publications.

Table 12 Summary of 3D/3D comparisons publications

Heseltine et al. (2004)	Fishersurface method, PCA and linear discriminant analysis on sample of 1770 3D face models	Reduction of Equal Error rate to 8.2%.
Mohammadzdzade and Hatzinakos (2013)	Iterative closest normal point (ICNP)	Method reached the verification rates of 99.6 and 99.2% at a false acceptance rate of 0.1%.
Chua et al. (2000)	Point Signature using rigid facial parts	The system is reaching 78–93% accuracy.
Chang et al. (2006)	Iterative closes point (ICP) applied to three regions around nose	Three nose region surfaces individually achieve 95-96% recognition rate in a neutral expression.
Bronstein et al. (2005)	construction of expression invariant face by isometrically embedding of the surface into a low-dimensional space with convenient geometry – known as canonical forms, tested on dataset of 220 faces of 30 subjects	Fully automatic prototype resulted in good recognition accuracy especially in the case of great expression differences; canonization can "hide" true identity.
Zhang et al. (2004)	discrete conformal mapping with eigenface algorithm	The method was not robust against the facial expression change but it improved the robustness to head pose variations.
Tanaka et al. (1998)	correlation-based approach based on the analysis of maximum and minimal principal curvatures measured by Fisher´s spherical correlation	Robust to glasses, hair or change of hairstyle, correct match in 44%.
Nagamine et al. (1992)	3D facial sectioning and comparison of curves by Euclidian distance	The vertical section at –20 and +20 degrees from the central region showed 100% recognition, the similar recognition rate of 100% achieved circular section near both corners of eyes.
Papatheodorou and Rueckert (2004)	Iterative Closest Point algorithm (ICP) used on 4D data of 70 subjects	The correct recognition of 98.40% - 100% was achieved in the frontal view; 66.60–93.60% in 45° view; 68.85–86.88% for smiling faces and 95–100% for 20° *x*-axis tilt.
Lao et al. (2000)	method of canonization, calculation of mean differences in depth tested on database of 10	Recognition rates varies from 0.89 to 0.96.

	persons	
Guo et al. (2016)	Rotational Projection Statistics (RoPS)	Identification rate of 99.4% was reached for faces with neutral expression and 94.0% for non-neutral expressions
Aeria et al. (2010)	Principal Component Analysis (PCA) using Euclidean and Mahalanobis distance	Decomposed Euclidean distances outperformed the undecomposed Mahalanobis distances (recognition rate 97.8% and 94.8%).
Guo et al. (2012)	intrinsic 3D facial sparse representation	Method increased rank-one identification.
Wang et al. (2008)	Haar feature-based Collective Shape Difference Classifier (CSDC)	Achieving recognition rate of 98.22% with nearly real-time speed.
Kakadiaris et al. (2007)	based on Haar Metrics and Pyramid Metrics	Model achieved high recognition rate (99% rank-one rate).

2.1.3.5. Comparison of 2D and 3D images

Since the early 2000s, the combination of the 3D scanning and classical 2D photography has been emerging. 3D scanning offers a great advantage of the rotation, adjustment of the head position and the true shape; while 2D image keeps information about the texture (lost by process of 3D scanning) (Blanz & Vetter, 2003). Even if the 3D scanning is becoming more available, the sensitivity of capturing of some facial parts (e.g. eyebrows) is lower than in case of the classical photography. As 3D technology is still not spread into everyday life the 3D/3D recognition is less applicable. The fusion of 2D and 3D aimed towards the improvement of the recognition accuracy and the creation of robust recognition system which can cope with the change of facial expressions which changes the human face. The summary of overviewed publication can be found in Table 13.

Studies are ordered based on the year of publication to demonstrate the change and development of the topic.

The use of the combination of 3D and 2D images for facial comparisons started in the early 2000s by Yoshino et al. (2000). Authors developed a system for face-to-face superimposition, morphological comparison and anthropometric analysis of 3D scans and 2D images. The 3D scan allowed adjustment of the orientation of the head to match the 2D image, and a simple examination by fade-out or wipe mode could be made. Moreover, up to 18 landmarks were selected on both 3D and 2D images for distance and angle measurements; and the reciprocal point-to-point differences of distances of two corresponding anthropometrical points on both images calculated from the coordinate values were used as a matching criterion.

Yoshino et al. continued the work of 2D/3D comparisons focusing on disguised faces (Yoshino, et al., 2002). In the following study, the software was developed and the face-to-face superimposition was performed on Japanese sample of 100 3D scans and three 2D images of the target person with sunglasses, gauze mask, and a baseball cap. The morphometrical matching was implemented by comparing facial outlines of 2D and 3D images obtained by connecting 10 marked points. The comparison of outlines was performed by calculation of the average perpendicular distance. Then the superimposition of landmarks on the 2D and 3D image was performed by computing the average point-to-point differences of distances of two corresponding anthropometrical points on both images calculated from the coordinate values. The matching criterion was set as a sum of two averages. The technique showed the average difference of 2.3–2.8 mm for matching faces; 4.0–14.6 mm for non-matching faces and no false positive matches were reported.

Even with the increasing availability of 3D scanning machines, the cost still remains high. Therefore, a different approach of obtaining 3D models of the face can be seen in the study of Lynnerup et al. (2003). 3D models were created by commercially available software Photomodeler® (Eos Systems Inc., 2003) which creates wireframe models from multiple 2D photographs. In the study, wireframes and 2D photographs were superimposed in frontal and lateral view; and the fit was evaluated in the blind test by observers. Sixty percent of superimpositions were assigned correctly as a match. The incorrect assignment was probably due to the different facial expression on the wireframe and photograph.

Later Yoshino et al. (2005) developed automatic software for 2D/3D superimposition of one 2D image to multiple 3D scans in the database. Fourteen anatomical landmarks on the 3D scan were used for the automatic adjustment of the orientation to common axes and 2D to multiple 3D superimpositions was made. The automatic software performed 132 superimpositions in about 2 minutes giving the rank list of the "match" based on the distance between 50 facial landmarks. Three different facial orientations were tested (frontal, right and left oblique) giving the first rank percentage 24.1%, 26.7%, and 23.8% respectively. The percentage showed that while the correct recognition was not dependent on the orientation of the face, differences in the lighting and shading might have played an important role. When the top ten rank list is taken, the percentage was 75.9% for the frontal image, 65.0% for left and 66.7% for the right oblique view. Based on lower "match" rates authors suggested that the system could be used as a screening tool rather than the identification tool.

The application of Yoshino et al. work (2000) on non-Japanese population was performed using frontal and oblique images (Fraser, et al., 2003). The average distances between the corresponding landmarks on two images were calculated from the coordinate values and used as a matching criterion. Average distances for frontal non-Japanese images were 1.8–3.0 mm for the match, 2.9–6.8 mm for nonmatch. If oblique images were tested, 1.7–2.5 mm difference for the match and 3.0–7.1 mm for the non-match were stated. When compared to data from Japanese sample, two significant differences were observed between the mean distance from apex to *subnasale;* and in the measure of the 3D line between *stomion* and right *chelion*. However, the authors (Fraser, et al., 2003) considered Yoshino et al.´s method (2000) applicable to non-Japanese individuals.

The return to superimposition techniques can be observed in 2009 (Lynnerup, et al., 2009) (De Angelis, et al., 2009). Compared to the previous 2D/2D superimposition method, the comparison of 2D and 3D started. While Lynnerup et al. (2009) performed superimposition of facial photographs taken at 45° angles, De Angelis et al. (2009) focused on images from video recordings in different angulations. The evaluation method also differed – (Lynnerup, et al., 2009) created a blind test and observers assessed the fit of the superimposition, resulting in 100% true positive match; De Angelis et al. (2009) introduced semi-automatic method of verification (consisting of an automatic resizing and manual repositioning) which would aid the evaluation by the professional. Automatic software for correction of the distortion of used images was developed as well (Biwasaka, et al., 2008).

Biwasaka et al. (2010) tested the distortion-corrected images form ATM surveillance cameras in 2D/3D superimposition using the evaluation method by Yoshino (Yoshino, et al., 2000). Photographs taken from different angles were used. The correction was firstly calculated for the test chart (multiple dots) and then applied to facial images. After the image correction, the average discrepancies between the 3D and 2D images in the superimposition were lower than the practical threshold set by Yoshino (Yoshino, et al., 2000), moreover, no false positive and false negative identification was obtained.

The evaluation of the "fit" in the 2D/3D superimposition was of the interest of several authors (Yoshino, et al., 2002) (Goos, et al., 2006). Cattaneo et al. (2012) proposed a different technique of quantification of the probability of the match focusing on profile views. The profile traced on every photograph of 50 individuals was compared to each of 3D scans of five persons using a method by (De Angelis, et al., 2009). The quantification was characterized as a "differences between the areas described by two profile lines, the differences in minima and maxima points of curvatures extracted automatically" (Cattaneo, et al., 2012) – the maxima being *glabella*, tip of the nose, the fore point of upper and lower lips, *pogonion*; the minima being *selion*, *subnasale*, *stomion* and *suprapogonion*. Authors reported the mean difference in the areas for nonmatch superimposition being 1731.1 mm^2 and for correct matches 87.4 mm^2. The mean difference between the maxima points also showed to be different in cases of nonmatch and match – 5.33 mm and 1.28 mm respectively. Similar differences were observed for minima points – mean difference of 6.49 mm for nonmatch and 1.20 mm for the match. The proposed technique was successful in the differentiation of the match and nonmatch 2D/3D profile view superimposition. The study also showed the possibility of distinguishing the correct and incorrect match increased with the higher number of points used for the comparison.

The effect of aging, facial expressions and presence of twin siblings in 2D/3D superimposition were verified (Atsuchi, et al., 2013). Three-dimensional scans of 20 Japanese males in their 50s were superimposed to 2D images of three age groups (20s, 30s, 40s). Three superimpositions using 16 facial landmarks were carried on for each of the 2D images and reciprocal point-to-point differences of distances of two corresponding anthropometrical points on both images from the coordinate values between landmarks were calculated. The study identified the changes related to the aging by superimposing three different age groups (e.g. *ectocanthion* moved downward when comparing 20 years old and 50 years old, or *alare* showed the smallest change). The average distance between all selected landmarks in the 20s group was 2.6 mm, in 30s group 2.3 mm, and in 40s group 2.2 mm. The effect of the facial expression was observed by superimposing 3D scans with neutral facial expression to 2D images in laughter, sadness, anger, and surprise. The effect was characterized as a distance between chosen corresponding landmarks. The recorded mean differences were too high for every emotion and therefore authors do not recommend using a superimposition when dealing with expression-different images. The same method was used for the evaluation of individuality in the 2D/3D superimposition of nine pairs of monozygotic twins. The average distance of the superimposition of the same twin (1.1 mm) and different twins (2.0 mm) was below the threshold by (Yoshino, et al., 2000) and therefore, the study concluded it is difficult to distinguish monozygotic twins by morphometric analysis based on the 2D/3D superimposition.

The distance and absolute error between the set of the corresponding landmarks on 3D and 2D facial image was base of a small study by (Goos, et al., 2006) which resulted in finding that the absolute error of 4 landmarks in cases of "match faces" was larger compared to "non-match faces", the same results were obtained when using 7 landmarks. The non-matching pair could not be distinguished using the method even in nearly optimal conditions.

A different method was proposed by Wang et al. (2002). Four feature points were described on a 3D scan by Point Signature and 10 feature points on the 2D image by Gabor filters; as well as their corresponding Jets. The extracted shape and texture features were then projected into subspace by PCA and the match was identified using a similarity function. The method was tested on facial images of 50 individuals in different viewpoints. Recognition rate 90% was achieved.

Chang et al. (2003) supported the use of a combination of 2D and 3D for facial recognition. The study of a single probe and multi-probe showed that the combination of 2D and 3D data improved the recognition – the use of 3D only outperformed the 2D; however, the combination of 2D and 3D scored 98.5% correct recognition rate in a single probe study and 98.8% in a multi-probe study. Author's method was based on PCA.

The advantage of the combination of a 3D surface geometry and a color map using PCA recognition was described by Godil et al. (2004). The recognition rates (Cumulative Match Characteristic) are slightly better when based on the color map instead of a 3D surface (0.728

and 0.708). The fusion of two biometrics (surface geometry and color map) at score level improved the correct recognition (0.81).

The illumination conditions, camera and scene geometry are important parameters which cause the variability in the facial recognition. Therefore, they should be separated from the distinctive facial features. The combination of the 3D deformable model with the simulation of projection and illumination was presented (Blanz & Vetter, 2003). The morphable model was learned from the dataset of 3D scans and was able to automatically estimate the head orientation, illumination and focal length of the camera. The model was then fitted into 2D image and recognition rate up to 95.9% was reached by PCA.

The fusion of the local and global geometrical cues are the base of the method of a probe-to-large-database matching (AI-Osaimi, et al., 2008). Multiple tensors (vectors) fields, calculated from each point of the point cloud from its local neighborhood and from the global structure of the 2.5D point cloud, represent the two-and-half dimensional (2.5D) point cloud. Each tensor field is integrated with the global field in the 2D histogram. PCA coefficients of each field of 2D histograms are linked together in a single vector. The fusion of geometrical cues has proven the increase identification rate up to 93.78% and verification rate up to 95.37%.

To overcome variations caused by the change of the facial expression, a single image could be broken into 75 smaller independent parts; each observed and classified individually and then combined at score level using Support Vector Machines (Cook, et al., 2006). The method Log-Gabor Templates was based on Gabor wavelets; the new algorithm was developed (based on Mahalanobis Cosine distance measure, a generalization of Euclidean distance) for the distance measure between eigenvectors. Recognition rate between 91.65% and 93.16% was achieved depending on the number of combined regions of the face.

In the last 10 years (since 2007) several different approaches aiming towards the improvement of the robustness of the algorithms against the change of facial expressions can be identified.

The combination of the feature based and holistic face matching as a solution to the problem of the facial expressions is presented by Mian et al. (2007). The fully automatic algorithm performs the 2D/3D face matching by forming a rejection classifier (Spherical Face Representation and Scale-Invariant Feature Transform) which rejects a large number of the faces from the database. The facial features of remaining faces are then extracted and compared using ICP. The eyes, forehead and the nose were chosen as facial parts influenced the least by changing expressions. The algorithm was tested on 3D database reaching 98.31% (neutral face) and 99.74% (non-neutral face) verification rate and 95.37% (neutral face) and 99.02% (non-neutral face) identification rate. The described algorithm used 3D nose as an autonomous biometrics and outperformed other algorithms tested on the same database.

Riccio and Dugelay (2007) reported an asymmetric protocol for the face recognition using geometric invariants. Face as a flexible object changes its geometry with the changing expressions. Authors chose 19 control point and 16 geometric invariants, with the aim to identify those control points with the highest discrimination power. For each control point, the centroid has been calculated to average its position on a set of 150 faces; standard deviation describes the variability. Any new addition to the dataset is enrolled in the form of 3D scan and 2D picture. All control points are located on the 2D image; corresponding 3D points are located on 3D representation and stored. 2D and 3D base invariants are then used separately – 2D based is used for the database screening, selecting the subset of faces and the best candidate for the match; and the 3D based invariant is used for the identification task.

In the publication by Yang et al. (2008), 2D images serve as a probe and 3D data as a gallery. The method is using the Canonical Correlation Analysis (CCA) for learning the correlation between sets of matching 2D and 3D images (the probe and the gallery). Canonical Correlation Analysis is performed on separate parts of the face to ensure the robustness against changing facial expressions, and then sum up together. After the training, the method was tested on the 3D data of 200 subjects. The results showed an improvement in the recognition score from 42.59% to 70.37% when using the sum of the parts of the face compared to the holistic approach. Authors then proposed Kernel method, which improved the recognition rate even more – from 70.37% to 85.19%.

In the recent years, the development of neural networks offers a great improvement in many different scientific fields. Neural networks have a capacity of learning and fast classification, which is of use for the facial recognition. The use of the neural network for 2D/3D facial recognition based on Hybrid Taguchi-Particle Swarm Optimization is described by Lin et al. (2008). Texture data was extracted from 2D images, depth from 3D images, and the facial features were extracted by Gabor wavelets from normalized faces in different scales and orientation. The texture and the surface information were combined using PCA and a hybrid algorithm based on multilayer neural network was used for identification reaching 90% accuracy. Neural networks can be used for creating a three-dimensional representation of 2D faces. Zhang et al. (2017) described a deep feedforward neural network created for such a task. Stacked Contractive Autoencoders are used as a subspace learner for the feature extraction; one-layer neural network then builds the mapping function.

Several different approaches can be seen in 2017. The combination of multiple face descriptors (Local Binary Patterns, Local Phase Quantization, and Binarized Statistical Image Features) and modalities (Exponential Discriminant Analysis and Within Class Covariance Normalization) form the base of the automatic framework by Oumane et al. (2017). The method was tested on two datasets, resulting in 98.60% and 99.12% verification rates.

Napoleon and Alfalou (2017) presented pose-invariant face recognition of the 3D model from a single photograph. Their work does not include a comparison of 2D and 3D images; rather the utilization of a single 2D photograph for the creation of the 3D representation of the same face, which may be rotated. Therefore, one face can be seen in different angles and the comparison is performed in 2D. The 3D meshes were created from selected landmarks; edges were highlighted by applying Gaussian filtering, and each mesh was deformed and adapted to every person. A new database of faces in different poses was created and matching was performed using VanderLugt correlator. The recognition rate of 84.6 – 100% was achieved. The construction of a subject-specific 3D model from the combination of 2D and 3D image, which is then used for one-to-one or one-to-many comparisons with the 2D data, is presented by Kakadiaris et al. (2017). The pairwise similarity score is obtained from a global orientation-based correlation metrics. The results (recognition up to 99.1%) showed the advantages of the method on a dataset containing facial images with different illuminations and head poses.

Table 13 Summary of publications of 2D/3D comparisons

Authors	Used method	Result
Yoshino et al. (2000)	superimposition, morphological comparison, and anthropometric analysis	The method provided objective and reliable analysis.
Yoshino et al. (2002)	morphometrical matching by calculation of the average perpendicular distance of matching outlines	The average difference of 2.3–2.8 mm for matching faces; 4.0–14.6 mm for non-matching faces and no false positive matches were reported.
Yoshino et al. (2005)	automatic superimposition based on distance between 50 landmarks	The system could be used as a screening tool rather than the identification tool based on low first rank rates – 23.8–26.7%.
Fraser et al. (2003)	application of (Yoshino, et al., 2005) to non-Japanese population	Method is applicable to non-Japanese individuals.
Wang et al. (2008)	four feature points described on 3D	Recognition rate 90% was

	scan by Point Signature and 10 feature points on 2D image by Gabor filters; extracted information are matched using PCA and a similarity function	achieved.
Blanz and Vetter (2003)	3D deformable model with the simulation of projection and illumination	Recognition rate up to 95.9% was reached.
Chang et al (2003)	PCA based method	The combination of 2D and 3D data improved the recognition – 98.5% for a single probe and 98.8% for multi-probe study.
Lynnerup et al. (2003)	3D wireframes created by commercial software and superimposed, evaluated in a blind test	Sixty percent of superimpositions were assigned correctly as a match.
Godil et al. (2004)	combination of a 3D surface geometry and a color map using PCA recognition	Combination reached recognition of 81%.
Goos et al. (2006)	distance and absolute error between the set of the corresponding landmarks	The non-matching pair could not have been distinguished with this method even in nearly optimal conditions.
Cook et al. (2006)	Log-Gabor Templates was based on Gabor wavelets; the algorithm based on Mahalanobis Cosine was used for the distance measure between eigenvectors of 75 smaller parts of the face	Recognition rate between 91.65% and 93.16% was achieved.
Mian et al. (2007)	Spherical Face Representation and Scale-Invariant Feature Transform as a rejection classifier and Iterative Closest Point for comparison	Method reached 98.31% (neutral face) and 99.74% (nonneutral face) verification rate and 95.37% (neutral face) and 99.02% (nonneutral face) identification rate.
Riccio and Dugelay (2007)	calculation of centroid and standard deviation for 19 control points, geometric invariants computes the match	Two-step algorithm decrease probability of misclassification of subjects.
Al-Osaimi et al. (2008)	fusion of the local and global geometrical cues	The increase of the identification rate up to 93.78% and verification rate up to 95.37%.

Lin et al. (2008)	neural network based on Hybrid Taguchi-Particle Swarm Optimization	The accuracy of 90% was reached.
Yang et al. (2008)	Canonical correlation analysis (CCA)	Improvement of the recognition score from 42.59% to 70.37% when using the sum of the parts of the face compared to the holistic approach.
Lynnerup et al. (2009)	superimposition of facial photographs taken at 45° angles evaluated in a blind test	100% true positive match was reached.
De Angelis et al. (2009)	semi-automatic superimposition	May aid the evaluation of the professional.
Biwasaka et al. (2010)	distortion of images was corrected and evaluated by (Yoshino, et al., 2005) method	The average was lower than the practical threshold set by Yoshino [44] and no false positive and false negative identification was obtained.
Cattaneo et al. (2012)	comparison of mean differences in areas, minima and maxima points of profile curvature	The proposed technique was successful in differentiation the match and nonmatch 2D/3D profile view superimposition.
Atsuchi et al. (2013)	effect of aging, facial expression and twin effect by reciprocal point-to-point differences between landmarks	The differences between age groups are described as well as different facial expressions. Method failed to differentiate monozygotic twins.
Oumane et al. (2017)	combination of several face descriptors (Local Binary Patterns, Local Phase Quantization, and Binarized Statistical Image Features) and modalities (Exponential Discriminant Analysis and Within Class Covariance Normalization)	Verification rates of 98.60% and 99.12% reached.
Napoleon and Alfalou (2017)	adapted deformed 3D meshes created from a single frontal photograph; 2D/2D comparison using VanderLught correlator	The recognition rate of 84.6–100% was achieved.
Kakadiaris et al. (2017)	creation of subject-specific 3D model from 2D+3D data; pairwise similarity score is obtained from a global orientation-based correlation metrics	Recognition up to 99.1% showed the advantage of the method on pose and illumination different dataset.

Table 14, 15, 16 offers a summary of methods used in the facial recognition and matching.

Table 14 Methods of 2D vs 2D comparisons

	Method	Recognition rates	Used feature	Publication
2D versus 2D	Photo-anthropometry	Limited use	linear and angular measurements	Davis et al. (2010), Kleiberg et al. (2007)
			Proportions	Moreton and Morley (2011)
			feature vectors, Cosine *Θ* distance	Kleinberg and Siebert (2012)
	Photo-superimposition: - wipe out an evaluation of morphology	Subjective evaluation	Morphology of the face	Vanezis and Brielrey (1996)
	Statistical active shape and appearance modeling	up to 58%	correlation between the shape and texture	Cootes el at. (2001), Peacock and Goode (2004)
	Principal Component Analysis (PCA)	up to 97.5%	Pixels	Javed (2013), Tome et al. (2013), Hesher et al. (2003)
	Kernel PCA	up to 97.5%	Pixels	Kim et al. (2002)
	Gabor wavelets: - Dynamic Link Architecture (DLA) - Elastic Bunch Graph Matching (EBGM)	88–100%	Pixels	Duc et al. (1999), Wiskott et al. (1999)
	Euclidean distances of vectors in the feature space	80–100%	vectors of depth and curvature features	Gordon (1992)
	Support Vector Machine	up to 98%		Huang et al. (2002)

Table 15 Methods of 3D vs 3D comparisons

	Method	Recognition rates	Used feature	Publication
3D versus 3D	Fisher´s spherical correlation of Extended Gaussian Image	up to 44%	Curvatures	Tanaka et al. (1998)
	Euclidian distance	up to 100%	vertical, horizontal and circular curvatures	Nagamine et al. (1992)
	Point Signature	78–93%	points with the nearest distance	Chua et al. (2000)
	Iterative closest point (ICP)	95–99.6%	Points	Chang et al. (2006), Papatheodorou and Rueckert (2004)
	Iterative closest-normal point (ICNP)	99.6%	Points	Mohammadzdzade and Hatzinakos (2013)
	Canonization	no false matches	Surface	Bronstein et al. (2005), Lao et al. (2000)
	Rotational Projection Statistics (RoPS)	up to 99.4%	Shape	Guo et al. (2016)
	Principal Component Analysis (PCA)	up to 97.8%	Distance	Aeria et al. (2010)
	Collective Shape Difference Classifier (CSDC)	up to 98.22%	shape differences	Wang et al. (2008)
	Distance measure based on Haar Metrics and Pyramid Metrics	99% rank-one rate	Distances	Kakadiaris et al. (2007)

Table 16 Methods of 2D vs 3D comparisons

	Method	Recognition rates	Used feature	Publication
3D vs 2D	3D/2D superimposition: - Reciprocal point-to-point difference between landmarks	difference ≤ 2.3–2.8 mm for Japanese; difference ≤ 1.7–2.5 mm for non-Japanese	landmarks	Yoshino et al. (2005), Fraser et al. (2003), Biwasaka et al. (2010)
	- the average perpendicular distance between outlines of the face	up to 26% first-rank match	facial outlines	Yoshino et al. (2002)
	- mean difference in the areas	successful distinguishing the correct and incorrect match	profile curvatures	Cattaneo et al. (2012)
	Point Signature + Gabor filters + similarity function	up to 90%	Points	Wang et al. (2008)
	Principal Component Analysis (PCA)	up to 98.8%	Pixels	Chang et al (2003), Godil et al. (2004)
	Log-Gabor Templates	91.65-93.16%	parts of the face	Cook et al. (2006)
	Iterative Closest Point	98.31%	Points	Mian et al. (2007)
	Geometric invariants		Points	Riccio and Dugelay (2007)
	Canonical Correlation Analysis (CCA)	70.37%	the sum of parts	Yang et al. (2008)
	Neural networks: - Hybrid Taguchi-Particle Swarm Optimization - Stacked Contractive Autoencoders	 - 90% - 84.6–100%		Lin et al. (2008)
	The combination of several face descriptors: Local Binary Patterns Local Phase Quantization Binarized Statistical Image Features and modalities: Exponential Discriminant Analysis Within Class Covariance Normalization	98.60% and 99.12% verification rates		Oumane et al. (2017)
	VanderLugt correlator	84.6–100%		Napoleon and Alfalou (2017)
	Reciprocal point-to-point differences		landmarks	Atsuchi et al. (2013)

2.2. Changes in facial morphology

The changes of human face, related to the growth, maturation, aging or changing environmental conditions (such as illumination and pose of the head) influence the comparison of any two images for the purpose of forensic identification. While the influence of environmental changes on the face does not play a significant role when using 3D technology; other unstoppable morphological changes of the human face are important to be considered. The human face and its morphology changes during the lifetime, moreover the influences of outer factors are visible in the appearance of the face through the day. The most visible changes are due to the growth and development, which take place in first years of the life until the person reaches adulthood (Sforza, et al., 2010) (Sforza, et al., 2009) (Bishara, et al., 1998) (Vahdettin & Altug, 2012). The domain of facial changes of children and young adults is well described. The rapid changes influence the face to the extent that outdated picture of a child may no longer represent the current look. Therefore, it is important to consider to the growth and development related facial changes if comparing pictures of youngsters, and especially in cases of long-term missing children. For this reason, the age progression software was developed. Although not reliable, they offer age manipulation of outdated images and prediction of the current appearance (Lampinen, et al., 2012) (Charman & Carol, 2012).

Faces of adult people undergo changes as well, however not so dramatic. Compared to the growth and maturation of youngsters; the changes of the face of adults are related to the aging process. Both soft and bony tissues undergo modifications during the whole life.

The human face is also influenced by other outer and environmental factors. While some, for instance, ultraviolet (UV) radiation, speed up the aging of the skin and cause permanent modifications; others, such as facial expressions, cause temporary changes in the appearance of the face (Iblher, et al., 2013).

Currently, the three-dimensional scanning technology in craniofacial and medical research is mostly used to obtain 3D surface scans of sitting participants. Different studies are using 3D scans created by CT or MRI which require patient in a supine position. This data was used, for example, for the research of the depth of the facial tissue for the craniofacial reconstruction, which should represent the appearance of the person (Bulut, et al., 2017). Similarly, the photographic documentation of deceased is obtained in the supine position. Therefore, the caution should be taken when comparing 3D data, and 2D data as well, obtained in a different position, as gravitation causes the movement and different distribution of the facial tissue (Iblher, et al., 2013).

2.2.1. Age-related changes of adult face

Age-related changes of faces of adults are challenging many successfully applied face recognition and face identification biometric methods. It is not fully understood to what extent aging effects face-based biometric technologies (Patterson, et al., 2007). Different studies had been conducted to simulate the aging in facial images, for instance, a layered simulation of wrinkles, or direct manipulation of shape or texture (Wu, et al., 1999), (Tidderman, et al., 2001). Changes of the bony and soft tissue from the early stages of the life, through the young adulthood to senescence, are well understood – general pattern and some skeletal changes were described (Patterson, et al., 2007). Compared to the dramatic changes that occur during the childhood, changes of adult faces are less obvious (Bishara, et al., 1998).

Generally, two types of facial aging can be distinguished – intrinsic and extrinsic. Intrinsic aging is as well called “natural” aging; while extrinsic aging is caused by external environmental factors. Similarly, two types of changes can be seen – changes of the skin and soft tissue, and changes in the bony tissue (Sveikata, et al., 2011).

2.2.1.1. Extrinsic ageing

Environmental factors, except orthodontic treatments or medical interventions, cause changes in the soft tissue and the skin. Extrinsic aging is mainly caused by UV radiation. So-called photodamaged skin is characterized by reduced collagen content and changes on the cellular level, moreover, the development of wrinkles is faster (Sadick, et al., 2009). Other environmental factors causing extrinsic aging are wind, arid climate, drug use or smoking. However, the influence of the sun exposure is the highest (Sveikata, et al., 2011).

Orthodontic treatment in adulthood causes changes of the appearance of the face. Extraction of premolars and molars effects lips – lower lip is more retruded and lower labial sulcus is more pronounced. Similarly, removal of third molars from maxilla causes the face to appear narrower (Bravo , et al., 1997).

2.2.1.2. Intrinsic ageing

Intrinsic aging, also called innate, genetic or chronological, are modifications that occur naturally over time (Zimbler , et al., 2001). Intrinsic changes result either from changes in bony tissue (naturally or for example, after tooth loss) or aging of the skin and changes in the soft tissue, which reflect changes of the underlying bony changes. The pattern of the intrinsic aging is known; however, the rate of aging differs between sexes and varies across adult ages. The rate of changes of the face is lower in ages twenty and thirty, and is significantly higher in ages fifty and sixty. Similarly, females tend to mature and age faster and earlier than males (Albert, et al., 2007).

Bony tissue intrinsic changes

The bony tissue is continuously forming, is removed and replaced during the life. In most individuals by age 28 the formation and the growth of the skeletal system is complete, and any later bony changes are due to the bone remodeling and resorption (Sveikata, et al., 2011). The bony changes of the head continue to the fifth and sixth decade of the life and display no uniformity.

Horizontal changes – head circumference, head length, bizygomatic breadth, and head breadth are of small magnitude (from 1.1 mm to 1.6 mm), but the impact of the bony changes on soft tissue may be high. Similarly, the increase of 1.6 mm of the height of the face (mostly in its lower part) is reported, which represents the majority of the vertical changes. Very aged people, on the other hand, show a decrease in the craniofacial skeletal size, probably due to bone resorption and remodeling after teeth loss (Albert, et al., 2007), (Forsberg, et al., 1991) (Behrents, 1985). Resorption of the bone after the teeth loss is more visible in the maxilla then mandible and is strongly correlated to the decrease of the facial height. Moreover, the loss of the teeth from the lateral side of the jaw causes narrowing the face and hollowing cheeks. The use of dentures may inhibit the bone loss to some extent (Sveikata, et al., 2011), (Bartlett, et al., 1992), (Crothers & Sandham, 1993).

Soft tissue intrinsic changes

The aging starts by the appearance of fine facial lines in the 20s, which deepen in 30s. The changes of the soft tissue (reduced skin elasticity, gravity, repeated contraction of muscles) in the 40s cause the drop of the eyebrows and the upper eyelid; and thinning and prolongation of lips. The age differences in size of lip area and thickness of lips can be seen - younger people have a larger lip area and thickness than aged (De Menezes, et al., 2011). In the 50s more tissue may develop on the upper eyelid, which drops further and covers the crease of upper lid; thinning of the lips continues, as well as deepening of facial creases. Double chin may develop as well. In the 60s the changes are more visible, the nose and ears appear longer, the tissue of the neck sag. From the 30s to 40s the lips move downwards caused by drop of perioral soft tissue (Rosati, et al., 2012). Around 45 years of age the vertical enlargement in the tip of the nose and forward movement of the chin cause the increase of the facial convexity (Albert, et al., 2007), (Bishara, et al., 1998), (West & McNamara, 1999). Loss of the volume of the soft tissue is typical for aging and occurs at periorbital, forehead, malar, temporal, mandibular, mental, glabellar and perioral regions (Sadick, et al., 2009).

2.2.2. Moles on age-different images of children

Similarly to the facial morphology, soft biometric traits (moles, scars or freckles) can aid a facial recognition by providing additional information. The combination of demographic information and soft biometric was proposed for the face matching (Park & Jain, 2010), which may be beneficial for identification of fast-growing and changing children. Still, it is important to consider that also soft biometric traits such as moles change through a life – for example raised moles to tend to increase in size and large moles (flat or raised) do not disappear; but there are many exceptions to this general pattern (Siskind, et al., 2002).

The publication which deals with the possibility of utilization of moles for face matching of age different images of children was authored by the author of this thesis and published as:

Z. Caplova, V. Compassi, S. Giancola, D. M. Gibelli, Z. Obertova, P. Poppa, R. Sala, C. Sforza and C. Cattaneo, "Recognition of children on age-different images: Facial morphology and age-stable features," Science and Justice, 2017.

The aim of the study was to evaluate the utilization of the position of moles as a method facilitating recognition of the same person on age-different photographs by using an automatic computational approach (Caplova, et al., 2017).

Materials and methods

A series of good-quality age-different photographs of the face with at least one visible mole in frontal or slightly lateral view were collected from 16 Italian subjects (13 females and 3 males) with an informed consent (in total 110 images). From the full set of photographs, 68 pairs were purposefully selected. Pairs represented persons of the same sex with moles in approximately the same position or in the same part of the face; age-different photographs of the same person and also of different persons. Pairs of photographs with the largest possible age gap between the youngest and the oldest face were selected for the comparison of age-different photographs (Caplova, et al., 2017).

Pairs of photographs were divided into three groups (Caplova, et al., 2017):

Group A. 22 photographs were compared with their copies to test the precision in setting the landmarks (intra-observer error);

Group B. 27 pairs of age-different photographs of the same subject were used to assess the change of the position of the mole due to the growth;

Group C. 19 pairs of age-different photographs of different subjects were used to test the sensitivity and specificity of the approach (the possibility of distinguished false match).

To plot and measure the change of the position of the moles an algorithm using the Computer Vision toolbox of MATLAB was developed. The face was detected using the detection algorithm based on Viola-Jones algorithm (Viola & Jones, 2001). The Viola-Jones algorithm provides real-time image-based detection, by learning a classifier from a large number of labeled data. The training is based on Haar features found on integral image cleverly selected with an Adaboost algorithm that finds the best classifier as a linear combination of the weaker classifier.

The images of the faces were cropped and scaled in the training process, in order for the output of such a classifier to be normalized. Ten fixed landmarks (Table 17) were manually selected by two operators on pairs of facial images to identify the orientation of the person's face according to their definitions in section "Landmark definitions" listed in the beginning of the dissertation thesis.

Table 17 Used landmarks (Caplova, et al., 2017)

Reference points	
Exocanthion (*ex* dex., *ex* sin.)	**Gnathion** *gn*
Endocanthion (*en* dex., *en* sin.)	**Sides of philtrum** (*ph* dex., *ph* sin.)
Alare (*al* dex., *al* sin.)	**Centre of the Cupid´s bow** *lp* (lip tubercle)

Same ten reference points were used to find the homographic transformation between pairs of images to create a univocal mapping of the faces' skin surfaces. The moles were then manually selected and their positions were compared by computing the distance in pixel between a mole in a reference photograph and a mole in a comparative photograph projected onto the reference one (Figure 7). The shape of the moles was not considered (Caplova, et al., 2017).

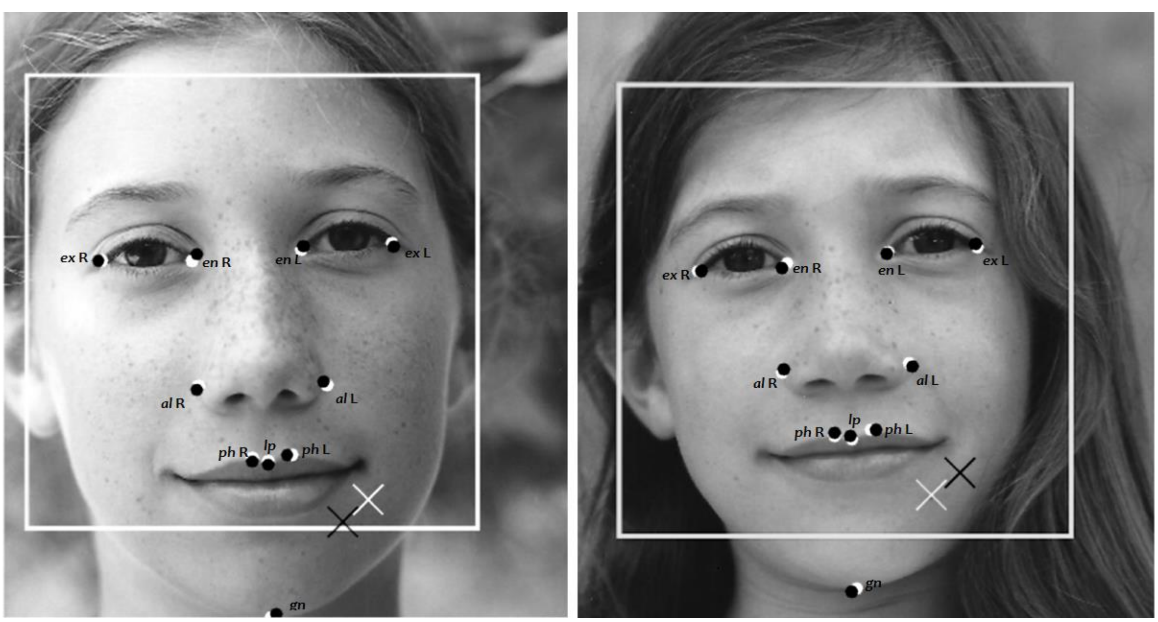

Figure 7 Ten reference points with the mole (manually selected and indicated by a cross) (Caplova, et al., 2017)

The homographic transformation introduces an error in the projection of a pixel in another face. Therefore, the accuracy of the superimposition was assessed by Homography Distance Score given as the mean distance between ten reference points. Since images were normalized, the mean distances given in pixels were comparable (Caplova, et al., 2017).

The Mole Distance was introduced to estimate the distance between two moles in the pair of images projected onto each other. As a result, the Similarity Score was calculated as a percentage of similarity in the position between two moles taking into account the accuracy of the Homography Distance between one face and another – the smaller the Mole Distance, the higher the Similarity Score and vice versa. Similarity Scores were obtained from two observers.

The Similarity Scores was calculated using the equation:

$$Similarity\ Score = \frac{Homography\ Distance}{Mole\ Distance + Homography\ Distance}$$

To increase the sample size for assessing the performance of the algorithm, the similarity scores obtained by the two observers were combined in these analyses – probability density function, and the probability of belonging to one group or the other as a function of a given Similarity Score (Caplova, et al., 2017).

Results

The intra-observer error in setting 10 landmarks was 5% for each of the observers, which is classified as a good or acceptable error.

The mean similarity score of 35%, with a standard deviation of 18% and a range of 10% to 94%, was observed when comparing the same subject with a mole at the same age and of the same subject at different ages (Group A vs Group B). This means that the data from age-different images are too similar; it does not seem possible to discriminate the age of a subject from the position of her/his mole which indicates that moles are age-stable features (Figure 8) (Caplova, et al., 2017).

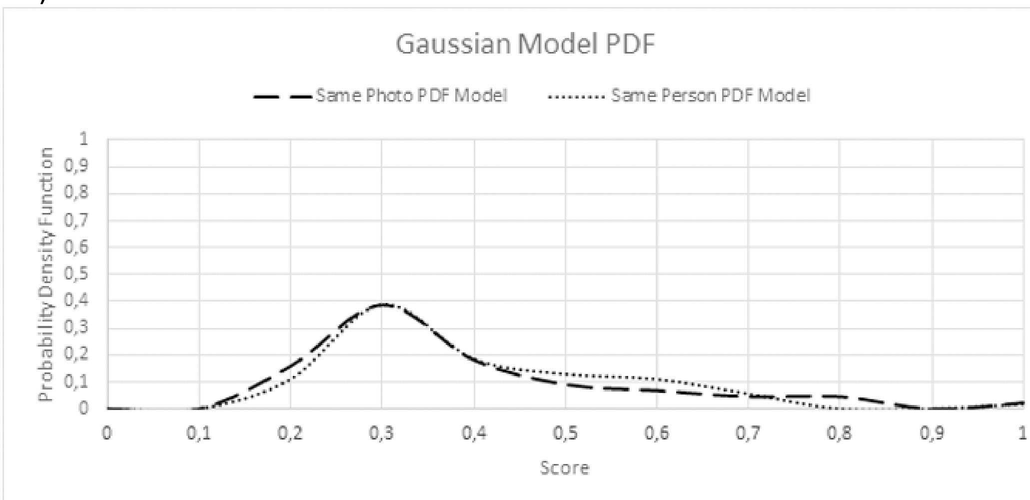

Figure 8 Probability Density Function (PDF) of Group A vs Group B: The similar shape of the Similarity Score curve illustrates that moles do not change position with the facial growth and maturation, and the person could be recognized on age-different different images by the position of the mole (Caplova, et al., 2017)

In the comparison of the same images and age-different images of the same person and different persons (Group A + Group B vs Group C) two statistical trends were detected – the first corresponds to the same-person similarity score, with a mean value of 0.35 (SD = ±0.18); while the second corresponds to the different-person similarity score, with a mean value of 0.1 (SD = ±0.07) (Figure 9) (Caplova, et al., 2017).

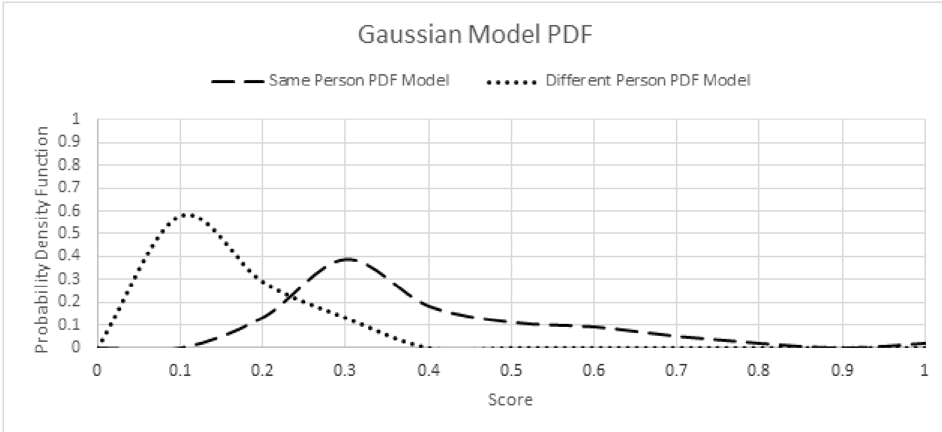

Figure 9 Probability Density Function (PDF) of Group A + Group B vs Group C: the different shapes of the similarity score curves illustrate the possibility to discriminate between the same person and different persons by the position of their moles (Caplova, et al., 2017).

The difference between means of the Similarity Scores shows the possibility to differentiate the same and a different person. Therefore it is possible to classify whether a new image belongs to the given (same) person or not (Caplova, et al., 2017).

Subsequently, Figure 10 shows the probability of a facial image being of the same or different person with similarity scores below 0.1 indicating that two different subjects; scores above 0.3 indicate images representing the same person based on the position of their mole.

The threshold of the Similarity Score of 0.22 represents the discrimination between the same and different person. Employing the threshold, 78% of facial images using a position of the mole returned a true positive result, 8% a false negative and 92% a true negative. In other words, the sensitivity of the method was 78%, the specificity 92%, and the miss rate was 8% (Caplova, et al., 2017).

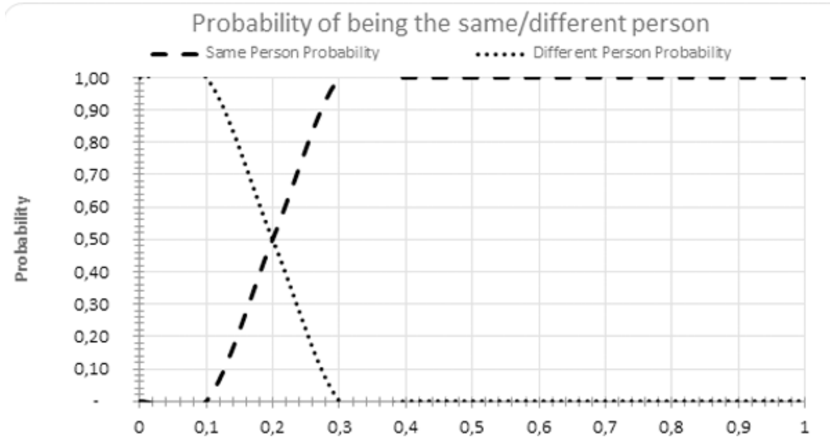

Figure 10 Probability scores plotted against the probability of classification as the same person or not: the threshold similarity score is 0.22 (Caplova, et al., 2017)

Discussion

The study explored the possibility to use the position of moles on the face for the purpose of the comparison of age-different images of children. The comparison was performed by using a specific algorithm developed for the verification of the growth-related changes of the position of moles; and for differencing a given person from other persons with moles located in an approximately same part of the face (Caplova, et al., 2017).

The experiment showed that proposed scheme may be useful for matching age-different facial images of the same person or differentiating different persons. Moles seem to be stable in their position over time as no differences in the pattern of results were noted when comparing images of the same subject at the same age with respect to the ones at different ages (Caplova, et al., 2017).

The Similarity Scores below 0.1 indicate two images represent different subjects and scores above 0.3 indicate images representing the same person. The Similarity Score of 0.22 was identified as the threshold of discriminating between the same and a different person. Despite promising results (the sensitivity of the approach 78%, the specificity 92%, and the miss rate

8%), the range of Similarity Scores for the same and different persons was too wide and therefore, the method needs to be improved (Caplova, et al., 2017).

Possibly, using better-quality images, employment of 3D and 2D comparisons, and minimizing human intervention in landmark setting could improve results. In addition, a better understanding of the anatomical evolution and changes of moles with growth and development of the child and aging of an adult, and potentially also the choice of different reference landmarks could be beneficial (Caplova, et al., 2017).

2.3. Chapter summary

Forensic identification of the living individual is as important as of the deceased. While primary identification methods, namely DNA profiling and fingerprint comparison, are the most reliable primary identification methods in both cases; great attention is paid to the faces of living. Presented overview of extensive research focusing on the recognition and identification of faces of living highlights the importance of the topic.

Some limitations, such as pose of the head and illumination can be overcome by the employment of the 3D scanning. Other limitations – aging of living and decomposition of deceased individuals play an important role and remain challenging in the facial recognition and identification process.

The previous chapter (Chapter 1) presented the current practice of the identification procedure of deceased. It can be seen, that the most reliable identification methods are not always applicable; and identification has to rely on secondary markers or on images of the deceased.

Interestingly, in comparison to images of living, very little attention is paid to facial images of deceased, which are currently used only for the visual confirmation of the identity.

The use of the 3D scanning brought many advantages into the research of faces, especially beneficial is the fusion of 3D and 2D images. As nowadays the spread of photographic cameras or mobile phones with cameras is worldwide, the existence of antemortem images of deceased is not rare. The fusion and the use of 2D antemortem and 3D postmortem image comparison for the purpose of facial recognition of deceased were not presented yet. However, research of living faces offers multiple methods and algorithms to be tested on faces of deceased.

3. Three-dimensional scanning of the faces of the deceased

Findings of the recognition test (1.4.2.Reliability of facial recognition of deceased persons on photographs) showed that comparisons of the antemortem and postmortem facial images that differ in pose, lighting, and age of the person may be used as a preliminary means of the recognition. However, the overall recognition score did not significantly differ between the professionals and students. The average scores of 78.1% for students and 80.0% for professionals were too low to consider the recognition method as a reliable identification, and thus needs to be supported by other means (Caplova, et al., 2017).

In real life scenarios, the visual recognition is performed by family or friends, and therefore it is the recognition of a familiar person (Uzun, et al., 2012). Performed recognition experiment tested whether a person can also recognize unfamiliar deceased, as in many cases the family or friends of the deceased are not able to perform the visual recognition (Caplova, et al., 2017). Therefore, there is a need for scientifically tested and valid method supporting the comparison of the morphology of the face of deceased to his/her antemortem photographs.

Previous literature overview of image comparison methods offered a variety of different techniques which had been studied or used for the recognition and identification of the living. By now, none of those methods were tested on the deceased, except previously mentioned study by Broach et al. (2017) who used simulated post-mortem images and algorithm offering no control or modification.

This type of comparison (AM 2D/ PM 3D) could be particularly helpful as a screening or exclusion tool in cases of mass disasters, when no other identification methods may be applicable. The identification of the victims very often takes place in temporary environmental conditions, such as set up military tents, aftermath the disaster. Those particular conditions may not allow the use of 3D technology requiring specific lighting conditions and space conditions.

Nowadays, different types of 3D scanning technology exist, which in case of no presence of CT scan or MRI could serve to capture surface of the face (or skeleton) in 3D. Three-dimensional models could then serve for different purposes, for instance as alternative to 2D photographs. Three types of 3D scanners were tested especially for the mentioned purpose.

3.1. Data collection

To overcome one of the main restrictions in facial recognition/identification – different pose of the head; 3D scanning can be employed as an alternative.

Three different methods were used to collect 3D scans of the faces of selected deceased in accordance with Mortuary Regulations of the Section of Legal Medicine in Milan, Italy. Deceased were selected based on the good state of preservation, no presence of head trauma and existence of antemortem photographs.

Firstly, two series of 2D photographs (resolution of 300 dpi) of the face and head were taken as illustrated in Figure 11 using Nikon COOLPIX S6200 camera (with resolution of 16 Megapixels).

The first series captured the right profile of the face including right ear, frontal face and left a profile of the face with left ear. The second series captured the top of the head, frontal face and bottom of the chin. Two series of photographs were then processed in Autodesk© Remake (Autodesk, Inc., 2015) free software to automatically create a 3D model. Software creates 3D meshes of 29.000 to 98.000 vertices per facial part of the head scan.

Second used method for obtaining a 3D scan of the face was scanning by laser hand-held Sense^{TM} 3D scanner (3D systems, 2016) capturing full-color 3D scans (Figure 12). Cubify SENSE™ (3D systems, 2016) the handheld scanner is a portable lightweight 3D imaging system using laser triangulation to capture the shape and color of objects located in distance rage about 0.2–1.6 meters. The scanner generates a point cloud by triangulation of projected arrays of individual laser points onto scanned surface. The depth and spatial x/y resolution differ depending on the distance from the scanned object; at the distance of 0.5 m, a spatial x/y resolution of 0.9 mm and a depth resolution of 1 mm are reported. No prior calibration is needed, the 3D scanner calibrates automatically at the beginning of each scanning session. The 3D model of the scanned object is seen in real time during the scanning, allowing adjustment of the speed of hand movement or distance from the object. Scanning time differs depending on the size of the scanned object and the experience of the operator. On average, less than 1 minute is needed to obtain a full-face scan of the deceased. All faces were scanned in automatic head scan setting, in which the triangulation of facial parts of faces (after unused parts are removed) varies from 70.000 to 500.000 vertices per scan.

The third method was 3D scanning using Minolta Vivid 910 Non-contact 3D scanner (Konica Minolta, 2016) which uses a laser beam to scan objects and digitizes them into 3D models (Figure 13). The scanner captures multiple scans from different angles and automatically merges them into one based on manually selected landmarks creating facial scans of 250.000 to 550.000 vertices. Time needed for a single scan is 2.5 seconds and at least 3 single scans are needed to capture the whole face. Therefore, an additional time of several minutes is needed for adjusting scanned views by moving scanned object or scanner itself. Merging can be performed immediately after the scanning or later. The scanner captures surface colors in a resolution of 640 x 480 pixels. The highest range resolution (Z-Depth) of 0.05 mm, and resolution (x and y) of 0.175 mm are reported (ViRVIG, 2017).

All deceased were scanned in the horizontal position, and if possible in sitting position.

Altogether, 36 three-dimensional scans of 12 deceased (1 female and 11 males) were obtained in different combinations of three mentioned methods (Table 18). Table 19 summarizes the advantages and disadvantages of three different 3D scans.

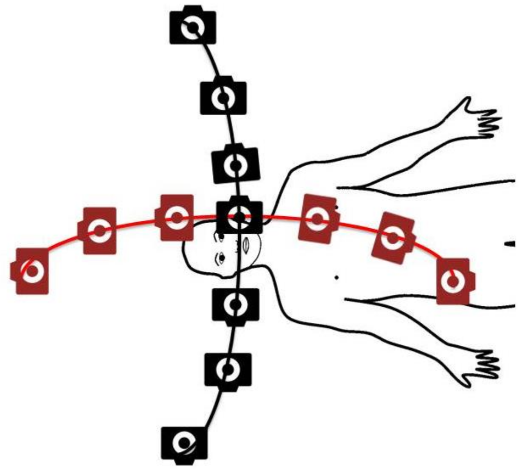

Figure 11 Photographs taken for 3D scan

Figure 12 An example of scanning by SenseTM 3D scanner (3D systems, 2016)

Figure 13 An example of scanning by Konica Minolta Vivid 910 (Qubic, 2016)

Table 18 Obtained postmortem scans and antemortem photographs

ID and sex	Number of 3D models from photographs	Head position	Number of Sense 3D models	Head position	Number of Konica Minolta Vivid 3D models	Head position	Total number of PM scans	Total number of AM photographs
1F	1	Head supported	1	Head supported			2	1
2M	1	Head down closed mouth	1	Head down closed mouth				
	1	Head down opened mouth	1	Head down opened mouth			4	4
3M	1	Head supported	1	Head supported			2	1
4M			1	Head supported closed mouth				
			1	Head supported closed mouth			2	2
5M	1	Head down	2	Head down			3	7
6M			2	Head down				
			1	Sitting			3	1
7M			1	Head supported				
			1	Head down			2	1
8M			1	Head down			1	9
9M	1	Head supported	1	Head supported	1	Head supported		
	1	Sitting	1	Sitting	1	Sitting	6	2
10M	1	Head down	1	Sitting	1	Head supported	3	7
11M	2	Head down	2	Head down	2	Head down	6	6
12M			1	Head down	1	Head down	2	3

Table 19 Advantages (green) and disadvantages (red) of three types of 3D scans

3D from photographs	Sense^{tm} 3D scanner	Konica Minolta Vivid 910
Fast	Fast	Time consuming
Lower quality	Moderate quality	High quality
No immediate visualization	Immediate visualization	Immediate visualization
Difficulties with format	No difficulties with format	Difficulties with format
Not a real representation of shapes	Questionable representation of shapes	Real representation of shapes
Easy to obtain	Easy to obtain	Difficult to obtain
No special equipment	Special equipment	Special equipment
Low price	Moderate price	High price

Shape index (s) was employed to assess the curve quality of each type of 3D scanner.

3.2. Shape index

Shape index (s) is a mathematical characterization of the local surface shape curvature of every point on the 3D scan, which can be used as an indicator of quality of 3D scan.

Values of shape index (s) characterize shape independently of its size into several categories – maximal and minimal shape Index values 1 and -1 characterize "spherical cup", values 0.5 and -0.5 characterize cylindrical shapes "ridge" and "rut", and lastly shape Index 0 characterizes plantar point with indeterminate shape (Koenderink & van Doorn, 1992). Table 20 lists all shapes characterized by values of Shape index.

Three-dimensional images are colored by values of the shape index (Figure 14), and then for example can be used together with curve definitions and landmark definitions based on points of maximum curvature along curves and on the crossing of the curves, to repeatedly landmark with lower intra-observer error. Landmarks are described as locations where curves bow mostly strongly, or where curves cross (Katina, et al., 2016).

Table 20 Shape index values and their shape characterizations (Koenderink & van Doorn, 1992)

Index range (s)	Shape
$[-1, -\frac{7}{8}]$	Spherical cup
$[-\frac{7}{8}, -\frac{5}{8}]$	Trough
$[-\frac{5}{8}, -\frac{3}{8}]$	Rut
$[-\frac{3}{8}, -\frac{1}{8}]$	Saddle rut
$[-\frac{1}{8}, +\frac{1}{8}]$	Saddle
$[+\frac{1}{8}, +\frac{3}{8}]$	Saddle ridge
$[+\frac{3}{8}, +\frac{5}{8}]$	Ridge
$[+\frac{5}{8}, +\frac{7}{8}]$	Dome
$[+\frac{7}{8}, +1]$	Spherical cap

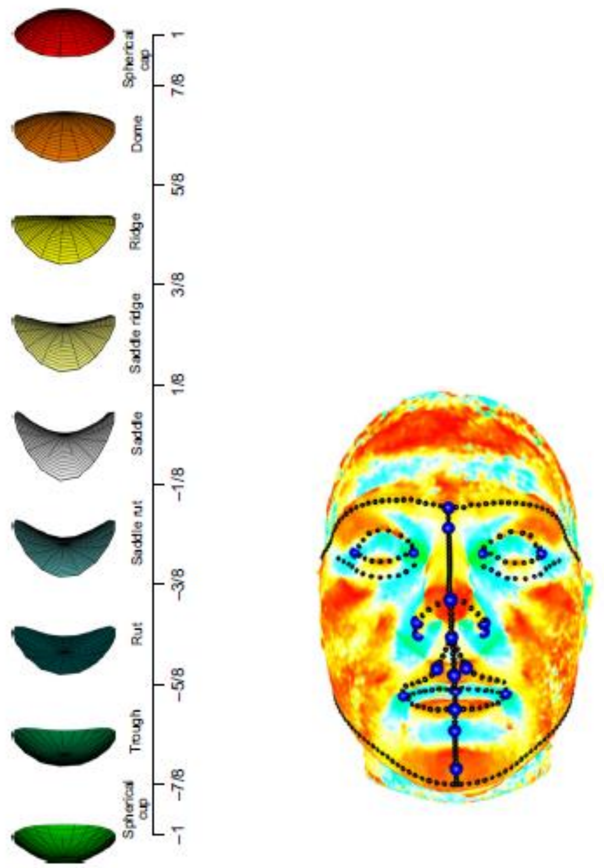

Figure 14 Colored map of the face scan and color coding of shapes characterized by shape Index (Katina, et al., 2016)

Restrictions

Several 3D model properties restricted or slow the process of shape Index (s) calculations. Five limitations were identified, namely:

- high resolution of 3D scans,
- holes in the 3D scan (result of scanning technique),
- problematic alignment of parts of the 3D scan,
- spikes in the 3D mash (result of uneven light conditions),
- presence of isolated vertices.

The high resolution of 3D scans (mostly Minolta Vivid 910 Non-contact 3D scanner) was lowered in software MeshLab (Visual Computing Lab -ISTI- CNR, 2012) using “Quadratic Edge Collapse Decimation” option, which simplifies the 3D mesh to pre-specified number of vertices. Three-dimensional scans with a number of vertices exceeding 200.000 were simplified to 100.000-200.000 vertices.

Small holes, spikes and presence of isolated vertices/pieces were removed in software MeshLab (Visual Computing Lab -ISTI- CNR, 2012) using options “remove duplicate faces”, “remove duplicate vertices”, “remove unreferenced vertex”, “remove zero area faces” and “close holes”.

Problematic (imprecise) alignment of part of the 3D scan is an issue resulting either from the incorrect alignment using an automatic algorithm (for example scans created from photographs by Autodesk© Remake), or from the imprecise building of the 3D scan during the scanning (for example Sense scanner). It is not possible to remove this restriction.

From all 36 3D scans obtained for the purpose of the comparison, the calculation of the shape index was not successful in 2 cases due to the above-mentioned restrictions (Table 21).

Table 21 List of 3D scans, shape index calculation restrictions/scanning errors and curvature quality after shape Index calculation

ID	File Name	Shape index calculation error	Scanning errors	Curvature Quality
1	1_1PMSenseH	NO	NO	GOOD
2	1_1PMPhotoH	NO	NO	FLAT
3	2_1PMSenseLC	NO	NO	GOOD
4	2_2PMSenseLO	NO	NO	GOOD
5	2_1PMPhotoLC	NO	NO	FLAT
6	2_1PMPhotoLO	NO	NO	FLAT
7	3_1PMSenseHO	NO	NO	GOOD

8	3_1PMPhotoHO	NO	NO	FLAT
9	4_1PMSenseHO	NO	NO	GOOD
10	4_2PMSenseHC	NO	NO	GOOD
11	5_1PMSenseLO	NO	NO	GOOD
12	5_2PMSenseLO	NO	NO	GOOD
13	5_1PMPhotoLO	NO	NO	FLAT
14	6_1PMSenseLC	NO	NO	GOOD
15	6_2PMSenseLC	NO	NO	GOOD
16	6_3PMSenseSO	NO	NO	GOOD
17	7_1PMSenseLC	NO	NO	GOOD
18	7_2PMSenseHC	NO	NO	GOOD
19	8_1PMSenseLC	NO	NO	GOOD
20	9_1PMSenseHC	YES	extremely high resolution	-
20	9_1PMSenseHC_lr	NO	NO	GOOD
21	9_2PMSenseSC	NO	NO	GOOD
22	9_1PMPhotoHC	NO	NO	FLAT
23	9_2PMPhotoSC	NO	NO	FLAT
24	9_1PMMinoltaSC	NO	extremely high resolution	-
24	9_1PMMinoltaSC_lr	NO	NO	GOOD
25	9_2PMMinoltaHC	NO	extremely high resolution	GOOD
25	9_2PMMinoltaHC_lr	YES		-
26	10_2PMSenseSC	YES	extremely high resolution	-
26	10_2PMSenseSC_lr	YES	spikes and isolated vertices	-
26	10_2PMSenceSC_lr_ch	NO	NO	GOOD
27	10_1PMMinoltaHO	YES	extremely high resolution	-
27	10_1PMMinoltaHO_lr	YES	unprecise Alignment	-
28	10_1PMPhotoLC	NO	NO	FLAT
29	11_1PMSenseLCba	NO	NO	GOOD
30	11_2PMSenseLCaa	NO	NO	GOOD
31	11_1PMMinoltaLCba	NO	extremely high resolution	GOOD
31	11_1PMMinoltaLCba_lr	NO	NO	GOOD
32	11_2PMMinoltaLCaa		extremely high resolution	-
32	11_2PMMinoltaLCaa_lr	NO	NO	GOOD
33	11_1PMPhotoLCba	NO	NO	-
34	11_2_PMPhotoLCaa		extremely high resolution	-
34	11_2_PMPhotoLCaa_lr	NO	NO	FLAT
35	12_1PMMinoltaLC		extremely high resolution	-
35	12_1PMMinoltaLC_lr	NO	NO	GOOD
36	12_2PMSenseLO	YES	extremely high resolution	-
36	12_2PMSenseLO_lr	YES	spikes and isolated vertices	-
36	12_2PMSenseLO_lr_ch	NO	NO	GOOD

_lr – lower resolution; _ch – removed spikes and isolated vertices

Results

Two types of curvature quality were observed – good and flat (Table 21, Figure 15).

As it can be seen in Table 22, in some cases (for example scans number 20 and 24) the high resolution was the main restriction for a successful shape index calculation. However, in case of the scan number 25 the high resolution did not play a role in Shape index calculation; moreover, after the resolution was lowered, the calculation was not successful.

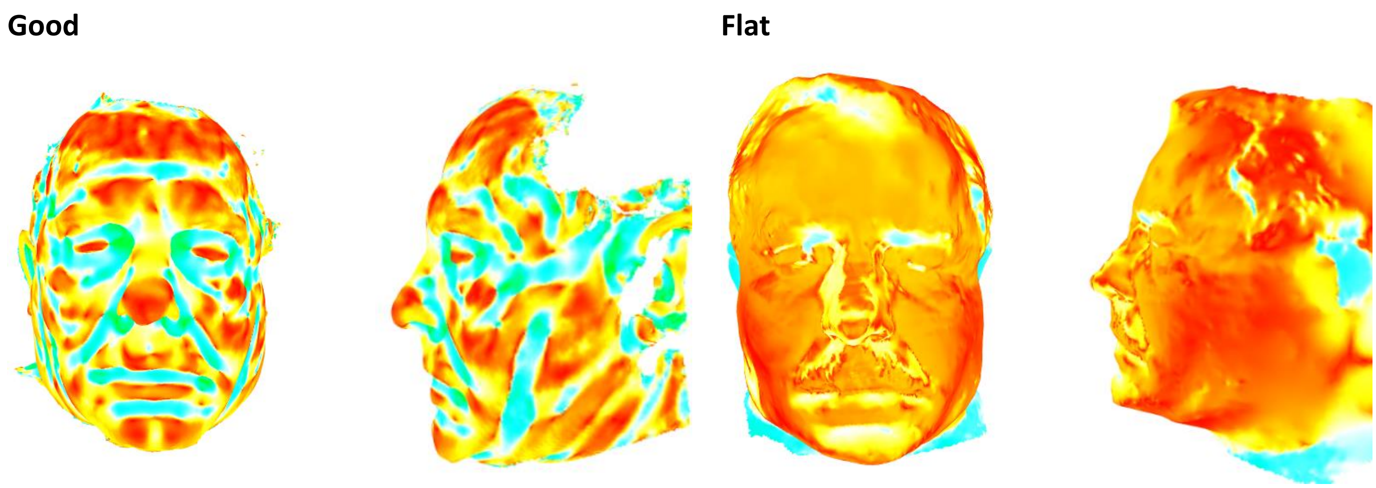

Figure 15 Two types of curvature quality of scans after Shape Index calculation

When spikes and isolated vertices were present (scans number 26 and 36), lowering the high resolution was not sufficient, and spikes and isolated vertices had to be removed.

Three-dimensional scans created from 2D photographs by (Autodesk, Inc., 2015) showed no restriction in shape index calculations but as it can be seen in Table 22, the shape index calculation of every 3D scan resulted flat.

From 20 three-dimensional scans captured by Sense™ 3D scanner (3D systems, 2016) the calculation of Shape index was possible in 17 cases without any prior adjustments. The high resolution had to be adjusted in one scan, and spikes and vertices had to be removed in two cases. All shape index calculation resulted in good quality.

All of the 3D scans captured by Minolta Vivid 910 Non-contact 3D scanner (Konica Minolta, 2016) were of too high resolution for shape index calculation. After the adjustment, all resulted in good quality.

Each method and 3D scanning system has its pros and cons. While 3D scan from photographs is easily and fast obtainable, it does not require any special equipment or help of another person, but it is of lower quality (number of vertices). The highest quality of 3D scans is provided by Konica Minolta Vivid 910 but its price and difficultness in terms of time and personnel needed for each facial scan, are the major drawbacks. The main advantage of Sense™ 3D scanner is its portability and low cost in comparison to Konica Minolta Vivid 910, especially in challenging conditions (time restriction, space restriction and possibly also body fluids) of autopsy room and mortuary. The selection of the scanning method depends on the aim and use of the scans – for instance, 3D scans from photographs could be sufficient as documentation or visualization and Konica Minolta Vivid 910 for further analysis. However, the high resolution is not always an advantage

3.3. Landmarking

Shape index (s) could also serve as guiding tool for more precise landmark placement to minimize intra- and inter-observer error. Facial landmarks are used in facial recognition either for space orientation or for match matching itself. Employment of the Shape index was tested in this matter.

Twenty-four facial landmarks coordinates were marked on each postmortem 3D scan in Landmark Version 3.0 software (Wiley & Institute of Data Analysis and Visualization, 2005). Table 20 summarizes all selected 3D landmarks. Used landmarks and their definition were proposed by Katina et al. (2016) who defined 3D landmarks based on curves and their crossing points and definitions are listed in the section "Landmark definition".

Coordinates of facial landmarks were marked in the exact order as described in Table 22.

To assess the single operator error (intra-observer error), each landmarking was performed twice before the shape index calculation and after.

Table 22 Selection of 3D landmarks and their correspondence

	3D	
Landmark Name	**ID**	**Measured**
Selion	0	1
Pronasale	1	1
Subnasale	2	1
Alare dex.	3	1
Alare sin.	4	1
Alare crest dex.	5	1
Alare crest sin.	6	1
Labiale superius	7	1
Labiale inferius	8	1
Sublabiale	9	1
Gnathion	10	1
Exocanthion dex.	11	1
Exocanthion sin.	12	1
Endocanthion dex.	13	1
Endocanthion sin.	14	1
Frontoyzgomatic dex.	15	1
Frontoyzgomatic sin.	16	1
Chelion dex.	17	1
Chelion sin.	18	1
Otobasion Inferius dex.	19	1
Otobasion superius dex.	20	1

Otobasion inferius sin.	21	1
Otobasion superius sin.	22	1
Nasion	23	1

1 – landmarked

Landmarking Quality Control

Quality Control was completed to assess the quality of the landmarking. Algorithm and codebook developed by Assoc. Prof. PaedDr. RNDr. Stanislav Katina, PhD. was used to search for the errors of landmarking, focusing on the order and remote landmarks. Quality Control was performed in R software environment for statistical computing and graphics (R Development Core Team, 2017).

In general, Quality Control algorithm pairs and loads files containing coordinates of the first and corresponding second landmarking. Based on the created codebook including names and the exact order of used landmarks, the correct template, and two corresponding landmarkings are visualized in a 2×1 grid. Correct template and landmarking of each photograph/scan are shown in the separate window (Figure 16).

Landmarks are numbered, colored (first landmarking is red, second is blue) and pictured. The correct position of each landmark was checked using the template as a reference; then the distance between red and blue corresponding coordinates was controlled. The smaller the distance, the more precise is the landmarking and vice versa. If only blue landmark number is displayed, the coordinates of the first and second landmarking are identical.

Template and output of the Quality Control of 3D landmarking are movable in 3D space (*x,y* and *z*-axis).

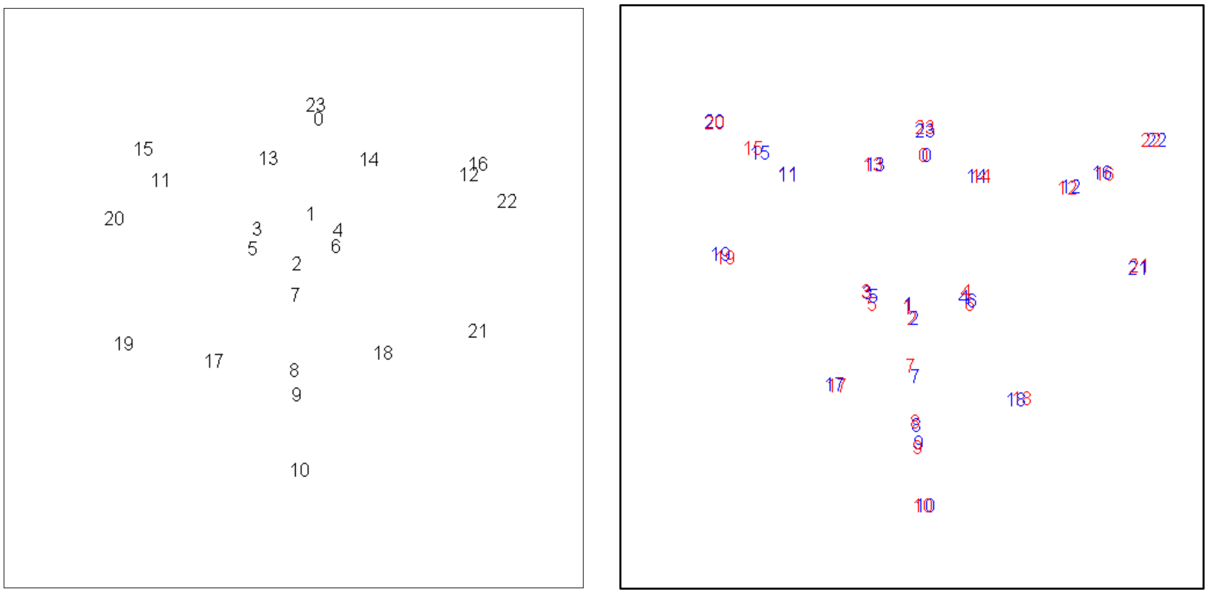

Figure 16 Quality control of 3D landmarking

Quality Control – results

Two types of errors of Quality Control of 3D landmarking were observed – the distance between corresponding landmarks and disordered landmarks (caused by the skipped landmark). Quality control of 36 3D scans was performed (864 pairs of landmarks in total); 85 landmark pairs (9.84%) on 22 scans were noted as more distant and all landmarks of one 3D scan were landmarked again because of incorrect order. Distant landmark pairs were not corrected as the shape Index was later calculated to test the precision of repeated landmarking (to assess intra-observer error).

Repeated Landmarking

The second set of 3D landmarking was placed using the same methodology as described in the section 3.3 Landmark selection and landmarking. Colored 3D scans (as illustrated in Figure 15) were landmarked twice to assess the intra-observer error (Figure 17).

Repeated Landmarking Quality Control

The quality of the second set of 3D landmarking was controlled as described in the section 3.4 Landmarking Quality Control.

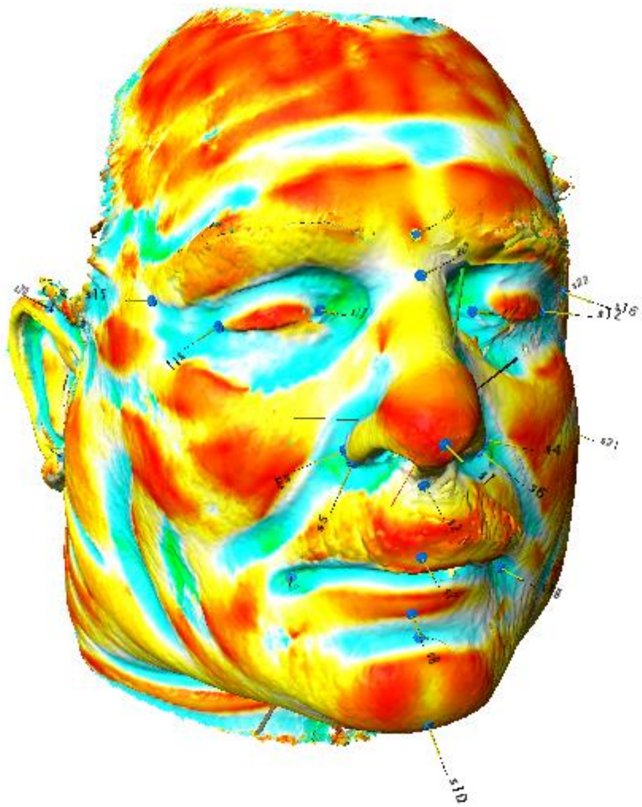

Figure 17 Landmarking of 3D scans colored by shape Index (s)

Repeated Quality Control – results

Quality control of 34 3D scans was performed (816 pairs of landmarks in total); 40 landmark pairs (4.9%) were noted as more distant, no incorrect order was observed.

3.4. Assessment of intra-observer error

Thirty-four of 36 3D scans were landmarked by a single operator twice before the calculation of shape index and twice after the calculation. This allows the identification of differences between repeated landmarkings. The hierarchical structure of the variability for a single 3D scan can be seen in Figure 18.

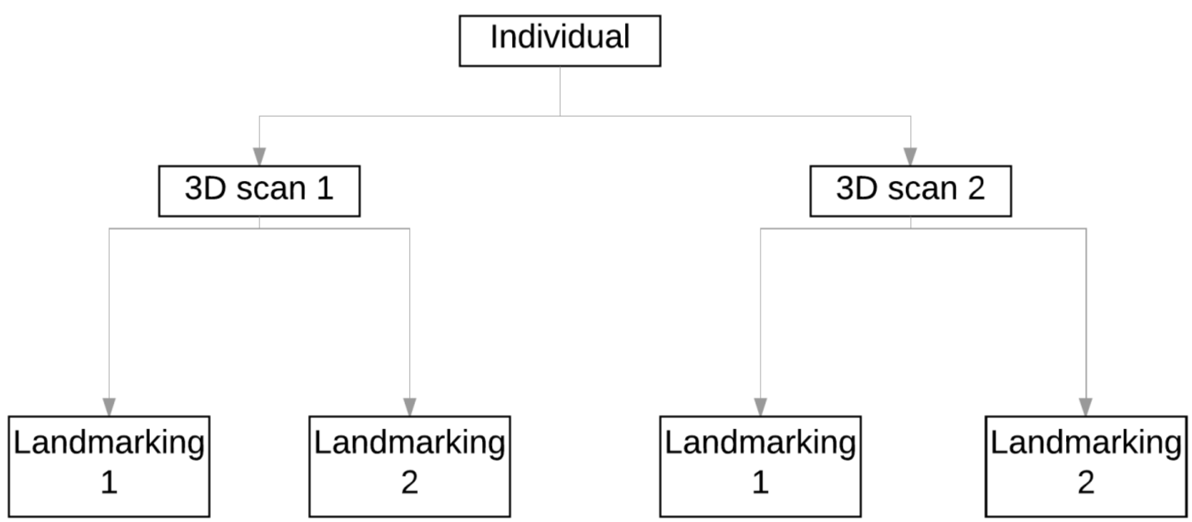

Figure 18 The hierarchical structure of the variability for a single observer

Two 3D scans were excluded from the second set of landmarking because the mentioned restrictions did not allow the shape index calculation.

Two random variation effects are influencing the hierarchy – different types of scans and the repetition of landmarking. The intra-observer error was calculated for repeated landmarking (measurement pair).

Mixed Effect Linear Regression Model (MELRM) was used for intra-observer error assessment, as described in Katina et al. (2016). Dependent variables are coordinates (each dimension separately), the fixed effect is only an intercept and random effects are Scan Type nested to the Individual.

The model is fitted to the data from single-observer´s landmarking before the shape index calculation and after the calculation, and to each landmarking separately. This allows the expression of the effect of shape index.

Landmark configurations are registered by Generalized Procrustes Analyses and this method applied to the arithmetic averages of the pairs of landmarkings of the same 3D scan. Size of the variation is estimated as the residual standard deviation of the model.

In the calculation of the intra-observer error (the study of the reliability of 3D data) the pairs of landmarkings before the shape index calculation and pairs of landmarking after the shape index calculations were grouped into groups of four and configuration matrices of coordinates of each group were fitted. As each 3D scan was initially oriented differently in the space, the orientation was standardized based on the arithmetic averages of each group of four. Repeated measurements of 3D coordinates on the same individual can't be superimposed, because they were measured on the same individual and the error is measured within individual repetitions. Four landmarks were used for the standardization (orientation in the space, frontal view, because the reliability intra-observer error is calculated for each direction *x, y*, and *z*) – *Nasion*, *Subnasale*, left and right *Exocanthion*.

Four landmarks were used for the standardization – *Nasion*, *Subnasale*, left and right *Exocanthion*.

Similarly, the positions of 3D scans were centered to the arithmetic average, as each 3D scan was placed differently in the space. The standardization of the orientation and position eliminated their influences in the study of reliability. The influence of the different size was not eliminated, repeated measurements on one individual can't be rescaled, and the study of the reliability of 3D data was calculated in millimeters.

3.4.1. Results

Results of intra-observer error (in mm) of repeated 3D landmarking, as well as the influence of the shape index, are listed in Table 23 and mean differences (*x,y,z* axis) between landmarking of grey-colored facial surfaces and shape-index colored facial surfaces are shown in Figure 22.

Table 23 lists standard deviations which represent variability of the landmarkings (in mm) separately for each landmark in each dimension (x, y and z), and the mean across all the dimensions.

Intra-observer error was calculated for group of four (two images of grey-colored facial surface and two mages of shape-index colored facial surface) and for each pair separately. Green color represents differences smaller than 1 mm (small intra-observer error), orange color between 1 and 2 mm (moderate intra-observer error), and red color over 2 mm (high intra-observer error).

Table 23 Intra-observer errors (in mm) – both types of surfaces (grey-colored facial surfaces and shape-index colored facial surfaces are not distinguished in intra-observer error calculation), grey-colored facial surfaces and shape-index colored facial surfaces.

Landmark	**Both types of surfaces**				**Grey-colored surface**				**Shape-index colored surface**			
	x	**y**	**z**	**mean (x,y,z)**	**X**	**y**	**z**	**mean (x,y,z)**	**X**	**y**	**z**	**mean (x,y,z)**
Selion	0.48	0.99	0.13	0.54	0.45	0.99	0.13	0.52	0.48	0.99	0.13	0.53
Pronasale	0.57	0.98	0.47	0.67	0.51	0.89	0.45	0.62	0.63	0.96	0.43	0.67
Subnasale	0.66	0.47	0.48	0.54	0.58	0.41	0.35	0.45	0.69	0.42	0.51	0.54
Alare dex	0.94	0.88	3.01	1.61	0.42	0.83	0.93	0.73	0.33	0.67	0.65	0.55
Alare sin	1.12	0.96	3.33	1.81	0.47	0.81	1.10	0.79	0.29	0.83	0.69	0.60
Alare crest dex	0.80	0.89	1.08	0.93	0.63	1.03	0.74	0.80	0.59	0.65	0.70	0.64
Alare crest sin	0.67	0.98	0.88	0.84	0.64	0.99	0.72	0.78	0.58	0.97	0.67	0.74
Labiale superius	0.69	1.68	0.40	0.92	0.59	1.16	0.38	0.71	0.76	1.41	0.38	0.85
Labiale inferius	0.86	1.22	0.76	0.95	0.88	1.01	0.67	0.85	0.85	1.09	0.64	0.86
Sublabiale	0.85	1.19	0.35	0.80	0.85	1.05	0.32	0.74	0.86	1.00	0.25	0.70
Gnathion	0.93	0.74	1.36	1.01	0.96	0.60	1.05	0.87	0.90	0.72	1.45	1.02
Exocanthion dex	1.24	0.86	1.77	1.29	1.10	0.97	1.53	1.20	0.95	0.64	1.22	0.94
Exocanthion sin	5.37	1.00	2.12	2.83	2.64	0.93	1.44	1.67	6.87	1.05	2.39	3.43
Endocanthion dex	5.46	0.77	1.46	2.56	2.42	0.70	0.72	1.28	7.07	0.77	1.90	3.25
Endocanthion sin	1.47	0.90	0.36	0.91	1.42	0.87	0.34	0.88	1.51	0.84	0.32	0.89
Frontoyzgomatic dex	1.01	1.51	1.70	1.41	0.76	1.55	1.60	1.31	1.04	1.26	1.73	1.34
Frontoyzgomatic sin	1.17	1.68	2.00	1.62	1.09	1.54	1.72	1.45	0.99	1.74	1.68	1.47
Chelion dex	0.96	0.91	0.80	0.89	0.93	0.79	0.71	0.81	0.99	0.82	0.89	0.90
Chelion sin	1.33	0.87	0.94	1.04	1.30	0.89	0.83	1.01	1.36	0.69	1.00	1.02
Otobasion Inferius dex	0.70	1.29	1.50	1.16	0.65	1.27	1.47	1.13	0.75	1.31	1.52	1.19
Otobasion superius dex	0.84	1.31	1.75	1.30	0.81	1.29	1.48	1.19	0.86	1.21	1.93	1.33
Otobasion inferius sin	0.69	1.95	1.97	1.54	0.57	1.87	1.51	1.32	0.80	1.88	2.23	1.64
Otobasion superius sin	0.91	1.74	2.59	1.75	0.88	1.31	2.75	1.65	0.94	1.85	2.30	1.69
Nasion	0.63	1.95	0.37	0.98	0.63	1.47	0.30	0.80	0.63	1.47	0.29	0.80

Green color represents small intra-observer error (≤ 1 mm); orange represents moderate intra-observer error (1-2 mm); red represents high intra-observer error (≥ 2 mm)

In the combined group of four, higher number of high intra-observer error occurred. Namely *Alare dex, Alare sin* and *Frontozygomatic sin* showed higher errors. Only in the single case (z-axis of *Otobasion inferius sin*) the error was lower in the combined group of four.

Table 24 clarifies whether shape index helped in more precise landmarking by lowering the intra-observer error. When x, y, z coordinates and mean values of each landmark for grey-colored facial surfaces and shape-index colored facial surfaces are compared, it is clear that shape index did improve landmarking accuracy only in case of few landmarks. Negative value -1 represents higher accuracy of grey-colored facial surfaces, positive value 1 represents higher or the same accuracy of shape-index colored facial surfaces. Values in the Table 24 are colored for easier orientation. Improvement of 33% was recorded on *x*-axis, 41% on *y*-axis, and 50% on *z*-axis. The mean improvement on all three axes was recorded in 25% of landmarks. The highest improvement can be seen in the area around nose (landmarks *Alare dex* and *sin*, *Alare crest dex* and *sin*).

Table 24 Comparison of accuracy of 3D landmarking

	Selion	Pronasale	Subnasale	Alare dex	Alare sin	Alare crest dex	Alare crest sin	Labiale superius	Labiale inferius	Sublabiale	Gnathion	Exocanthion dex	Exocanthion sin	Endocanthion dex	Endocanthion sin	Frontoyzgomatic dex	Frontoyzgomatic sin	Chelion dex	Chelion sin	Otobasion Inferius dex	Otobasion superius dex	Otobasion inferius sin	Otobasion superius sin	Nasion
x axis	-1	-1	-1	1	1	1	1	-1	1	-1	1	1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1
y axis	1	-1	-1	1	-1	1	1	-1	-1	1	-1	1	-1	-1	1	1	-1	-1	1	-1	1	-1	-1	-1
z axis	-1	1	-1	1	1	1	1	-1	1	1	-1	1	-1	-1	1	-1	1	-1	-1	-1	-1	-1	1	1
mean (*x,y,z*)	-1	-1	-1	1	1	1	1	-1	-1	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

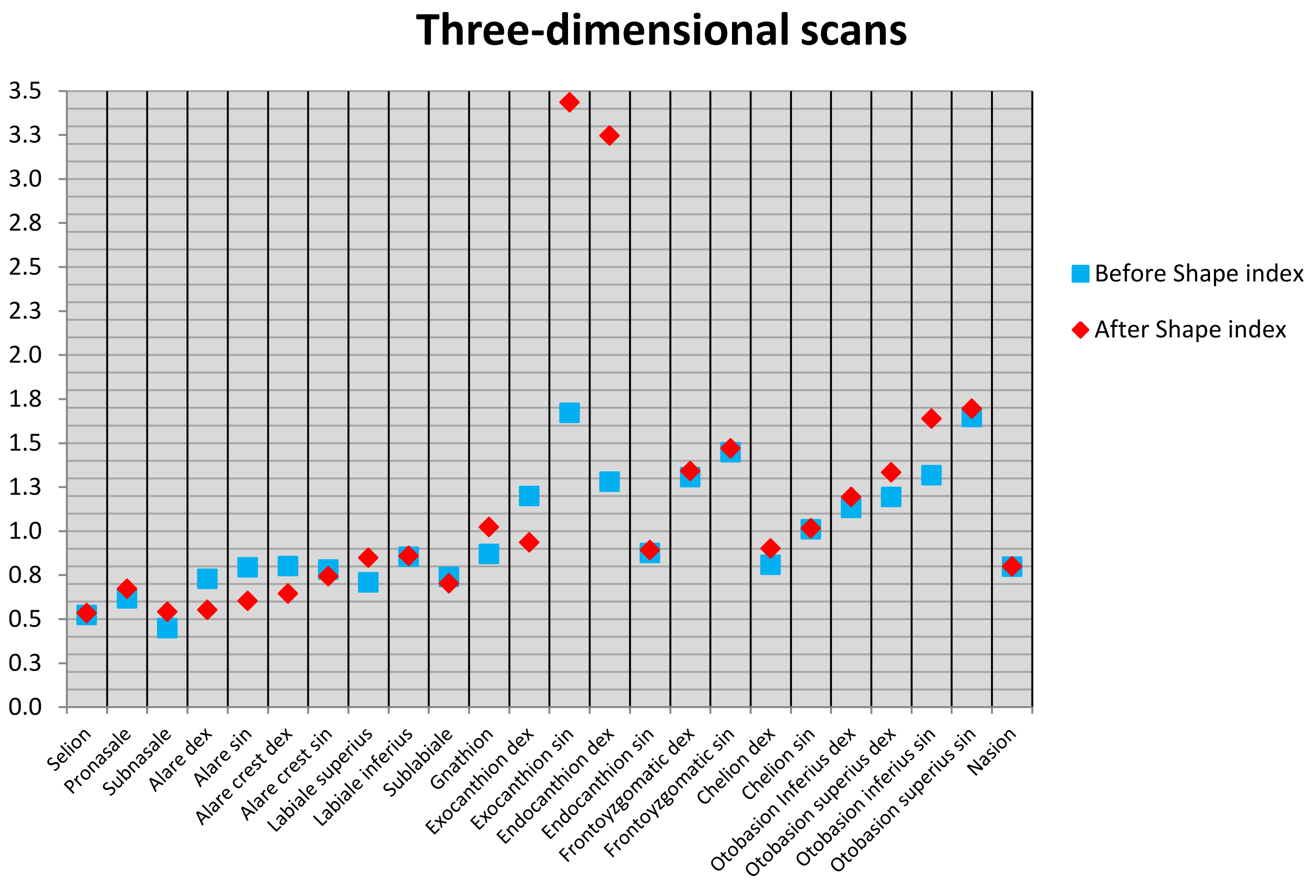

Figure 19 Means (x,y,z axis) of differences (in mm) between 3D landmarkings

As it can be seen on Figure 19, shape index significantly lowered the mean precision of repeated landmarking of the area around eyes, namely Exocanthion dex and Endocanthion sin. The intra-observer differences reach up to 6.8 and 7.0 mm on *x*-axis.

Orbital areas, together with the area around ears, are the areas with the highest mean intra-observer error.

4. Discussion

Forensic experts often deal with personal identification, either of living or deceased people. While primary means of identification – DNA analysis, comparison of dental records and fingerprints, are the most reliable in terms of low identification errors, their use may be limited by the lack of data for comparison. Forensic identification is a complex process with high importance and therefore is the interest of many researchers, as well as this Ph.D. dissertation. Multiple publications dealing with the identification of living can be found and depending on utilized methodology, also its application on the deceased. The exception, however, is the facial recognition and identification. While facial matching, facial recognition, and identification of living people are in the focus of many, its application on deceased was tested only recently (Broach, et al., 2017). Interestingly, particularly the appearance of the face of the deceased is sometimes the only information which could lead to the establishment of identity. In those cases, simply viewing the body, or postmortem photographs are in some jurisdictions considered enough. Even if low-error-rates algorithms of the facial matching of living faces exist e.g. (Davis, et al., 2010), they are not used for deceased face matching. If used, they may offer a quick aid of preliminary recognition during mass disasters, when the number of deceased is high. According to published literature (Caplova, et al., 2017), the current practice differs – simple recognition by relatives or friends is considered as a visual identification method. Error rates of visual recognition are known to be high in case of living people. No publications could be found which would test the recognition rates on the dead, but the emotional stress of loss of the family member or friend can cause even higher misidentification errors as in case of the living.

Presented dissertation thesis deals with the problem of the recognition of deceased faces. In the first part, currently used identification methods of deceased based on the appearance of the human face and body is summarized; then the human ability to recognize faces is described, as well as differences which influence the recognition. Then visual recognition of deceased faces is tested, similarly, the process of early decomposition of the face and new method of quantification of the process is described.

In the second part, which is dedicated to living individuals, an extensive overview of methods of identification based on the appearance of the human body is offered to point out the differences compared to the identification of deceased. One of the methods, namely morphological evaluation using morphological atlas is tested on several series of age different images of the same individual and the subjectivity of the approach is highlighted. Soft biometric facial features (as scars, freckles or moles) individualize human face and could aid the identification. An algorithm, developed and described in this part of the dissertation comparing the position of facial moles on age different images was tested.

The third part focuses solely on the possibilities of postmortem 3D scanning images. Shape Index (s) was employed to characterize three different 3D scans and to minimize the inter-observer error of landmark coordinates in 3D. Results could serve as a base for further research or for testing existing algorithms developed for the living faces matching.

4.1. Forensic identification of the deceased

The first chapter focuses on the identification methods of the deceased, with emphasis on methods based on the appearance of the human face and body. All approaches listed in the chapter (1.3 and 1.4) represent by now published research or reports of a real-life practice. Compared to the identification of living, the identification of deceased does not pay much attention to the morphology of the human face. Several studies using morphology of facial parts (ears or facial creases) were found (Caplova, et al., 2017), however, none deals with a face as a whole which is the case in living face matching.

In theory, methods that have been used and tested on the living may also aid the personal identification of the deceased. Still, there are a number of questions that need to be explored, including (1) whether the methods of personal identification of living individuals are at all applicable to the deceased; (2) to identify parts of the face whose morphology remains unchanged and uninfluenced by (early) decomposition changes; (3) if the position of the deceased affects the appearance on photographs or 3D scans of the face the same way as in case of living; (4) whether the assessment of soft biometrics (moles, scars) and tattoos can be utilized considering the decomposition processes; and (5) more specifically, how decomposition changes the visibility and colors of tattoos.

Currently used methods of postmortem identification from the appearance of the human body, except dental superimposition, are not validated and accurate enough. Even with a decrease of the cost and progress of DNA testing; the use of fingerprints and comparison of dental medical data; these methods are still not applicable in all cases of deaths. More and more cases require alternative techniques of personal identification, especially with recent free movement and migration, in which the existence of the AM data may be limited to simple photographs.

In conclusion, the findings stress the need to establish tested, reliable and accurate techniques and protocols, which would aid identification of the deceased from the physical appearance of their face and body.

4.1.1. Reliability of facial recognition of deceased persons on photographs

Natural ability to recognize faces of familiar and unfamiliar people is not errorless. Error rates of recognition of living faces are well studied and known and are considered high (Hofmann, et al., 2006) (Light, et al., 1979). Nevertheless, the visual recognition is in many cases used as a form of visual identification – for example, eyewitness identification. The same visual identification had been used in the aftermath of mass disasters, even if it is not recommended. It was important to test the error rates of recognition of familiar and unfamiliar faces of deceased to conclude whether visual identification should be attempted in those cases.

As the experiment showed (Caplova , et al., 2017), several factors should be considered in advance when attempting the recognition of the unfamiliar face of deceased by comparison to antemortem photographs. While the differences in the pose, lighting, and age may not influence the recognition of the deceased; alternations of facial hair seem to pose a significant obstacle to correctly match AM and PM photographs.

The overall recognition score did not significantly differ between students and professionals, on the other hand, the median score of 78.1% for students and 80.0% for professionals is not sufficient to consider it as a reliable identification method. Therefore, when attempting the identification by face matching, the verification by other methods is needed.

In cases of low correct recognition rates, professionals performed with higher accuracy. To increase the accuracy of recognition, professionals could be trained to focus on more individualizing features (scars, discoloration, teeth), which remained mostly unnoticed by students.

As the quality of photographs used in the study might be higher than the quality of photographs obtained in real cases, more research is needed to explore the recognition accuracy of low-quality images. Likewise, further research is necessary to test images in the ¾ view, as it was reported to offer a better opportunity for recognizing an unfamiliar face (Baddley & Woodhead, 1983).

To conclude, the recognition of unfamiliar faces of deceased persons may be used as an initial screening tool, but the current state of research shows that it should not be used as the only method for positive identification.

4.1.2. Quantitative analysis of early decomposition changes

Postmortem and decomposition processes start shortly after death. The general decomposition of the human body is well studied and known and early decomposition changes of the face have been studied only lately (Wilkinson & Tillotson, 2012). Early decomposition plays a significant role in the facial recognition and identification. Compared to the recognition of living faces, when mimicry and aging are the main factors of facial changes, the postmortem and decomposition processes are the only factors causing changes after death.

The progress of the decomposition of the human body and the face itself is influenced, among others, by the environment (for instance wet/dry/warm). Similarly, it is known that low temperatures, in which the body is stored, slow down the processes. In case of the unidentified body, the storage in low temperatures for some period of time is the most likely scenario. As decomposition processes are still ongoing it is essential to know when the human face loses its individual morphological features which could potentially be used for the comparison with antemortem 2D or 3D images.

The presented experiment (1.4.3.1. Quantitative analysis of early decomposition changes) describes the early decomposition of the face of a single donor at the temperature of 4 degrees Celsius for a period of 2 months. Moreover, it uses Root Mean Squared value (RMS), which is often used in a research of living faces, to quantify the decomposition changes in relation to time since death.

The methodology succeeded to identify daily changes in decomposition, which were illustrated by color map function (Figure 6), and therefore, could be qualitatively described. A high linear correlation (r=0.863) between daily RMS values and time passed since death confirms the potential of the approach.

In the described case, possibly other factors influenced the process of early decomposition of the face as well – health condition and medical treatment. However, the observed pattern of changes was in accordance with previously described changes in the different environment (Wilkinson & Tillotson, 2012).

A novel approach to quantification of the early decomposition changes of the human face could be of use for forensic recognition and identification of the deceased. A better understanding of the decomposition changes could improve the accuracy of facial approximation and, potentially, could allow the direct comparisons of antemortem and postmortem 3D/3D and 2D/3D images using developed algorithms and software. If early decomposition changes of faces in different environmental conditions are known and quantified, the comparison of medical head scans of living people (or any other 2D antemortem images) with 3D postmortem scans opens new possibilities for personal recognition and identification from physical appearance.

4.2. Forensic identification of living

The second chapter focuses on identification of the living. The extensive literature clearly shows the importance of this matter, as well as its development in comparison to the identification of the deceased. The appearance of the human face represents significantly individualizing feature of the human body which is widely studied and used for the identification of the living. As described in the chapter (2. Forensic identification of living) different morphological and metrical methods of the facial recognition and identification are employed. Some, such as the utilization of morphological atlas or superimposition of photographs, are rather subjective in the evaluation of the match. Others, such as Principal Component Analysis (PCA) based algorithms objectively recognize and match faces with low error rates.

This dissertation thesis includes two experiments conducted on images of living people, even though the main topic of the thesis is the identification of the deceased, as in both tests multiple age-different images of the same persons were required. However, due to the fact that use of the morphological atlas as well as using soft biometrics for the face matching of deceased is restricted by postmortem and decomposition changes, and could be used only shortly after death, experiments on the age-related variations in living persons can provide information with a potential application to the deceased.

Growth and aging considerably influence the appearance of one´s face. Especially in case of children, or outdated photographs of adults, attention has to be paid to possible changes of facial morphology when compared with a target image. Age progression, a technique which simulates growth and maturation of face of a child, has been rated as insufficient. The face grows and matures in a complex way, and multiple factors such as ethnicity, age group and gender play significant role (Ramanathan, et al., 2009). A single path of growth and maturation cannot be identified and the age progressed images were shown to offer no advantage over outdated images of youngsters (Lampinen, et al., 2012).

Some facial morphological features change rapidly during the growth, others undergo only minimal changes. The presented dissertation thesis explores two possible ways of evaluation of stability of morphology of the face – facial features and position of facial moles or marks (soft biometrics).

4.2.1. Morphological atlas

The simple experiment offered more insights into the errors of morphological assessment of facial features. It would be expected that Anthropological Atlas would eliminate any subjectivity in the classification. However, relatively high mismatch percentage (45%) proved the unreliability of the method. Moreover, the experiment did not identify any set of facial features that would be considered stable over time and classified into the same category by all observers.

In comparison, Ritz-Timme et al. (2011) reported the mean inter-observer mismatch percentage 39% when evaluating single photographs of adult males; the intra-observer mismatch percentages ranged from 19% to 30%.

Both experiments (Ritz-Timme, et al., 2011) (Caplova, et al., 2017) showed the subjectivity of the method on single images of adults and on age-different images of children. Both experiments used an Anthropological Atlases by (Aßmann, et al., 2007) (Ohlrogge, et al., 2009), therefore different results using other atlases could be achieved.

Although subjective, when applied to deceased faces the classification of facial features may aid the face matching in the search of the identity when no other methods are applicable. No studies of the application of the same or similar method on deceased were found. On the other hand, the morphological classification of facial features of living is erroneous and post-mortem changes, which alter the appearance of the face, as mentioned before would play an important role in the categorization of facial features. Such a method would be applicable only shortly after death due to the postmortem and early decomposition changes which start immediately.

4.2.2. Moles on age-different images of children

Moles or any marks which persist on the skin for longer period of time could be used as individualizing features. The described simple algorithm evaluated the change of the position of selected mole on the face of children on age different images. The comparison of the position of moles across age-different images of one person and among different persons may have the potential for the recognition of missing children over time. The position of moles seems to be an individualizing feature and seems to be stable over time. However, this study focused on the position of single moles and not their shape, moreover in a limited sample. Further research on larger samples and with focus on a set of multiple moles on one face, possibly including their shape, would likely strengthen the individualizing potential of this feature.

The question of how many moles would be considered individualizing “enough” still remains, similarly if it would be achievable to use the position of a single or multiple moles as a biological indicator of identity. The present study is far from being able to answer those questions; however, tool mark and material analysis may provide an inspiration for further forensic analysis, the discussion about uniqueness of moles and scars in forensic sciences.

Moreover, similar approach could be used in case of identification of deceased – the difference in the position of moles or scars on AM and PM images could be quantified.

4.3. Three-dimensional scanning of the faces of the deceased

Similarly to face matching of the living faces, the face of the deceased carries individualizing morphology which could be used as a primary screening tool when no other data for personal identification are available. Developed 3D scanning technology offers a great advantage over 2D images – the dimension of the depth. As previously mentioned, numerous different 2D/3D facial comparison approaches exist, but none was tested on the images of the deceased. Even though, the 3D technology is spreading into research and slowly to everyday life, the cost of high-quality 3D scanners still remains high. Therefore, three different methods of data collection were used to observe the differences between the matching performance of 3D scans of different resolution, different scanning method, and different price. The 3D data collection was constrained by the state of preservation and availability of antemortem images. The 3D dataset is rather small, but several preliminary conclusions can be drawn from the experiment.

4.3.1. Shape index

Precise landmarking with low intra-observer error is needed for successful application of multiple algorithms. Shape index was employed to improve the landmarking of 3D images. Several 3D scans required adjusting in terms of resolution or fixes of the 3D mesh.

High resolution of 3D scans by Minolta Vivid 910 Non-contact 3D scanner (Konica Minolta, 2016) is an advantage of capturing the exact shape of the face. On the other hand, the scans had to be simplified, which may lead to the loss of “true” shapes. Opposed to Konica Minolta, SenseTM 3D scanner (3D systems, 2016) was employed as an alternative. Sense creates facial scans with relatively high number of points, but due to its sensibility to changing lighting conditions, the scans present spikes and isolated vertices. Three-dimensional models created by free software Autodesk© Remake (Autodesk, Inc., 2015) showed the least number of restrictions, however, after the shape index calculation, the curve surface quality was showed to be insufficient.

4.3.2. Assessment of intra-observer error

The results of the assessment of intra-observer error showed overall slight improvement of accuracy of repeated landmarking after shape index calculation of some landmarks. Compared to the values of landmarking before shape index, the increase of the improvement was on average by 13% on the *x*-axis, by 16% on the *y*-axis, and by 12% on the *z*-axis. Shape index, however, similarly lowered the accuracy of landmarking, namely on average by 37% on the x-axis, by 11% on the *y*-axis and by 42% on the *z*-axis.

Overall, if the mean intra-observer error was improved by the shape index, the increase by 14% was observed, while if the mean intra-observer error was lowered by the shape index, the decrease by on average 21% was observed.

As reported in the section Restrictions of subchapter 3.5 Shape index, the low curvature quality of 3D scans after the shape index calculations was observed mostly in the case of 3D scans created by (Autodesk, Inc., 2015). Low curvature quality reflects a lack of the real representation of the shape (the face), which was detected by shape index. Therefore, the color map created by values of shape index had no use in the landmarking.

Further studies of landmarking accuracy improvement by shape Index should focus on only one type of 3D scans. Shape index as an indicator of the curvature quality, therefore the real representation of the scanning object, could be tested as a validation tool of different 3D scanners.

Despite the existence of advanced identification techniques, development of DNA comparisons and huge ongoing research of the face matching of living faces, the personal identification of the deceased at times fails and human remains are buried unidentified. The appearance of the face and body, especially the morphology of face and soft biometric traits of the deceased offer other individualizing features with potential in the forensic application. The research of the topic is involving the study of postmortem and decomposition changes of human face, scars, moles and tattoos. Regardless the importance of such identification, very few publications can be found.

Identification methods base on the appearance of the deceased is still far from having their errors known. Huge inter-personal variability and differing environmental conditions in which death occurred influence the appearance. In order to be used in forensic cases and at court, the error rates of those methods need to be tested. Only then they can be considered reliable and respect Daubert and Kumo guidelines (Daubert v. Merrell Dow Pharmaceuticals, 1993) (Kumho Tire Company, Ltd. v Carmichael, 1999).

5. Conclusion

The dissertation thesis titled "Morphology of the face as a postmortem personal identifier" summarizes multiple research topics – visual recognition, factors influencing recognition, recognition aided by morphological atlas and the utilization of soft biometrics for face matching. As a first step, the project explores the face recognition and face matching of the deceased. The study which used simply designed line-up questionnaires was first of its kind and drew interesting conclusions. The main concerns in "visual identification" of living and deceased are the high error rates, alternations of the face due to facial expressions, illuminations, aging and decomposition changes. The test indicated similar error rates for living, deceased and mixed face matching. However, the rates over 20% are insufficient and "visual identification" in a form of visual face matching of the deceased should be avoided in the forensic scenario - but could be used as an initial screening tool.

In contrast to this finding, already published literature revealed the use visual identification in case of mass disasters despite its high error rates. Moreover, in some publications, no other confirmation of identity was undertaken.

Multiple factors affect the general visual face recognition and face matching. Early postmortem and decomposition changes are one of the main influences in case of the deceased. The proposed methodology of the quantification of changes (described in 1.4.3.1) showed that the process is ongoing and trackable from the first day after the death in the low temperature, which in case of the forensic identification raises the question of the reliability of visual recognition of deceased. Furthermore, the early decomposition rate of the face will differ from person to person, and will change in diverse environmental conditions.

On the other hand, the possibility to track the early decomposition changes opens new possibilities in the forensic identification. Defining the time-after-death-limits in which the face decomposition does not hinder the face matching in various environmental conditions, could enable the face matching with images obtained lately after death.

Similarly, if the progress of early decomposition of the face is known, the morphological evaluation using morphological atlases could aid the screening or recognition. High inter-observer error (Chapter 2.1.3.1) precludes the utilization of this method in the forensic identification. On the other hand, in cases when no other identification means are applicable, and the appearance of the face is the only identifier, the face matching or exclusion could be attempted by assessing the morphological profile of the face by morphological atlas. A trained evaluator and atlas with clear definitions of features could improve the error rates and could be used as exclusion preliminary tool.

Relatively high errors of visual recognition and morphological assessment by atlas confirm that another mean of comparisons of the face of decedents is needed. Similarly to the face matching of living, the face matching of decedents could provide strong arguments in forensic identification. The decomposition process alters the appearance of the face, but so is the case of facial expressions and aging of living. The quantification of the match of images of living and deceased faces could be researched similarly, and factors influencing the comparison could be studied and integrated into the deceased face matching as is the case of facial expressions of living.

The deceased face matching could be focused on soft biometric traits (as moles or scars) or on the morphology of facial features.

Chapter 2.2.2. offered simple mole matching algorithm on age-different images of living, which could be applicable to age-different images of deceased.

Soft biometric traits, namely moles, seem stable over time and are highly individualizing. Decomposition process may influence the appearance of the moles, their size and shift in position, which leads to previously mentioned importance of research of time-after-death-limits in different environmental conditions.

Three-dimensional images offer multiple advantages over two dimensional. The technology is widely used in research of living faces. The research of the deceased is however characterized by different environmental conditions, in which the usage of all types of 3D scanners is not possible.

The comparison of three different scanning methods was presented in Chapter 3. Despite of unusual or worse environmental conditions, 3D scans of sufficient quality can be obtained and later used for the face matching of AM and PM faces.

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