Forensic Science International: Synergy 10 (2025) 100579

Contents lists available at ScienceDirect

Forensic Science International: Synergy

journal homepage: www.sciencedirect.com/journal/forensic-science-international-synergy

# A transdisciplinary integrated approach to improve identification outcomes for decomposed decedents in medicolegal death investigations

Victoria E. Gibbon [a,*], Laura J. Heathfield [b], Kathryn Smith [c,d], Judith C. Sealy [e], Lorna J. Martin [b]

[a] Division of Clinical Anatomy and Biological Anthropology, Department of Human Biology, Health Sciences Faculty, University of Cape Town, South Africa
[b] Division of Forensic Medicine and Toxicology, Department of Pathology, Faculty of Health Sciences, University of Cape Town, South Africa
[c] VIZ.Lab, Department of Visual Arts, Stellenbosch University, Stellenbosch, South Africa
[d] Face Lab, Liverpool John Moores University, Liverpool, United Kingdom
[e] Department of Archaeology, University of Cape Town, Cape Town, South Africa

ARTICLE INFO

*Keywords:*
South Africa
Western Cape Province
Forensic science
Forensic isotopes
Forensic genetics
Forensic anthropology
Forensic facial depiction
Forensic pathology

ABSTRACT

*Introduction:* Successful identification of unidentified decedents is a priority to address the global burden and health crisis created by such deaths. A newly developed transdisciplinary and integrative approach is presented as a protocol. The aim is to facilitate forensic leads for medico-legal death investigations that utilize external expertise to provide additional information as an act of re-humanization of the decedent.

*Methods and analysis:* There are three critical phases to the protocol. This transdisciplinary research approach in sensitive medicolegal environments requires, first, establishment of a robust ethical framework (implementation of permissions, contracts, and ethics) to maintain evidentiary integrity and protect those involved. It also needs to facilitate dissemination of the generated facial depictions to the public to enable investigative leads. Second, it requires the identification of useful and available scientific analyses and establishment of the multi-disciplinary team. These include a medicolegal death investigation and a forensic pathology postmortem record review inclusive of forensic contextual and case data information (such as unique identifiers and personal belongings), radiographic analyses, osteobiography anthropological assessment, conventional and specialized forensic genetic analyses, and possibly stable isotope analyses to provide a richer picture and understanding of the person. Third, these multifactorial data need to be integrated into a narrative, including facial reconstruction and depiction to elicit memory and identification via public appeals for information on unresolved cases. Should an investigative lead be followed, and a possible forensic identification established, conventional methods to confirm identity can be applied (e.g. DNA profiling). While it is the first time this approach has been applied in an African context, this protocol can be replicated and adapted for other regions to improve medicolegal death investigations, Ultimately, facilitating and improving identification can provide social justice and familial closure.

## 1. Introduction

The number of unidentified decedents globally is a public health crisis and carries unfavorable implications for dispensation of justice and familial closure [1]. The burden of unidentified decedents is greater in developing countries, with India and South Africa documenting some of the highest rates [2,3]. Internationally, increasing attention is being given to the crisis of the missing and unidentified resulting from irregular human migration [4–9].

Successful identification is a priority to aid social and criminal justice processes, such as the prosecution of wrongful death, finalizing of deceased estates, and restoring dignity and humanity to those who might otherwise have died in obscurity [1,10–12]. Naidoo [13] emphasizes identification in death as a human right. It also carries socio-cultural, religious, ethical and judicial importance, and may assist families to accept a death and find closure [14] and alleviate the psychosocial burden of suffering ambiguous loss [15].

Visual recognition by next-of-kin is a procedural requirement, but is

* Corresponding author. Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Anatomy Building, level 5, room 5.14, Anzio Rd, Observatory 7925 Cape Town, South Africa.

*E-mail addresses:* victoria.gibbon@uct.ac.za (V.E. Gibbon), laura.royle@uct.ac.za (L.J. Heathfield), kathryns@sun.ac.za (K. Smith), judith.sealy@uct.ac.za (J.C. Sealy), lornaj.martin@uct.ac.za (L.J. Martin).

https://doi.org/10.1016/j.fsisyn.2025.100579
Received 20 December 2024; Received in revised form 14 February 2025; Accepted 17 February 2025

not possible when the body is decomposed, skeletonized, or burnt. Its reliability has also come under scrutiny and the emotional impact on relatives has been highlighted [16–18]. Scientific methods of identification are inconsistently applied across the medicolegal death investigation (MLDI) system, and when they are used, it is often in isolation from other methods. Therefore, the aim of this protocol is to develop an integrated and innovative approach to human identification.

### 1.1. Integrated and innovative approach

We present our approach as a protocol to integrate innovative multifactorial and transdisciplinary methodologies alongside established techniques, drawing on external expertise to provide more identifying information as an act of re-humanization. The approaches include MLDI forensic pathology postmortem record review inclusive of forensic contextual and case data information (such as unique identifiers and personal belongings), radiographic analyses, osteobiography anthropological assessment, conventional and advanced DNA analyses, and stable isotope analyses to provide a richer picture and understanding of the person. Facial reconstruction and depiction are the medium of integration of these multifactorial methods to elicit memory and identification via public appeals for information on unresolved cases, with associated descriptive narrative. Establishing a robust ethical framework for this transdisciplinary research approach in sensitive medicolegal environments is deemed important to maintain evidentiary integrity and to protect individuals involved, all while facilitating dissemination of the generated facial depictions to the public to enable investigative leads. Should an investigative lead be followed, and a possible identification established, then conventional methods to confirm identity can be applied (e.g. DNA profiling).

This approach has grown out of mutual recognition of complementary skills, and a shared commitment to advancing science through a community-focused, participatory approach informed by forensic humanitarian values, a science with the potential and commitment to expand this approach into forensic service [19–23]. We have drawn from the use of similar integrated analyses in historical/archaeological contexts [24] but to date, this holistic approach has not been applied in the MLDI context.

Our approach is further informed by international case studies in similarly complex forensic identification contexts wherein new approaches are also advancing science, such as in the Mexico/US border zones, deaths at sea in the Mediterranean region, and cold case reviews [25–30]. These examples have used a combination of forensic genealogy, stable isotopes, osteobiography and revised facial depictions and online community networks to publicize cases, which conventional law enforcement protocols view as somewhat controversial. Some of our analyses have been applied (standalone) to casework previously, but never before in an African forensic context have these data been integrated to inform the resulting facial depiction and used to create an accompanying ‘story’ about the decedent, as a form of science communication to assist police in their public appeals.

We hope this approach will improve policy and procedure around forensic identification and could be particularly valuable in cases of the missing and unidentified [29,31]. Unidentified decedents tend to be from the most vulnerable and marginalized communities in society [32–35]. Therefore, implementation of this protocol may address some social injustices in criminal justice systems.

Partnerships between service entities and expertise at tertiary education institutions supports the burden of cost and time associated with forensic identification otherwise carried by state or government entities, and further builds capacity through knowledge-sharing and real-life training opportunities for students working to enter forensic practice [36].

To engage and enable this research approach requires three major considerations: 1) a robust ethical and permission framework; 2) identification and establishment of a transdisciplinary research team; 3) data integration and results dissemination (Fig. 1).

### 1.2. South African forensic background

In South Africa, unidentified decedents who have died due to unnatural causes outnumber those who die of natural causes [37,38]. They are investigated in the MLDI system, which is the system that exists in South Africa for the investigation of unnatural death [39]. The mandate for identifying individuals in the South African MLDI system lies with the South African Police Service (SAPS), as directed by the judiciary, assisted by the Forensic Pathology Service (FPS) of the relevant provincial health department. However, despite scientific attempts at identification, communication and feedback from local police to key role-players is poor [11,38].

Of South Africa’s nine provinces, Gauteng and the Western Cape have among the highest burden of cases, and only the Western Cape currently has a digitized records system. There is a critical shortage of qualified forensic pathologists in South Africa to conduct MLDIs into the 70 000 unnatural deaths per annum [14]. About 10 % of cases at the forensic pathology laboratories in South Africa are unidentified [3,38, 40–42]. Briefly, the high rates of unidentified cases are due to complex interconnections of socio-economic and socio-political factors in South Africa as a whole and within the Department of Health and social justice system [3,11–14,40–44]. Significant obstacles exist in the existing partnerships, protocols and access to expertise that may improve service delivery for forensic identification.

The Western Cape Cold Case Consortium (W4C) is a transdisciplinary team of expert research-practitioners based in academic institutions in Western Cape, South Africa who collaborate with the forensic pathologists in the Western Cape Government Department of Health and Wellness, FPS, on the application of scientific and visual analytic techniques in MLDI of the unidentified deceased at Salt River Mortuary (now Observatory Forensic Pathology Institute).

## 2. Protocol

### 2.1. Ethical framework

Through the development of this protocol the ethical approach required assessment of the risks and benefits for the research, consideration for the decedents, researchers, institutions (pathology, police, tertiary institute), evidentiary standards for active police investigations, including information pertaining to the case (case details) inclusive of generated data and how these will be managed and disseminated to foster identification. Therefore, a robust ethical procedure, inclusive of legal agreements and permissions is required.

It is acknowledged that deceased individuals cannot provide consent for these forensic analyses. Their families cannot consent since the deceased (and their families) are unknown. Therefore, participation is not autonomous. Identification of the deceased, the primary aim of this research approach, outweighs the absence of consent. We believe that people would prefer to be identified and reunited with family than be buried as an unknown decedent with other unknown bodies in communal graves. A risk assessment estimates minimal risk and no physical harm, and it is deemed that this project is ethically justified as the benefits of potential identification outweigh the risks for the individual and living relatives/families.

Notwithstanding the ethical considerations in MLDI, in the South African context there are several laws that provide for the scientific process of identification to be pursued by the state-mandated MLDI teams, and which do not require family member consent.

Criminal investigations and the requirement to uphold evidentiary standards in MLDI do, however, bring additional risks to the decedent, pathologists, researchers, the investigation and ultimately the dispensation of justice. Not all MLDI are homicide or criminal, but the standard of practice for the protocol needs to meet the highest level of evidentiary

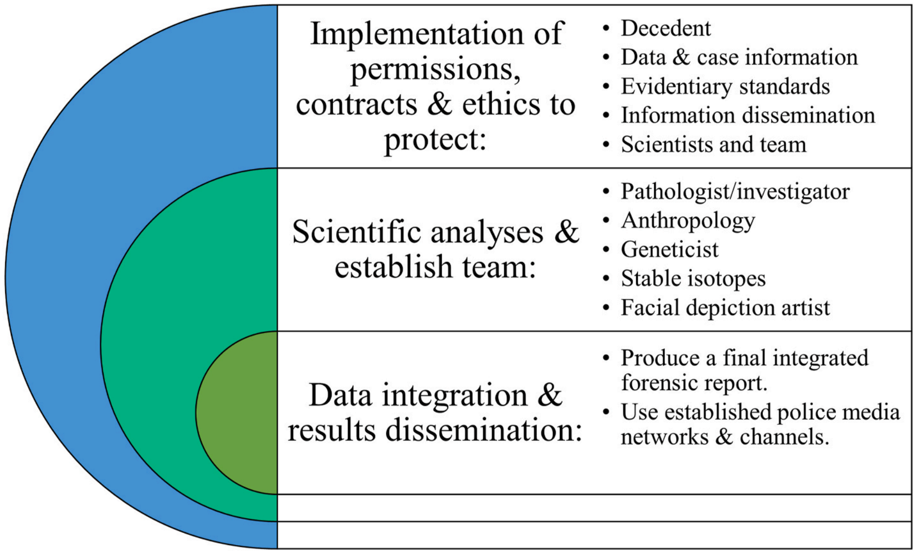


**Fig. 1.** An overview schematic of the protocol illustrating that the entire process exists within an ethical framework.

procedure to ensure it is robust for all potential cases. In some circumstances, being involved in the investigation and generating data to facilitate justice can put these persons at risk, and maintaining the anonymity of academic researchers is therefore important. All researchers also bring risk to the investigation as there is sharing and access to investigative and case information. Therefore, to protect all individuals involved and maintain evidentiary standards the following are suggested.

- To prevent information sharing beyond the investigative team, non-disclosure agreements should be implemented between the researchers and the relevant service entities leading the MLDI.
- To formalize processes of data protection, management and sharing, a memorandum of understanding and/or research collaboration agreement as well as a materials transfer agreement between the researchers and/or institutions involved should be signed and implemented.
- Detailed procedures for data management, sharing and dissemination are required. One of the concerns with a transdisciplinary integrative approach is that the data generated and outcomes from different disciplines are informed, and in some cases are reliant, on data generated by other team members. To this end, the team will need to create a data management plan, which includes a statement of the type of data and whether it is original or existing, data sharing, data storage and long-term curation. In brief, the cases should be coded using a unique identification number (*i.e.* alphanumeric coding system rather than actual case numbers). Raw data generated by each researcher should be retained by that researcher on their password-protected laptop and backed up regularly to a secure online drive. These data should also be shared for curation and long-term storage with the principal investigator, pathologist, and police investigator as per the relevant local legislation procedure. Data sharing among investigators should be done according to a memorandum of agreement and certain forensic data will need to be integrated to inform the forensic facial depiction. Access to data will be restricted to the listed investigators using a password protected cloud storage system. Public awareness and dissemination of the results to the public to facilitate identification is discussed later.

### 2.2. *Transdisciplinary analyses*

The transdisciplinary approach presented in Fig. 2 includes the MLDI forensic pathology postmortem record review inclusive of forensic contextual and case data information (such as unique identifiers and personal belongings), radiographic analyses, osteobiography anthropological assessment, conventional and advanced DNA analyses and stable isotope analyses. These data are compiled into an integrated final report and used for the creation of a facial reconstruction and final depiction.

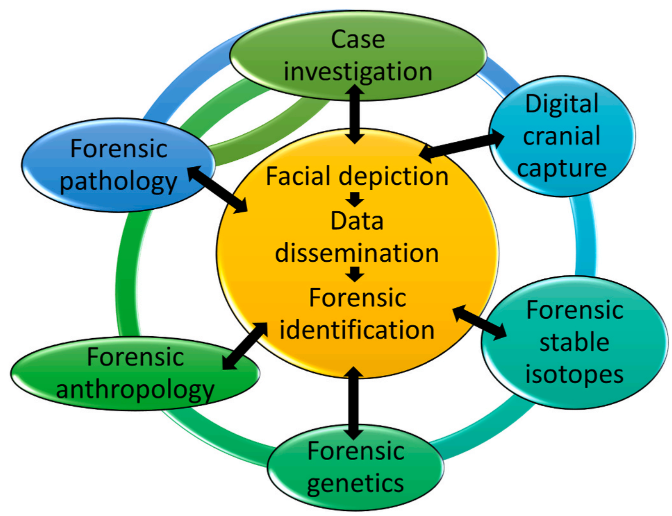


**Fig. 2.** The transdisciplinary approach presented including the MLDI forensic pathology postmortem record review inclusive of forensic contextual and case data information (such as unique identifiers and personal belongings), radiographic analyses, osteobiography anthropological assessment, conventional and advanced DNA analyses and stable isotope analyses. These data are compiled into an integrated final report and used for the creation of a facial reconstruction and final depiction.

#### 2.2.1. *MLDI – forensic pathology*

Postmortem examination of MLDI cases in South Africa follows a standardized and structured format, which is based on international best practices, and is legislated for various Acts and Regulations [45]. The mandate for identification of decedents lies with the SAPS, who are closely assisted by the FPS as all the processes undertaken for identification of decedents occur in the FPS medicolegal mortuaries facilitated and implemented by mortuary staff. Most of the FPS in South Africa do not have the capability to perform all the ancillary investigations that some cases will require. These are thus contracted out to various other agencies, including those in the W4C project. The forensic pathologist and the FPS are the agency who confirm identity for SAPS, and thus, at whose discretion any other services are used.

Location of body discovery, circumstances at death and autopsy reports are reviewed. The post-mortem records are consulted for any additional identification information such as clinical history and secondary identifiers. Photographs of the individual at the scene of discovery as well as at autopsy will be consulted. Secondary identifiers can be found from hair texture/color, tattoos, scars, piercings, antemortem trauma and pathologies, as identified in the postmortem report. Also, information from personal belongings such as hair extensions, clothing, spectacles, and jewelry can assist with identification.

*2.2.2. Radiographic analyses*

To diagnose ante- and peri-mortem trauma, pathology, and signs of physiological stress radiographic analyses in the form of Lodox® and CT can be valuable. Additionally, the CT can be used to create a digital 3D cranial model for the creation of digital facial reconstructions.

*2.2.2.1. Lodox statscan X-ray scanning.* Low dose X-ray scanning should be carried out to identify pathology, trauma and physiological stress markers that can be useful in reconstructing identity. All data collection on the Lodox system will be carried out with a person who is trained to use the device [46]. Two sets of images of each individual will be acquired; one set imaged with a calibration tool, the other without the calibration tool. The individuals should be imaged in the anteroposterior and lateral views, stored in the DICOM format allowing for easy digital transfer.

*2.2.2.2. Quantitative Computed Tomography scanning.* Computed tomography (CT) uses high energy X-ray beams to provide a means to image a body in three dimensions (3D). The CT imaging of the remains will be done using a Computed Tomography Scanner. Data collection on the CT will be carried out by a trained radiologist with the 'bone window' setting (60 kW, 140 kVp, 30 mA) to maximize radiation dose at a slice thickness of 2.0 mm, increment of 1.0 mm, and between-slice spacing of 0.10 mm. High resolution CT images will be acquired. Store these images in DICOM format to allow for easy digital transfer and secure storage.

Image post-processing entails segmentation that is required to create 3D mesh models directly from the CT data, following standard protocols. Segmented images should be exported as standard tessellation language (.stl) files for manual landmarking and processing. Landmarked 3D images can be exported for interactive fitting by non-rigid registration as Java-script object notation (.json) for dense correspondence.

*2.2.3. Osteobiography*

Osteobiography is achieved through examination of skeletonized remains to reconstruct an individual and their life history, and is arguably the foundation of human identification, and in some cases, rehumanization of a person [47,48]. The skeletal elements of the decedent should be assessed to estimate a 'biological profile' incorporating sex, age-at-death, population affinity and living height. Also, the assessment should include information on how they lived and died (e.g. activity markers, evidence of disease, pathology and trauma). Not all members of society have an equal chance of living with poor health or dying prematurely or violently; some are structurally vulnerable. Structural vulnerability is a concept referring to experiences of people who experience social marginalization (e.g. class, gender, race), and thus, suffer because of structures like discrimination, oppression, and socio-economic status. These people carry increased vulnerability and have disproportionately poor health, which may be evident in the medico-legal death context [32,49–52]. Thus, the osteobiography must go beyond demographics to include biomarkers of inequity and be applied within a structural vulnerability framework. This is when data on skeletally/dentally embodied experiences of inequity are contextualised with information from the scene, personal belongings, and circumstances of death to understand patterns of ill health and mortality as resulting from social/structural causes [49–52].

Osteobiographic data are obtained using non-invasive, non-destructive morphometric assessment methods, well established in the field of biological anthropology, to estimate sex, age, population affinity and living height [53–69]. Where available and relevant additional population specific methodology may be utilized, considering the need for Daubert's standard for inclusion wherein all methods must be peer reviewed and generally accepted [70]. Palaeopathology is utilized as a tool to investigate how people interacted with others and their environment, and how they adapted to it [71]. This feature of bone is what allows biological anthropologists to make paleopathological conclusions about the livelihood of a past person, as bone is indicative of the environmental stress, labor load and fitness of an individual. Any abnormalities should be identified, researched and studied [72–77].

The remains of each person (all available elements) should be visually assessed using non-invasive, non-destructive morphometric assessment methods, which are well established in the field of biological anthropology. A preservation assessment (weathering, fragmentation and taphonomy) should be recorded. To improve visual inspection, a magnifying lamp (3 diopter with 1.75× magnification) and measurements may be required using specialized osteometric equipment, *i.e.* Vernier calipers and osteometric boards. To document and record findings, photographs should be obtained and where relevant, data recorded in relevant repositories and registries.

*2.2.4. Conventional and advanced DNA analyses*

DNA will be extracted from biological samples from each individual using standard operating procedures that are based on published research and international best practice [78–80]. The sample used for DNA extraction will vary depending on availability of skeletal elements, but will aim for nail clippings, metacarpals, metatarsals, phalanges and teeth [80]. If these are not available, then rib endings, vertebrae, petrous bone or other samples will be targeted as per guidelines from the International Commission of Missing Persons [80,81].

DNA will be analysed using the ForenSeq DNA Signature Prep kit on the MiSeq FGx system, which has been internally validated at the University of Cape Town. However, alternative next generation sequencing based kits that have capacity to generate estimate phenotype data and are validated for forensic human identification applications could also be used. Using the resultant data, the biological sex of the donor can be determined, and an estimation made regarding hair color, eye color and biogeographical ancestry. Phenotype predictions based on these DNA variants are well established and have been validated across multiple studies [82,83]. Additionally, an objective melanin index may be determined based on candidate variants relevant to the local population (e.g. rs1426654 and rs16891982 in admixed populations)[84.] This phenotype information should inform the facial depiction process, which allows for reliable color to be introduced to the image (as opposed to producing a greyscale image).

*2.2.5. Stable isotope analyses*

Measurements of isotope ratios in body tissues can yield information on an individual's diet and geographical origins. There are naturally occurring variations in $^{2}H/^{1}H$, $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O/^{16}O$, $^{34}S/^{32}S$ and $^{87}Sr/^{86}Sr$ in different parts of the biosphere. These are reflected in consumer tissues, which are synthesized from ingested food and water. Such approaches are widely used in ecology and archaeology, amongst other disciplines, to assess resource use, migration and mobility. These isotope pairs can readily be measured in forensic contexts, even if only skeletonized remains are available [84]. Furthermore, multiple analyses of sequentially forming tissue (e.g. teeth, hair) can yield time series information that records changes in diet or place of residence during the period of tissue formation.

Isotope ratios of the light elements (H, C, N, O, S) are shaped by their respective biogeochemical cycles. Slightly more energy is required to make and break chemical bonds involving the heavier compared with the lighter isotope, leading to progressive shifts in the proportions of the two. $^{2}H/^{1}H$ and $^{18}O/^{16}O$ in humans depend mainly on drinking water, with some contribution from food and inspired oxygen. Global patterning in $^{2}H/^{1}H$ and $^{18}O/^{16}O$ in precipitation and groundwater are relatively well-understood and predictable (waterisotopes.org [85]), so these ratios are powerful tools for tracing long-distance movement.[87,88] $^{13}C/^{12}C$, $^{15}N/^{14}N$ and $^{34}S/^{32}S$ in consumers depend on the types of food consumed, with (for example) strong differences between maize-based and wheat- or rice-based diets, since maize photosynthesises using the $C_4$ pathway whereas wheat and rice use the $C_3$ pathway. In most environments, $^{87}Sr/^{86}Sr$ depends on the local geology, with ancient rocks and those with high levels of $^{87}Rb$ (which decays to $^{87}Sr$) leading to elevated $^{87}Sr/^{86}Sr$. For all these isotope pairs, ratios in the food are passed on to consumer tissues, with slight additional shifts ("fractionation") due to metabolic processes [86].

Stable isotope analyses of forensic tissue samples can provide information as to whether the individual is local or non-local. It is not possible to use this approach to determine precise origins, but it is possible to rule out areas that people did not come from, and in many cases to assess likely region/s of origin and some features of their diets. Values in teeth reflect early life [87], while those in bone provide longer-term averages, due to bone resorption and remodeling in life. Substantial within-individual differences are likely to signal movement across climatic or environmental boundaries [88]. Choice of tissue for analysis will depend on the questions to be answered, and on the skeletal element/s and other tissues available [89]. Laboratory protocols are now well-established [84–88,90–93].

#### 2.2.6. Data integration - facial depiction and reconstruction

Wilkinson [16,17] and Smith and Wilkinson [94] describe current international best-practice in depicting the deceased for forensic identification, including craniofacial analysis standards [95]. Sensitivity to the socio-cultural context where the depiction will circulate is imperative [16,96]. Post-mortem depiction refers to the process of creating a plausible representation of a living person using a post-mortem photograph as primary reference, instead of the cranium. Craniofacial analysis and reconstruction refer to the detailed analysis of a human cranium to produce the most plausible in-life appearance of an individual. Both are recognized methods of assisting with forensic identification of unidentified persons, to elicit familiar-face recall via public appeals for information on unresolved cases, and which also serves to rehumanize anonymous victims [17,97–100].

*2.2.6.1. Postmortem depiction.* Post-mortem depiction (also referred to as 'image sanitization' or 'clarification') refers to the production of an acceptable image of a deceased individual's most likely living appearance using a postmortem facial photograph as a reference for a drawing (sketch), or ideally, via digital image editing in a suitable graphic software program such as Adobe Photoshop [17,99,101].

If a suitable post-mortem photograph of the individual exists, this is a significantly more efficient and reliable method of generating a facial image for public circulation, as facial photography preserves superficial facial information that cannot be inferred from the skull alone. 'Suitable' means sufficient soft tissue remains to reasonably suggest living appearance, and that the photograph has been taken under appropriate conditions (even lighting, no lens or perspectival distortion, in focus). Corruption of the facial appearance due to trauma, decomposition, burning must be within certain limits, which the facial imaging practitioner must determine, for this method to be considered. With all supporting data, an experienced practitioner can complete a post-mortem depiction within 1–2 days on average [96].

*2.2.6.2. Craniofacial analyses and reconstruction.* An entirely digital and non-destructive workflow is possible and can be followed, by importing stereolithography (.stl) or object (.obj) files into Geomagic Freeform Plus (v.2019.1.69) with Phantom Touch X haptic device, processed from either CT data or 3D surface scan with the cranium and mandible scanned separately.

The virtual cranium and mandible need to be rearticulated to replicate occlusion with a relaxed jaw (upper and lower teeth slightly parted), then positioned in the Frankfurt horizontal plane prior to commencing with feature assessment and reconstruction. Following the Manchester method updated for virtual sculpture [102], virtual clay facial muscles from a pre-existing custom-built database can be placed and deformed according to individual cranial features. Facial features and fat should then be modelled using evaluated methods and finally a skin layer added, reflecting the estimated age and likely body mass of each individual, as well as adjusted to indicate any antemortem facial trauma, such as healed scars. Skin opacity is adjusted throughout the process to evaluate the accuracy and consistency of feature prediction methods.

Once the craniofacial shape reconstruction is complete, screenshots of the 3D model should be captured in various views and saved for visual reference and reporting purposes. The frontal view then imported into Adobe Photoshop CC, where appropriate facial textures and other relevant details (e.g. clothing, jewellery, hairstyles, tattoos, scars) can be added from a photographic database and edited accordingly using various techniques including digital drawing, layers, and layer masks. The result is a 2.5D depiction. A single reconstruction will take approximately two weeks.

Precise information about body mass, hair length or style, distinguishing marks, skin texture and color information are not available from the cranium; these details can also change during a person's life. In facial reconstruction, this information is interpreted using the best available associated information and is particularly relevant in the final presentation of facial appearance. For this reason, the forensic imaging specialist must receive a complete set of reports and visual documentation from both the scene and medicolegal examination, rather than having to request data piecemeal. This will enhance the richness of detail in depicting facial appearance, any relevant or unique personal effects, or characteristic marks, scars or tattoos, as well as the narrative accompanying the depiction.

## 3. Outcomes and dissemination of results

Within the context of a multifactorial methods approach, forensic facial depiction should be understood as performing an important function of science communication for social justice. It is a critical medium of integration for the data generated from the preceding scientific analyses (osteobiographical, DNA, post-mortem, and radiological findings), as well as any contextual information from the scene of recovery. The resulting visual depiction is crucial to an impactful public appeals campaign, which is, after all, the only reason for commissioning a facial depiction in a forensic context.

Presentation of the results should take place at a meeting of all stakeholders, including the research team members, the forensic pathologists and the investigating officers (police) who were assigned to each case, and managerial representatives from the relevant MLDI service providers. The research team should present and explain the research findings and the limitations thereof. The investigating officers will be able to disclose any considerations regarding the distribution of the facial depictions, e.g. areas last seen alive, possibility of compromising an ongoing investigation. If it is deemed that the distribution of the research outputs (i.e. facial depiction, corresponding biological data and case information) would be of benefit to the investigation, then it will be disseminated on public platforms by the mandated statutory bodies for identifying decedents in MLDI.

This will ensure maximum public engagement and that any resulting leads are properly directed. In addition to the facial image, the forensic imaging practitioner should supply clear instructions to the relevant authority on how images should be used in the media, including any restrictions regarding adjusting images. Any manipulation or adjustment to the facial images as supplied by investigative officials or the media, without consulting the imaging practitioner, is akin to tampering with analysis, as the images represent a visual expert statement, and is serious. As such, close communication between the investigating authority and the forensic artist, especially if the artist is external to the responsible authority, must be established prior to the images being circulated, and the artist should supply the image, including any accompanying information (date, location, logos), precisely as it will be circulated.

The entity leading the MLDI should be responsible for engaging with the public, who may recognize the faces using their existing infrastructure and processes. Should the forensic authorities obtain an investigative lead, then identification can be confirmed using standard methods such as routine kinship DNA testing or provision of antemortem data that matches the unidentified person.

### 3.1. Protocol summary

This approach is considered a final opportunity to generate investigative leads for unknown deceased persons where traditional primary (scientific) methods of identification have either failed or were unavailable. It can enable improved methodology and innovation to address an overall need and humanitarian crisis of unidentified persons in the medicolegal context. This approach is a commitment to a pracademic exchange [103] between public sector service providers, researchers, educators, industry and citizen allies. Fostering more open lines of communication between diverse stakeholders (*i.e.* pracademic exchange) including the families of the missing and unidentified deceased, and greater public awareness and access to information for those affected by such cases.

Application of this protocol in different parts of the world may require some adaptations and amendments in accordance with legal or legislative requirements and jurisdictions or individual case requirements. However, the template fosters and enables a transdisciplinary research approach using academic based researchers to improve forensic identification for decomposed MLDIs.

These improvements may include the standardized capturing of basic data on admission into mortuaries, standardized and integrated scientific analyses, improved lines of communication established between various stakeholders, and the development of new collaborations. To avoid untapped potential for the use of forensic sciences in MLDIs, to ensure consistent implementation and improvement of case outcomes in parallel legislation and policies for using the various forensic science disciplines should be reviewed/developed. Facilitating an increase in the identification rate for the victims of unnatural death not only ensures the preservation of these peoples' dignity and memory, but it stands to promote case resolution, especially in criminal matters.

## CRediT authorship contribution statement

**Victoria E. Gibbon:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Laura J. Heathfield:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kathryn Smith:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Judith C. Sealy:** Writing – review & editing, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Lorna J. Martin:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

## Disclaimers

None.

## Approvals

This study has received ethical approval from the Faculty of Health Science Human Research Ethics Committee at the University of Cape Town (HREC# 692/2021) and Stellenbosch University (HREC# N22/02/022_RECIP_UCT 692/2021).

## Patient and publc involvement statement

Our protocol was developed with communication with public involvement through government agencies.

## Funding statement

This work was supported by the Cape Higher Education Consortium and City of Cape Town 2021 Annual Research Programme; VG acknowledges the South African National Research Foundation (Grant No. 115357) and JS South African Research Chairs Initiative (Grant No. 84407). Opinions expressed and conclusions arrived at are those of the authors and not necessarily to be attributed to the NRF.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

We thank Prof. Caroline Wilkinson for sharing the Face Lab Craniofacial Muscle Database with VIZ.Lab to support the creation of facial depictions for this pilot. We acknowledge and thank the contribution that unidentified deceased make to improving identification. We thank the personnel and staff of the Western Cape Forensic Pathology Service and South African Police Services for their dedication and service to medico-legal death investigations. We thank T Mutsvangwa and all those who shaped this project directly and indirectly.

## References

[1] H. Suwalowska, J. Ali, J. Rangel de Almeida, et al., "The Nobodies": unidentified dead bodies—a global health crisis requiring urgent attention, Lancet Global Health 11 (11) (2023) e1691–e1693, https://doi.org/10.1016/S2214-109X(23)00420-5.

[2] C.A. Keyes, T.J. Mahon, A. Gilbert, Human decedent identification unit: identifying the deceased at a South African medico-legal mortuary, Int. J. Leg. Med. 136 (6) (2022) 1889–1896, https://doi.org/10.1007/s00414-022-02893-z.

[3] K.M. Reid, L.J. Martin, L.J. Heathfield, Understanding the burden of unidentified bodies: a systematic review, Int. J. Leg. Med. 137 (4) (2023) 1193–1202, https://doi.org/10.1007/s00414-023-02968-5.

[4] E. Nuzzolese, Missing people, migrants, identification and human rights, J Forensic OdontoStomatol 30 (1) (2012) 47–59.

[5] E.H. Kimmerle, Practicing forensic anthropology: a human rights approach to the global problem of missing and unidentified persons, Ann Anthropol Pract 38 (1) (2014) 1–6. https://anthrosource.onlinelibrary.wiley.com/doi/pdf/10.1111/napa.12038.

[6] I. Kovras, S. Robins, Death as the border: managing missing migrants and unidentified bodies at the EU's Mediterranean frontier, Polit. Geogr. 55 (2016) 40–49.

[7] F. Laczko, A. Singleton, J. Black, Fatal journeys volume 3 part 1: improving data on missing migrants [online], Int Org Migr 3 (2017) 317, https://publications.

iom.int/books/fatal-journeys-volume-3-part-1-improving-data-missing-migrants (September 30, 2024).
[8] L. Olivieri, D. Mazzarelli, B. Bertoglio, et al., Challenges in the identification of dead migrants in the Mediterranean: the case study of the Lampedusa shipwreck of October 3rd 2013, Forensic Sci. Int. 285 (2018) 121–128, https://doi.org/10.1016/j.forsciint.2018.01.029.
[9] S. Chandler, S.M. Sudi, K.C. Bailie, M. Chetty, The challenge of unidentified decedents in Africa: the need for training and research in forensic odontology to strengthen a multidisciplinary approach, Front Oral Health 3 (2022) 1017736, https://doi.org/10.3389/froh.2022.1017736.
[10] B. Krysztofiak, DNA Profiling of Uunidentified Human Remains in the South African Context: an Ethico-Legal Analysis, University of the Witwatersrand, Johannesburg (SA), 2016 [Masters thesis].
[11] A. Baliso, C. Finaughty, V.E. Gibbon, Identification of the deceased: use of forensic anthropology at Cape Town's busiest medico-legal laboratory, Forensic Sci Int Reports (2019) 100042, https://doi.org/10.1016/j.fsir.2019.100042.
[12] A. Baliso, V.E. Gibbon, L. Heathfield, Forensic human identification: retrospective investigation of anthropological assessments in the Western Cape, South Africa, Int. J. Leg. Med. (2022), https://doi.org/10.1007/s00414-022-02870-6.
[13] P. Naidoo, The Nature and Scope of the Problem of Identifying Unidentified Bodies at Medico-Legal Mortuaries in South Africa: A Medico-Legal Perspective [Masters Thesis], University of KwaZulu Natal, Durban (SA), 2007.
[14] V.E. Gibbon, C. Finaughty, I. Moller, D.A. Finaughty, Pressing need for national governmental recognition of forensic anthropology in South Africa as illustrated in a medico-legal case, Sci. Justice (2022) 411–417, https://doi.org/10.1016/j.scijus.2022.05.003.
[15] P. Boss, Families of the missing: psychosocial effects and therapeutic approaches, Int. Rev. Red Cross 99 (905) (2017) 519–534, https://doi.org/10.1017/S1816383118000140.
[16] C. Wilkinson, A review of the changing culture and social context relating to forensic facial depiction of the dead, Forensic Sci. Int. 245 (2014) 95–100, https://doi.org/10.1016/j.forsciint.2014.10.007.
[17] C. Wilkinson, A review of forensic art, Res. Rep. Forensic Med. Sci. (2015), https://doi.org/10.2147/RRFMS.S60767.
[18] K. Wright, A. Mundorff, J. Chaseling, et al., A new disaster victim identification management strategy targeting 'near identification-threshold' cases: experiences from the Boxing Day Tsunami, Forensic Sci. Int. 250 (2015) 91–97.
[19] M. Tidball-Binz, Using forensic science to care for the dead and search for the missing, Forensic Sci Humanit Action (2020) 1–23, https://doi.org/10.1002/9781119482062.ch1.
[20] S. Cordner, M. Tidball-Binz, Humanitarian forensic action — its origins and future, Forensic Sci. Int. 279 (2017) 65–71, https://doi.org/10.1016/j.forsciint.2017.08.011.
[21] A. M'charek, S. Casartelli, Identifying dead migrants: forensic care work and relational citizenship, Citiz. Stud. 23 (7) (2019) 738–757.
[22] C. Moon, Human rights, human remains: forensic humanitarianism and the human rights of the dead, Int. Soc. Sci. J. 65 (2016) 215–216, 49–63.
[23] I. Ketsekioulafis, K. Katsos, C. Kolentinis, D. Kouzos, K. Moraitis, C. Spiliopoulou, E.I. Sakelliadis, Humanitarian forensic medicine: a systematic review, Int. J. Leg. Med. (2024 Dec 2) 1–5, https://doi.org/10.1007/s00414-024-03381-2.
[24] V.E. Gibbon, L. Feris, J. Gretzinger, et al., Confronting historical legacies of biological anthropology in South Africa - restitution, redress and community-centered science: the Sutherland Nine, PLoS One 18 (5) (2023) e0284785, https://doi.org/10.1371/journal.pone.0284785.
[25] C. Cattaneo, M. Tidball-Binz, L. Penados, et al., The forgotten tragedy of unidentified dead in the Mediterranean, Forensic Sci. Int. 250 (2015) e1–e2, https://doi.org/10.1016/j.forsciint.2015.02.007.
[26] J. De Leon, The land of open graves: living and dying on the migrant trail. California Series in Public Anthropology, University of California Press, Oakland, 2015.
[27] T. Last, M. Giorgia, O. Ulusoy, et al., Deaths at the borders database: evidence of deceased migrants' bodies found along the southern external borders of the European Union, J. Ethnic Migrat. Stud. 43 (5) (2017) 693–712, https://doi.org/10.1080/1369183X.2016.1276825.
[28] K. Spradley, T.P. Gocha, Migrant deaths along the Texas/Mexico border, Forensic Sci Humanit Action (2020) 535–548, https://doi.org/10.1002/9781119482062.ch34.
[29] B. Chapman, D. Keatley, K. Bettels, et al., Joining forces: combining police and external expertise for cold case reviews, Forensic Sci. Int. 6 (2024) 112098, https://doi.org/10.1016/j.forsciint.2024.112098. June.
[30] A. Dahal, D. McNevin, M. Chikhani, J. Ward, An interdisciplinary forensic approach for human remains identification and missing persons investigations, WIRES Forensic Sci 5 (4) (2023 Jul) e1484, https://doi.org/10.1002/wfs2.1484.
[31] S.J. Morewitz, C.S. Colls (Eds.), Handbook of Missing Persons, Springer International Publishing, Cham, 2016, https://doi.org/10.1007/978-3-319-40199-7.
[32] P. Farmer, An anthropology of structural violence, Curr. Anthropol. 45 (3) (2004 Jun) 305–325. https://www.jstor.org/stable/10.1086/382250.
[33] G. Goad, Expanding humanitarian forensic action: an approach to US cold cases, Forensic Anthropol 3 (1) (2020) 50. https://doi/10.5744/fa.2020.1006.
[34] C.E. Bird, J.D. Bird, Devaluing the Dead. The Marginalized in Death: A Forensic Anthropology of Intersectional Identity in the Modern Era, Rowman & Littlefield, 2022 Aug 31, p. 93.
[35] A.P. Winburn, A.L. Jennings, D.W. Steadman, E.A. DiGangi, Ancestral diversity in skeletal collections: perspectives on African American body donation, Forensic Anthropol (2020) 1–2, https://doi.org/10.5744/fa.2020.1023.
[36] A. Cappella, D. Mazzarelli, L. Olivieri, et al., The relevant role of university in the identification of dead migrants: a comparative study on the experience of University of Milan and Texas State University, La Revue de Médecine Légale 8 (4) (2017) 183, https://doi.org/10.1016/j.medleg.2017.10.010.
[37] K. Geldenhuys, Dying anonymously Dealing with unidentified bodies, Servamus Community-based Saf Secur Mag 114 (9) (2021) 26–28, https://doi.org/10.10520/ejc-servamus_v114_n9_a8.
[38] L. Evert, Unidentified Bodies in Forensic Pathology Practice in South Africa: Demographic and Medico-Legal Perspectives [Masters Thesis]. Tshwane (SA), University of Pretoria, 2011.
[39] South African National Health Act 61 of 2003 (SA-NHA), updated in 2013 https://www.gov.za/documents/national-health-act (accessed September 5, 2024).
[40] D.M. Brits, M. Steyn, C. Hansmeyer, Identifying the unknown and the undocumented, Forensic Sci Humanit Action (2020) 681–692, https://doi.org/10.1002/9781119482062.ch44.
[41] M. Steyn, E.N. L'Abbé, J. Myburgh, Forensic anthropology as practiced in South Africa, in: S. Blau, D.H. Ubelaker (Eds.), Handbook of Forensic Anthropology and Archaeology, Routledge, London, UK, 2016, pp. 151–164, https://doi.org/10.4324/9781315528939.ch12.
[42] S. Wild, Three-part journalistic series on South African mortuaries. https://mg.co.za/article/2017-01-12-00-long-quest-to-understand-these-bodies-without-identities/, 2017. (Accessed 5 September 2024). https://www.euroscientist.com/identifying-south-africas-forgotten-dead/. https://www.pressreader.com/south-africa/mail-guardian/20170127/282570197827807. https://www.theopennotebook.com/2018/03/20/storygram-sarah-wilds-bones-specialists-try-to-prise-secrets-from-the-veld-bodies/.
[43] C.A. Keyes, T.J. Mahon, A. Gilbert, Human decedent identification unit: identifying the deceased at a South African medico-legal mortuary, Int. J. Leg. Med. 136 (6) (2022) 1889–1896.
[44] K.M. Reid, L.J. Martin, L.J. Heathfield, Bodies without names: a retrospective review of unidentified decedents at Salt River Mortuary, cape Town, South Africa, 2010-2017, S. Afr. Med. J. 110 (3) (2020) 223–228, https://doi.org/10.7196/SAMJ.2020.v110i3.14192.
[45] E.S. Dinkele, G. Kirk, L.J. Martin, Medico-legal death investigation systems- South Africa. Sri Lanka J forensic med, SciTech Lawyer 13 (2022) 50–52, https://doi.org/10.4038/sljfmsl.v13i0.7922.
[46] C. Bateman, New Local scanners transform forensic pathology, S. Afr. Med. J. 98 (2008) 75–82. https://www.scielo.org.za/scielo.php?pid=S0256-95742008000200007&script=sci_arttext.
[47] S.C. Agarwal, B.A. Glencross, Building a social bioarchaeology, in: S.C. Agarwal, B.A. Glencross (Eds.), Social Bioarchaeology, Wiley-Blackwell, Hoboken, 2011, pp. 1–12.
[48] L. Hosek, J. Robb, Osteobiography: a platform for bioarchaeological research, Bioarchaeol Int 3 (2019) 1–22, https://doi.org/10.5744/bi.2019.1005.
[49] J.J. Kim, A.P. Winburn, M.K. Moore, H. Scott, Adapting forensic case reporting to account for marginalization and vulnerability, Forensic Sci Int Synerg 7 (2023 Jan 1) 100436, https://doi.org/10.1016/j.fsisyn.2023.100436.
[50] J.J. Kim, H. Friedlander, If you see something, say something: structural vulnerability data and reporting in forensic anthropology casework, Forensic Sci Int Synerg 6 (2023 Jan 1) 100328, https://doi.org/10.1016/j.fsisyn.2023.100328.
[51] A.P. Winburn, K.A. Wolf, M.G. Marten, Operationalizing a Structural Vulnerability Profile for forensic anthropology: skeletal and dental biomarkers of embodied inequity, Forensic Sci Int Synerg 5 (2022 Jan 1) 100289, https://doi.org/10.1016/j.fsisyn.2022.100289.
[52] C.L. Znachko, A.P. Winburn, M. Frame, S. Maines, Operationalizing the structural vulnerability profile within the medical examiner context, Forensic Sci Int Synerg 6 (2023 Jan 1) 100334, https://doi.org/10.1016/j.fsisyn.2023.100334.
[53] M.Y. İşcan, M. Steyn, W.M. Krogman, The Human Skeleton in Forensic Medicine, third ed., Charles C Thomas, Springfield, 2013.
[54] J.E. Buikstra, D.H. Ubelaker, Standards for data collection from human skeletal remains, Fayetteville: Ark. Archeol. Surv. Res. Ser. 44 (1994).
[55] W.M. Krogman, M.Y. İşcan, The Human Skeleton in Forensic Medicine, Charles C Thomas, Springfield, 1986.
[56] T.W. Phenice, A newly developed visual method of sexing the *os pubis*, Am. J. Phys. Anthropol. 30 (1969) 297–302, https://doi.org/10.1002/ajpa.1330300214.
[57] R. Meindl, C. Lovejoy, Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures, Am. J. Phys. Anthropol. 68 (1985) 57–66, https://doi.org/10.1002/ajpa.1330680106.
[58] B.O. Lovejoy, R.S. Meindl, T.R. Pryzbeck, R.P. Mensforth, Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death, Am. J. Phys. Anthropol. 68 (1985) 15–28, https://doi.org/10.1002/ajpa.1330680103.
[59] J.M. Suchey, S.T. Brooks, D. Katz, Instructional materials accompanying female and male pubic symphyseal models of the suchey-brooks system. Fort Collins: France Casting, 1988.
[60] P.L. Walker, Sexing skulls using discriminant function analysis of visually assessed traits, Am. J. Phys. Anthropol. 136 (1) (2008) 39–50, https://doi.org/10.1002/ajpa.20776.
[61] A.R. Klales, S.D. Ousley, J.M. Vollner, A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods, Am. J. Phys. Anthropol. 149 (1) (2012) 104–114, https://doi.org/10.1002/ajpa.22102.
[62] I. Schour, M. Massler, The development of the human dentition, J. Am. Dent. Assoc. 28 (1941) 1153–1160, https://doi.org/10.1002/oa.2691.

[63] S. Byers, Calculation of age at formation of radiopaque transverse lines, Am. J. Phys. Anthropol. 85 (3) (1991) 339–343, https://doi.org/10.1002/ajpa.1330850314.
[64] J.L. Boldsen, G.R. Milner, Transition analysis: a new method for estimating age from skeletons, in: R.D. Hoppa, J.W. Vaupel (Eds.), Paleodeomography: Age Distributions from Skeletal Samples, Cambridge University Press, Cambridge, 2002, pp. 73–106.
[65] M. Schaefer, S.M. Black, L. Scheuer, Juvenile Osteology: A Laboratory and Field Manual, Academic Press, Amsterdam, 2009.
[66] M.Y. İşcan, S.R. Loth, R.K. Wright, Casts of age phases from the sternal end of the rib for white males and females, Bellvue, Colorado: France Casting (1993).
[67] E.A. Di Gangi, J.D. Bethard, Unlocking a lost cause: decolonizing ancestry estimation in the United States, Am. J. Phys. Anthropol. 175 (2021) 422–436, https://doi.org/10.1002/ajpa.24212.
[68] M.R. Feldsman, R.L. Fountain, "Race" specificity and the femur/stature ratio, Am. J. Phys. Anthropol. 100 (1996) 207–224. https://onlinelibrary.wiley.com/doi/10.1002/(SICI)1096-8644(199606)100:2%3C207::AID-AJPA4%3E3.0.CO;2-U.
[69] C.E. Merritt, The influence of body size on adult skeletal age estimation methods, Am. J. Phys. Anthropol. 156 (2015) 35–57, https://doi.org/10.1002/ajpa.22626.
[70] D. Lorandos, Expert evidence post-Daubert, Litigation 43 (3) (2017) 18–24, 2017, https://www.jstor.org/stable/10.2307/26402054.
[71] C.A. Roberts, K. Manchester, The Archaeology of Disease, Cornell University Press, New York, 2007.
[72] T.A. Cockburn, Infectious diseases in ancient populations, Curr. Anthropol. 12 (1971) 45–62, https://doi.org/10.1086/201168.
[73] N.C. Lovell, Trauma analysis in paleopathology, Yrbk Phys Anthropol 40 (1997) 139–170, https://doi.org/10.1002/(SICI)1096-8644(1997)25+<139::AID-AJPA6>3.0.CO;2-%23.
[74] A.C. Aufderheide, C. Rodríguez-Martín, The Cambridge Encyclopedia of Human Paleopathology, Cambridge University Press, Cambridge, 1998.
[75] D.J. Ortner, Identification of Pathological Conditions in Human Skeletal Remains, second ed., Academic Press, London, 2003.
[76] A.G. Morris, M. Steyn, Palaeopathological studies in South Africa: a history, in: J. Buikstra (Ed.), The Global History of Paleopathology: Pioneers and Prospects, Oxford University Press, New York, 2012, pp. 235–242, 2012.
[77] S.A. Mays, How should we diagnose disease in palaeopathology? Some epistemological considerations, Int J Paleopathol 20 (2018) 12–19.
[78] C. Finaughty, K.M. Reid, I.H. Alli, L.J. Heathfield, A first for forensic genetics in Africa: successful identification of skeletal remains from the marine environment using massively parallel sequencing, Forensic Sci. Int.: For. Genet. 49 (2020) 102370.
[79] L.J. Heathfield, T.E. Haikney, C.G. Mole, et al., Forensic human identification: investigation into tooth morphotype and DNA extraction methods from teeth, Sci. Justice 61 (4) (2021) 339–344.
[80] C. Finaughty, L.J. Heathfield, V. Kemp, N. Márquez-Grant, Forensic DNA extraction methods for human hard tissue: a systematic literature review and meta-analysis of technologies and sample type, Forensic Sci. Int.: For. Genet. (2023), https://doi.org/10.1016/j.fsigen.2022.102818.
[81] A. Miloš, A.A. Selmanović, L. Smajlović, et al., Success rates of nuclear short tandem repeat typing from different skeletal elements, Croat. Med. J. 48 (4) (2007) 486–493.
[82] C. Hollard, C. Keyser, T. Delabarde, et al., Case report on the use of the HID-Ion AmpliSeq™ Ancestry Panel in a real forensic case, Int. J. Leg. Med. 131 (2) (2017) 351–358, https://doi.org/10.1007/s00414-016-1425-1.
[83] S. Walsh, A. Lindenbergh, S.B. Zuniga, et al., Developmental validation of the IrisPlex system: determination of blue and brown iris colour for forensic intelligence, Forensic Sci. Int.: For. Genet. 5 (5) (2011) 464–471, https://doi.org/10.1016/j.fsigen.2010.09.008.
[84] L.A. Chesson, W. Meier-Augenstein, G.E. Berg, et al., Basic principles of stable isotope analysis in humanitarian forensic science, in: R.C. Parra, S.C. Zapico, D. H. Ubelaker (Eds.), Forensic Science and Humanitarian Action: Interacting with the Dead and the Living, Wiley, 2020, pp. 285–310.
[85] G.J. Bowen, J.S. Guo, S.T. Allen, A 3-D groundwater isocape of the contiguous USA for forensic and water resource science, PLoS One 17 (1) (2022) e0261651, https://doi.org/10.1371/journal.pone.0261651.
[86] G.J. Bowen, J.B. West, Isoscapes for terrestrial migration research, in: K. A. Hobson, L.I. Wassenaar (Eds.), Tracking Animal Migration with Terrestrial Isotopes, second ed., Academic Press, 2019, pp. 53–84, https://doi.org/10.1016/B978-0-12-814723-8.00003-9.
[87] J. Beaumont, J. Montgomery, Oral histories: a simple method of assigning chronological age to isotopic values from human dentine collagen, Ann. Hum. Biol. 42 (4) (2015) 407–414, https://doi.org/10.3109/03014460.2015.1045027.
[88] G.E. Berg, L.A. Chesson, J. Yuryang, et al., A large-scale evaluation of intraperson isotopic variation within human bone collagen and bioapatite, Forensic Sci. Int. 336 (2022), https://doi.org/10.1016/j.forsciint.2022.111319.
[89] A. Vanmali, C.M. Mole, L.J. Heathfield, The Assessment of Forensic Molecular Markers for Skin Colour in South Africans [MPhil Thesis], University of Cape Town, Cape Town (SA), 2019. https://open.uct.ac.za/handle/11427/33029.
[90] J.R. Ehleringer, G.J. Bowen, L.A. Chesson, A.G. West, D.W. Podlesak, T.E. Cerling, Hydrogen and oxygen isotope ratios in human hair are related to geography, Proc. Natl. Acad. Sci. U.S.A. 105 (2008) 2788–2793, https://doi.org/10.1073/pnas.0712228105.
[91] W. Meier-Augenstein, I. Fraser, Forensic isotope analysis leads to identification of mutilated murder victim, Sci. Justice 48 (2008) 153–159, https://doi.org/10.1016/j.scijus.2007.10.010.
[92] P.J.H. Dunn, J.F. Carter, in: Good Practice Guide for Isotope Ratio Mass Spectrometry, second ed., FIRMS, 2018, 978-0-948926-33-4, https://www.forensic-isotopes.org/gpg.html.
[93] S.P.G. Doyle, G. van der Peijl, FIRMS Guidance for the Forensic Interpretation of Isotope Ratio Data, 1st edition ver 1.1, FIRMS, 2020, 978-0-948926-37-2, https://www.forensic-isotopes.org/gfi-ird.html.
[94] K. Smith, C. Wilkinson, The Doppelgänger effect? A comparative study of forensic facial depiction methods, Forensic Sci. Int. 356 (2024) 111935, https://doi.org/10.1016/j.forsciint.2024.111935.
[95] C. Wilkinson, J.L. Ching Yiu, S. Shrimpton, E. Greenway, Craniofacial identification standards: a review of reliability, reproducibility, and implementation, Forensic Sci. Int. 359 (2024) 111993, https://doi.org/10.1016/j.forsciint.2024.111993.
[96] K. Smith, An operational study of post-mortem visual identification in South Africa, in: Laws of the Face: Restaging Forensic Art as a Counter-forensic Device [PhD Thesis], Liverpool John Moores University, Liverpool, 2020, pp. 111–170. http://researchonline.ljmu.ac.uk/id/eprint/14304/.
[97] C.C. Snow, B.P. Gatliff, K.R. McWilliams, Reconstruction of facial features from the skull: an evaluation of its usefulness in forensic anthropology, Am. J. Phys. Anthropol. 33 (2) (1970) 221–227, https://doi.org/10.1002/ajpa.1330330207.
[98] J. Prag, R.A.H. Neave, Making Faces: Using Forensic and Archaeological Evidence, British Museum Press, London. London, 1997.
[99] K.T. Taylor, Forensic Art and Illustration, CRC Press, Boca Raton, 2000.
[100] C. Wilkinson, A. Tillotson, Post-mortem prediction of facial appearance, in: Craniofacial Identification, Cambridge University Press, Cambridge, 2012, pp. 166–183.
[101] K. Smith, M. Roughley, S. Harris, et al., From Ta-Kesh to Ta-Kush: the affordances of digital, haptic visualisation for heritage accessibility, Digit Appli Archaeol Cult Herit 19 (2020) e00159, https://doi.org/10.1016/j.daach.2020.e00159.
[102] G. Mahoney, C. Wilkinson, Computer-generated facial depiction, in: C. Wilkinson, C. Rynn (Eds.), Craniofacial Identification, Cambridge University Press, Cambridge, 2012.
[103] P.L. Posner, The pracademic: an agenda for re-engaging practitioners and academics, Public Budg. Finance 29 (1) (2009) 12–26, https://doi.org/10.1111/j.1540-5850.2009.00921.