New Dimensions of Forensic Anthropology

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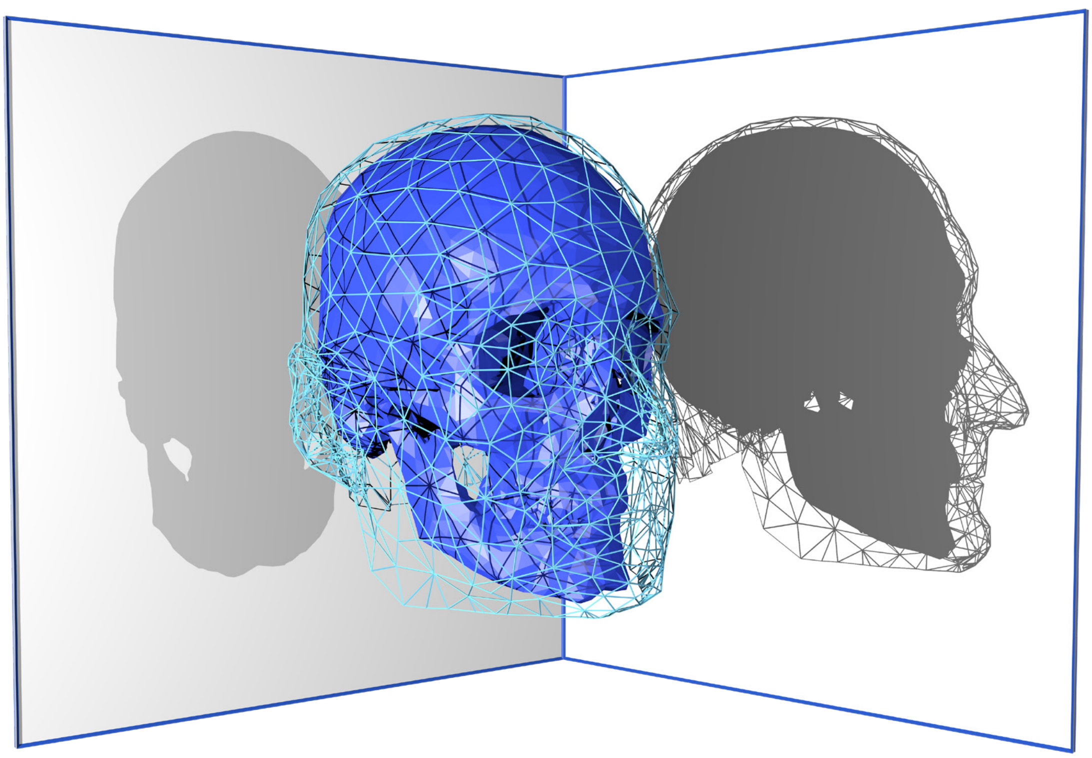

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PREFACE

In the eyes of many, forensic anthropology continues to be taken for an appendix of physical anthropology, whose focus is on identification of skeletal remains within a context of criminal investigation. Under this concept a forensic anthropologist is expected to find definite answers to three fundamental questions, asked upon the discovery of skeletal remains – how long has it been since the person died? Can the remains be identified? Is there any evidence of skeletal trauma, which can pinpoint the cause of death? This is, somewhat, skewed perception of forensic anthropology, fueled, among others, by an inaccurate portrait of anthropologists in media and pop culture, presented shamelessly as the "tech-savvy all-knowing bone collectors".

There are only a few practicing forensic anthropologists in our country. Having the privilege to be one of them has given me first-hand experiences to the eclectic nature of forensic casework and has provided me with an overview to recent shifts occurring in the intellectual foundation of the field.

The focus of this volume is to offer a better understanding of forensic anthropologist's work and to emphasize the importance of balancing anthropologist's skills with those adopted from other disciplines. Taking up a forensic case an anthropologist must possess the knowledge of biological (and not only biological) principles that goes far beyond a perfect understanding of human osteology, because today's forensic casework no longer demands a conventional methodological basis. It calls for multi-disciplinary approaches. Diverse types of evidence submitted for forensic examination and the booming development in imaging and computational technologies have added additional layers of scientific knowledge that has become indispensable in conducting a forensic examination. Throughout the progress in imaging technologies, particularly three-dimensional techniques, forensic sciences have become more dependent on numerical and visual data processing. This has introduced new dimensions, both real and theoretical, into the framework of forensic anthropology.

The volume, itself, is a collection of peer-reviewed scientific studies published (with one exception of a submitted manuscript) between years 2013 and 2016. The studies are structured into four main chapters. Each chapter opens with an introductory section providing an overview to a specific area of forensic anthropology casework or research and is followed by a short commentary on the published papers featured inside.

A recurring theme to the papers composing the volume is the employment of 3D technologies, modulated to be applicable to forensic casework. Over the last decade, the progress in 3D systems has launched multiple novel applications in forensics. Examination of fragmentary skeletal remains started relying on advanced geometric variables and virtual approaches (Chapter 1). Identification of living persons has turned to 3D face and motion recognition (Chapter 2). Traditional invasive "scalpel and scissors" dead body examination started being accompanied by non-invasive diagnostics grounded on full-body CT scans and a robotic assistance (Chapter 3 and 4). Computer-aided reconstructions of an incident featuring digital evidence of skeletal injuries have been created to aid investigations of violent deaths (Chapter 4). These techniques are rapidly becoming part of experts' life and are transforming the manner in which forensic casework is conducted.

The primary purpose for this volume was to straighten the public misconception of forensic anthropologists and to offer a commentary on the latest development in the field. Hopefully, I have succeeded at least in one of these goals.

Brno, August 2016

Petra Urbanová

ACKNOWLEDGEMENTS

The most thankworthy collaborators are acknowledged as co-authors on the next page and again throughout the volume. Therefore, I wish to dedicate this page specifically to those whom I had not had the pleasure to collaborate with on any of the featured studies. Yet, their professionalism, skills, erudition and wisdom have been inspirations, which transpire through the publications.

To **dr. Hana Eliášová**, Institute of Criminalistics Prague, my ever so patient and understanding mentor in forensic casework;

To **employees** of the **Departments of Forensic Medicine** in **Brno** (Masaryk University) and **Hradec Králové** (Charles University) for being excellent "partners in crime" willing to participate in our experiments with imaging technologies in forensic medicine and forensic pathology;

To **prof. dr. Edna Sadayo Miazato Iwamura**, Department of Pathology, Federal University of São Paulo, and **dr. Paulo Eduardo Miamoto Dias** for their hospitality, support and assistance in our ongoing Czech-Brazilian collaboration;

To **team members** and **students** participating in the **FIDENTIS Project** at Masaryk University for their dedication, insights, effort and for keeping up the good work;

To **co-workers** and **students** at the **Laboratory of Morphology and Forensic Anthropology** for showing up to work every day and only occasionally giving a headache.

Many thanks to the **Fulbright commission** for awarding me with the Fulbright Scholar grant. They say that being a Fulbrighter is for life…and I proudly add that rightly so. The U.S. milieu has made a great impact on professional decisions and has shaped my interests in the field. Also, special thanks to the **Council for International Exchange of Scholars** and the **Outreach Lecturing Fund** sponsored by the U.S. Department of State for providing me with the funding to visit forensic laboratories in Oahu, Hawaii, USA.

The published work presented in this volume has been undertaken with the financial assistance of **Masaryk University**. Together with the rest of the Laboratory of Morphology and Forensic Anthropology, I am grateful that they keep funding our research.

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Chapter 1

Forensic Osteology

Examination of skeletal remains of unknown origin continues to prevail as the primary task for forensic anthropologists despite the regional diversity in formal training and personal preferences for daily casework. As a result, the main effort is given to tasks involving identification of fully or partially skeletonized human remains. The routine osteological procedure starts with assessment of ancestry, biological sex, age-at-death and stature and carries on to examination of unique skeletal or dental traits to match or eliminate the person's identity. Basic, yet pertinent methods to carry out these tasks include visual assessment (e.g., morphoscopic or qualitative traits) and osteometrics (e.g., anthropometrics, craniometrics, quantitative traits).

In the last 30 years, a substantial body of work has been achieved in order to evolve analytical and diagnostic tools used in forensic osteology with a primary goal to move away from the subjectivity of visual comparison and the triviality of caliper-based measurements. Additionally, another concern has shaped the manners in which a forensic osteological expertise is nowadays executed. In mid-1990's the admissibility of many traditional osteological techniques in courts started being questioned and the criticism particularly intensified upon passing of the Daubert standards. Named after the ruling in the US case Daubert vs. Merrell Dow Pharmaceuticals, the standards state that scientific evidence admitted in court must be collected with known error rates. It also must reflect the scientific knowledge accepted among peers following dissemination in peer-reviewed scientific publications. Therefore, starting with the new millennium most of the research in forensic osteology has aimed at quantifying probability rates upon which the parameters retrieved from skeletal remains are estimated. The major goal has been to provide forensic experts with a more complex methodological basis that would fulfill the legal criteria and simultaneously would enhance the precision and replicability of used standards. This has logically placed higher demands on anthropologist's operating and analytical skills as well as technical lab equipment.

The state-of-the-art of forensic osteology is linked to two principal trends of systematic development. The first of them has been tied to the gradual employment of multivariate statistical algorithms combined with large sample sizes. This has allowed making use of the exploitative role of statistics as opposed to the previous descriptive and summarizing function. It also allowed interlacing multiple predictive skeletal features into a single complex descriptor. Applicable to both quantitative and qualitative variables, multivariate classification and predictive algorithms have become integral and irreplaceable parts of daily anthropological practice enabling to allocate an unknown individual into a demographic category (e.g., ancestral groups, biological sex etc.) with a given probability score or to estimate an individualizing criterion with a predicted error (e.g., stature). The field has also witnessed a tendency towards more progressive employment of highly sophisticated approaches based on Bayesian statistics or machine learning algorithms in form of classification trees or neural networks.

As the second research avenue of forensic osteology became focused on maximizing the amount and complexity of processed skeletal data, it became evident that the traditional approach utilizing trivial metric variables taken with measuring instruments cannot keep up with such demands. By contrast, the substantial progress accomplished in digital technologies permitted the improvement when linear or angular measurements started being replaced with geometry-derived variables (e.g., diameters, three-dimensional landmarks, radial coordinates, non-linear distances, outlines or curves). These variables processed by methods of geometric morphometrics or statistical shape analysis have been shown to enhance significantly assessments carried out in the course of examination of skeletal remains.

The most recent inspiration for the forensic practice has derived from parallel development made in three-dimensional acquisition technologies and computation performances. This increased availability and affordability of a wide range of recording hardware featuring contact and contactless digitizers, optical and laser scanners or medical imaging units. It also allowed collecting high-resolution 3D digital models of skeletal remains. Nowadays, 3D digital models of skeletal remains form sizable datasets employable as references on intra-population and inter-population skeletal variation. They are

taken for truthful replicas protecting the integrity of perishable physical evidence. They are even preferred as easily displayable alternatives to the real evidence when presented to investigators or jury members. And more importantly, they are used as the aforementioned sources of abundant quantitative and qualitative skeletal data.
Despite the outlined progress, integrating advanced methods into an everyday routine can be challenging. The novel approaches ask for larger learning curves and although a colorful spectrum of advanced computer-aided techniques is available, only a few of them are tailor-made to accommodate the level of computer literacy commonly encountered in forensic anthropologists. For experts who have difficulty keeping up with technological novelties due to caseloads it means that mastering additional necessary skills may be virtually beyond reach. In order to overcome these challenges team efforts are being extended to simplify scientific knowledge, to ease computational requirements and to offer experts user-friendly computer environments to treat morphological data retrieved from skeletal remains.

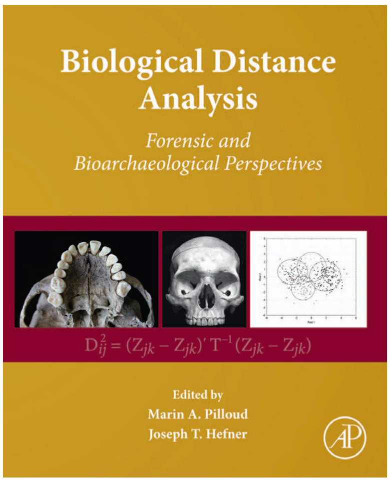
This chapter contains seven published studies falling under the rubric of forensic osteology. They aim to illustrate author's principal contributions to the development in the field. The first two titles *"Advanced Methods in 3-D Craniofacial Morphological Analysis"* and *"Complexity of Assessing Migrant Death Place of Origin"* are book chapters published in "Biological Distance Analysis. Forensic and Bioarchaeological Perspectives" edited by Marin A. Pilloud and Joseph T. Hefner. The chapters were co-authored by dr. Ann H. Ross and dr. Chelsey Juarez, both currently affiliated with North Carolina State University, Raleigh, USA and originated in current needs to re-valuate and update methods used to estimate ancestral origin from skeletal remains, especially if used to allocate an individual within a population of a complex and admixed background (e.g., illegal Hispanic/Latin immigrants in the United States or European and Admixed Brazilians in Brazil).
Together with the next paper *"Testing the Reliability of Software Tools in Sex and Ancestry Estimation in a Multi-Ancestral Brazilian Sample"*, the book chapters form a trilogy which provides insight into advanced 3D craniofacial analysis as performed in the course of forensic casework. The papers emphasize on the usage of computer-aided diagnostic tools within various world populations. They illustrate that three-dimensional data acquisition hardware combined with methods of advanced data processing is capable of boosting diagnostic powers and subsequently increases levels of accuracy. The results also send a warning to the forensic community that the advanced techniques should be applied with extreme caution because a number of missteps in form of an inadequate reference sample or an improper handling of a technique can seriously skew acquired results.
The trio on craniofacial variation is followed by another set of studies tied by a central theme – morphological variations of human hyoid bones. As part of skull, hyoid bone is an important, yet sometimes overlooked, element of human skeleton. The three studies demonstrate that hyoid bone represents a valuable source of information on individual's sex (*"The morphology of human hyoid bone in relation to sex, age and body proportions"*) as well as developmental issues (*"The Asymmetry and Modularity of the Hyoid Bone"*). More importantly, it plays a key role in forensic cases where foul play is suspected (see Chapter 4). Making hyoid bone a model skeletal element, the third of the hyoid-themed papers (*"What is the appropriate approach in sex determination of hyoid bones?"*) illustrates the range of multivariate statistical methods on which a predictive model to estimate identity-related skeletal indicators can be established.
The chapter concludes with a paper entitled *"Two-Dimensional Wavelet Analysis of Supraorbital Margins of the Human Skull for Characterizing Sexual Dimorphism"*, published with Sílvia Pinto and Roberto Cesar, Jr., author's long-time Brazilian collaborators affiliated with University of São Paulo. The paper follows biologists' (or author's for that matter) long-standing interests in quantifying biological shape variations (cross-sections to the supraorbital margin in this case) using progressive mathematical principles. In summary, the paper was written with objectives to overcome inconveniences of the

Fourier analysis, a relatively widespread shape quantifying technique whose core is the Fourier transform or harmonic decomposition. While the method excels in quantifying global shapes, it is less successful in specifying localized morphological abnormalities. By employing a decomposition technique grounded on a series of multiresolution wavelet functions (i.e., wavelet analysis), capable of specifying both global as well as local shape variations, the results show that the newly proposed approach, albeit elaborate, may represent a way to improve performances of sex estimation methods if incorporated as an integral part of anthropological methodology.

1.1. Advanced Methods in 3-D Craniofacial Morphological Analysis

by Petra Urbanová, Ann. H. Ross

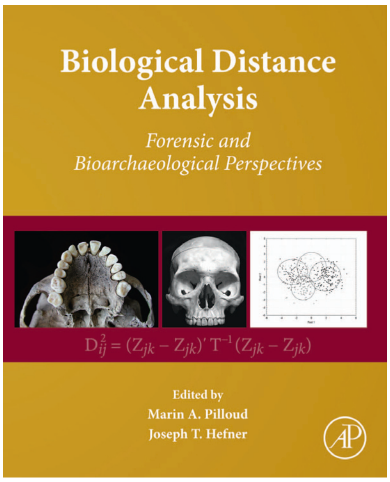
published in "Biological Distance Analysis. Forensic and Bioarchaeological Perspectives" edited by Marin A. Pilloud and Joseph T. Hefner



1.2. Complexity of Assessing Migrant Death Place of Origin

by Ann. H. Ross, Chelsey A. Juarez, Petra Urbanová

published in "Biological Distance Analysis. Forensic and Bioarchaeological Perspectives" edited by Marin A. Pilloud and Joseph T. Hefner



1.3. Testing the Reliability of Software Tools in Sex and Ancestry Estimation in a Multi-Ancestral Brazilian Sample

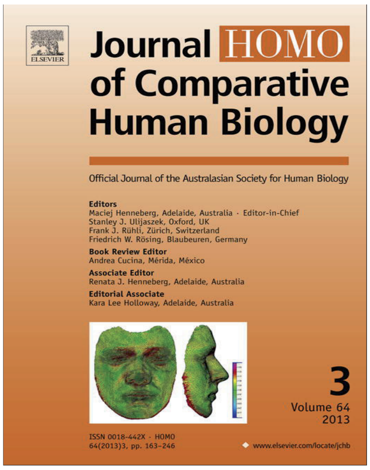
by Petra Urbanová, Ann H. Ross, Mikoláš Jurda, Maria-Ines Nogueira

published in Legal Medicine 16 (2014)

1.4. The Morphology of Human Hyoid Bone in Relation to Sex, Age and Body Proportions

by Petra Urbanová, Petr Hejna, Lenka Zátopková, Miroslav Šafr

published in HOMO - Journal of Comparative Human Biology 64 (2013)



1.5. The Asymmetry and Modularity of the Hyoid Bone

by Petra Urbanová, Petr Hejna, Lenka Zátopková, Miroslav Šafr

published in International Journal of Morphology 32 (2014)

1.6. What Is the Appropriate Approach in Sex Determination of Hyoid Bones?

by Petra Urbanová, Petr Hejna, Lenka Zátopková, Miroslav Šafr

published in Journal of Forensic and Legal Medicine 20 (2013)

1.7. Two-Dimensional Wavelet Analysis of Supraorbital Margins of the Human Skull for Characterizing Sexual Dimorphism

by Sílvia C. D. Pinto, Petra Urbanová, Roberto M. Cesar, Jr.

published in IEEE Transactions on Information Forensics and Security 11/7 (2016)

Chapter 2

Image-based Identification of the Living

Identification of living persons represents a specific, sometimes marginalized, area of forensic anthropology, nowadays linked almost exclusively to digital or digitized image evidence (photographs, X-rays, web-cam records etc.). Yet, images are valuable and nowadays omnipresent conveyors of individual and group specific features that point out the person's identity. In general, identification of living persons is conducted by matching DNA samples, imprints of various body parts (fingerprints, handprints, footprints, lip imprints, ear imprints), dental or medical records or physical appearance. Unfortunately, only some of these individualizing characteristics are observable or retrievable from image evidence secured at crime scenes. Of the few applicable, facial features, body proportions, gait dynamics and occasionally morphology of other body parts have been shown as the most appropriate for image-based identification.

The crucial element in image-based identification tasks is the quality of provided evidence. Standardized portrait photographs taken under controlled conditions are being submitted as evidence in cases where person's real identity is being questioned, such as false passports, frauds, money laundering, drug smuggling. In addition, three-part (or two-part) police photographs, otherwise known as mugshots or booking photos, have been taken as photographic evidence while in police custody since the Alphonse Bertillon's era. In most cases, however, images processed for identification purposes originate in uncontrolled, real-life situations, e.g., family snapshots, or in recordings of a crime, e.g., CCTV surveillance videos capturing a bank robbery.

Ideally, in order to extract and classify identity-specific body traits presented on images semi-automatic or automatic algorithms adopted from the fields of biometrics, signal and image processing or computer vision are employed. These algorithms, used mostly in commercial security systems and grouped under verification/authentication procedures and facial recognition, perform either one-to-one or one-to-many matching tasks. Yet, a universal use of these algorithms in forensics is problematic. Although various law-enforcement agencies have been successfully using automatic face recognition systems for screening and large-scale database inquiries, other tasks, such as negative identifications (i.e., ability to eliminate a person among many) or positive identification (i.e., ability to match a person among many) are proved more difficult to achieve.

It is a well-recognized issue that the tasks of personal identification (same-person comparison, inter-person comparison) are obstructed by the fact that image-based forensic evidence is presented for examination in very poor quality, with non-standard framing, viewpoints or optical distortion. In addition, perpetrator's behavior, occlusion or face expressions can pose additional inconveniences. In result, these images are rarely suitable for automatic or semi-automatic face recognition systems because discriminatory powers of individualizing features are diminished by technical noise and intra-individual variations due to an unstable relationship between a capturing system and a captured subject.

One of the few manners how to approach this kind of evidence is by means of anthropological examination. Generally, forensic anthropologists are accustomed to address tasks of similarity of identity-coding features depicted in images by one of three universal strategies: visual (morphological) assessment, somatometrics (anthropometrics, photo-anthropometry) or superimposition. By visual assessment, a specific body feature (e.g., facial components) is assigned into categories according to a standardized classification system. Various systems for classifying facial features (e.g., the facial form, nose tip shape, septum tilt etc.), body characteristics (e.g., somatotypes, posture) or descriptive parameters of a gait cycle (e.g., out-toed gait, drop foot, waddling gait etc.) have been developed. The metric approach, in contrast, relies on standardized measurements taken for a given body part (e.g., head length/width, arm length, step length) or a combination of them (e.g., height, cadence of gait). Alternatively, advanced quantitative techniques based on 2D or 3D spatial landmarks or outlines (silhouettes) are employed in casework of a more progressive nature. Ultimately, superimposition techniques place one set of probe images on top of target images and adjust them to make a visual comparison.

Unfortunately for forensic anthropologists, none of the universal strategies is universally applicable.

The visual approach has been scrutinized as largely subjective and strained by a relatively high intra-observer as well as inter-observer error rate. The metrics are known to be limited among others by image quality, camera angles and potential inconsistencies throughout person's lifetime (e.g., height, gait pattern, facial proportions) and the superimposition does not provide any measurable declaration of concordance between two superimposed images, nor does it allow assigning a probability score to a positive or negative outcome.
The most noticeable development in the area of forensic image-based identification in the last ten years has been linked to the development of 3D sensors. Nowadays, 3D images of living persons can be captured by a variety of in-lab devices. Dynamic body features – gait or hand gestures – can be acquired by precise motion tracking systems or even by systems designed to accessorize personal electronic devices such as tablets, cell phones or game consoles. This has allowed recording realistic images featuring depth information otherwise lost in the traditional images. The depth information has been largely advertised as capable of compensating for at least some of the key shortcomings associated with the traditional image-based methodology, primarily by offering 2D to 3D and 3D to 3D digital record matching of human body. Although this claim is not without its merits, 3D capturing devices are strained by their own technical limits (e.g., inability to record obscured regions and dynamic or reflective body features as such as hair, facial expression etc.), which can interfere with identification tasks and which are yet to be resolved.

The chapter includes three published papers that demonstrate author's contributions to the subject of forensic facial identification. All of them emerged from the FIDENTIS Project at Masaryk University. The FIDENTIS Project (the acronym stands for **F**orensic **Ident**ification **S**ystem) is a multi-disciplinary research group, which teamed up anthropologists with computer scientists in order to join efforts in researching issues of 3D facial identification. The project benefits from top-tier 3D recording equipment available at collaborators' workplaces and capable of collecting various types of 3D datasets (e.g., Vectra M1 optical scanner, Vectra XT half-body system, Vectra H1 scanner, Facial Motion Capture System, Microsoft Kinect). To date, the project has given origin to two main achievements: **FIDENTIS 3D Face Database (F3D-FD)** and **FIDENTIS Analyst** software (both available via project web pages at *www.fidentis.cz*).

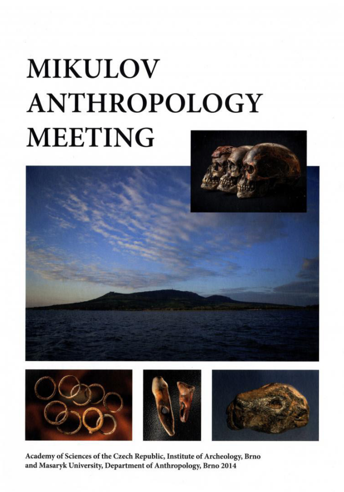
The first paper titled *"3D Virtual Model Database of Human Faces: Applications in Anthropology and Forensic Sciences"* provides an overview of the FIDENTIS 3D Face Database. The database represents one of the largest datasets of 3D facial scans currently available worldwide. It composes of single-scan entries and a smaller number of multi-scan entries varying in acquisition conditions. In 2014, which coincides with the date of publication, the database contained approximately 1,700 3D face scans. To date, 3D face scans and additional demographic data from over 2,300 participants (both adult and sub-adults) have been collected and listed in the database. The primary purpose of the database is to serve as a stand-alone reference sample encompassing the maximum possible range of inter- or intra-individual variations of facial features.
The second paper *"Performance of distance-based matching algorithms in 3D facial identification"* provides an introduction to functionalities incorporated into FIDENTIS Analyst program. FIDENTIS Analyst is a target-orientated computer interface designed for processing 3D images of human faces. Processing two or multiple 3D images is a challenging and computationally expensive task. In order to compare 3D images a forensic expert must possess sufficient familiarity with a number of 3D data processing techniques, such as 3D alignment, mesh undersampling, color-mapping etc. The software is being developed to facilitate many of these necessary tasks. For 3D facial images it enables a variety of morphological analyses – a 3D facial composite construction, automated landmark localization and face-to-face comparison in one-to-one, one-to-many and batch processing modes. The featured study tests performances of computation algorithms comprising 3D-to-3D image matching procedures. Spe-

cifically, it confronts identification rates based on manually collected 3D facial landmarks and automatic processing of 3D meshes. It is noteworthy that the testing was conducted on a dataset of 3D faces sampled from the FIDENTIS 3D Face Database.
The last included paper represents a large-scale collaborative study entitled *“Generating various composite human faces from real 3D facial images”*, which hints on another aspects of image-based forensic expertise – image composites. The study extends the traditional approach to the facial composites by introducing algorithms for creating 3D facial images based on real life data (3D facial components) extracted from the FIDENTIS Database. Although the paper was targeted at the non-forensic scientific community (it was meant for the gaming industry), the goal of presenting computation principles for generating composite human faces coincides with that of the forensics-oriented research. A two-fold user study was added to the descriptive sections of the paper to test a hypothesis whether the perception of human faces had shifted once one or more facial components had been modified. The outcome was confronted against those of a morphological analysis quantifying the extent of such facial alterations. The results suggest that to an extent the proposed automated algorithms are capable of producing realistic 3D face composites that are far from being caricatures and morphologically fall within the range of observed facial variation.

2.1. 3D Virtual Model Database of Human Faces: Applications in Anthropology and Forensic Sciences

by Zuzana Kotulanová, Igor Chalás, Petra Urbanová

published in The Dolní Věstonice Studies, vol. 20 - Mikulov Anthropology Meeting (2014)



2.2. Performance of Distance-based Matching Algorithms in 3D Facial Identification

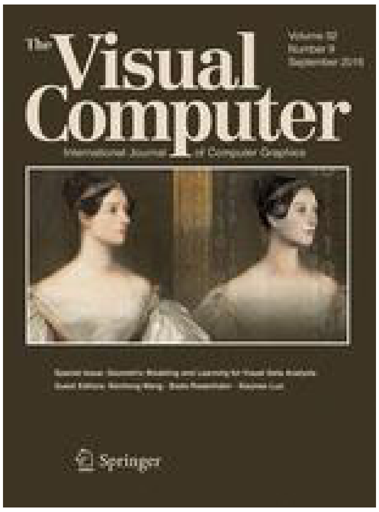
by Petra Urbanová

published in Egyptian Journal of Forensic Sciences 6 (2016)

2.3. Generating Various Composite Human Faces from Real 3D Facial Images

by Igor Chalás, Petra Urbanová, Vojtěch Juřík, Zuzana Ferková, Marie Jandová, Jiří Sochor, Barbora Kozlíková

published in The Visual Computer 32 (2016)



Chapter 3

Advanced Digital Techniques in Forensic Postmortem Examination

The gold standard of forensic documentation is conventional two-dimensional photography. Photography is the very first technique employed for documenting forensic scenes, dead bodies or skeletal remains on sites as well as throughout the entire process of in-lab postmortem examination (external assessment and internal 3-cavity autopsy). The core disadvantage of traditional photographs is the lack of depth information, which inherently reduces spatial relationships among the recorded objects to a two-dimensional level. This limits experts' abilities to interlink contextual information drawn from on-site photography with autopsy findings. It also diminishes chances to revisit original findings made during postmortem examinations.

In light of the recent achievements made in digital imaging technologies, several projects have invested into establishing three-dimensional postmortem documentation protocols by utilizing a variety of 3D acquisition hardware ranging from haptic devices, to close-range photogrammetry, to robotic surface scanning. It has been well demonstrated that these techniques bring numerous benefits in decision-making conducted inside as well as outside autopsy rooms or forensic laboratories. They manage to produce high-quality digital copies of real-life objects, which can be examined from infinite viewpoints, edited, revised, measured, shared by an unlimited number of practitioners and brought back to the physical world by the technology of 3D printing. If combined with high-resolution surface color information (i.e., texture) they also provide information about time-sensitive coloring, spots, or subtle external interferences important in diagnostics.

Three-dimensional postmortem documentation taken for an alternative to traditional photography is, however, part of a larger initiative oriented at establishing imaging technologies for the purpose of internal postmortem examination – forensic autopsy. Optical surface models are mere digital shells lacking, by definition, any information going underneath the surface. By contrast, medical or technical imaging modalities such as computed tomography, cone-beam CT, microCT or MRI generate cross-sectional (volume) data, which have the capacity to produce 3D model of any internal structure. Altogether the approach composed of non-invasive or minimally invasive techniques in postmortem examination is referred to as the virtual, also touch-free or scalpel-free autopsy.

For forensic anthropologists requested to assist a forensic pathologist in cases of assessment of skeletal injuries or identity confirmation, the image-based approach represents a welcome alternative to the time-consuming maceration and soft-tissue processing. 3D digital models have been proven valuable as virtual substitutes for physical bones in sex and ancestry assessment, age estimation or facial reconstructions. CT scans of arms and legs can uncover individual, sex or age-related markers – degree of ossification (epiphyseal fusion, hyoid bone, and thyroid cartilage), ossified or calcified elements (microtrauma, healed injuries, atherosclerotic lesions). In traditional autopsies, where only a portion of the body is examined, mostly for time-saving, economic or financial reasons or reasons of piety, these findings can easily go unnoticed. Furthermore, CT images of gross bone morphology, skeletal non-metric traits, surgical evidence, implants, endoprostheses, otherwise known as "morphological fingerprints" are helpful in identification efforts. Freely movable and rotatable CT-generated 3D models are particularly beneficial if a comparison with antemortem medical evidence is carried out.

As postmortem examination may evoke unwanted connotations image-based visual data also offer a psychological release when graphic forensic evidence is presented and the cause of death is explained to the police, jury members or next of kin.

Conducting image-based postmortem examination comprises a series of non-trivial consecutive tasks and by nature has to be collaborative and multidisciplinary. Nowadays, a strong voice can be heard calling for large-scale multi-centers that would be able to take on such responsibility. Still, the number of interdisciplinary centers worldwide is scarce and it is not expected to grow drastically. Moreover, due to their heavy caseload, forensic practitioners are rarely inclined towards experimenting with novel technologies and incorporating experimental approaches into everyday workflow. Yet, it has been shown that a symbiosis of sorts can be achieved on a smaller scale, particularly through collaboration with other experts, such as forensic anthropologists who are generally lighter on daily casework, more research-oriented and yet competent to assist at postmortem examination.

This chapter contains two studies, which touch the subject of implementing technical and technological novelties into the routine workflow of forensic postmortem examination. Both of them also highlight the fruitfulness of complementing pathologist's skillsets with those of a trained forensic anthropologist. The first paper entitled *"Testing photogrammetry-based techniques for three-dimensional surface documentation in forensic pathology"* marks the first attempt to employ techniques of optical surface scanning and single camera close-range photogrammetry as stand-alone alternatives to conventional forensic photography conducted inside an autopsy room. The acquired results particularly underline the fact that three-dimensional documentation at autopsies does not have to be costly luxury requiring top-notch devices, but it can be carried out with standard lab equipment.
Thematically, the second paper *"Tethered digital photography with built in Wi-Fi memory cards brings benefits to the environment of an autopsy room"* represents a step back from the 3D imaging techniques presented in the previous study by focusing on traditional photographic techniques. However, alike its predecessor, the paper introduces a sophisticated strategy that facilitates expert's routine workflow and increases the efficiency of teamwork inside an autopsy room or forensic laboratory. Specifically, the paper points out the benefits of using built-in wireless fidelity memory cards allowing cable-free transmission of images, their real-time visualization and instant quality control.

3.1. Testing Photogrammetry-based Techniques for Three-dimensional Surface Documentation in Forensic Pathology

by Petra Urbanová, Petr Hejna, Mikoláš Jurda

published in Forensic Science International 250 (2015)

3.2. Tethered Digital Photography with Built-in Wi-Fi Memory Cards Brings Benefits to the Environment of an Autopsy Room

by Petr Hejna, Martin Janík,
Petra Urbanová

published in Romanian Journal of Legal Medicine 23 (2015)

Chapter 4

Forensic Skeletal Traumatology

The main purpose of forensic (medicolegal) autopsy is to determine whether death occurred as a result of natural causes, suicide, or to confirm or reject foul play when suspected due to an accident or homicide. In early stages of body decomposition, recognizing violent deaths is a relatively straightforward task established on the basis of a variety of trauma differentiating evidence revealed in the course of external or internal body examination (e.g., cutaneous injuries, skin coloring, bloodstain patterns, incisions etc.). As soft tissues starts to decompose indicators of traumatic events lose their distinctiveness and signature diagnostic features. Their appearance turns more generic and prone to misdiagnoses. For heavily degraded, partially or completely skeletonized, cremated or mummified human remains, assessment of injuries is mostly dependent on examination of hard tissues (bones, teeth). In these cases, bones and teeth represent only direct evidence of violence, offering if not a permanent, then a highly resilient record of a death event.

Assessment of skeletal injuries and determination of their relevance to medicolegal death investigations is one of the main tasks a forensic anthropologist is asked to conduct in the course of a routine examination of human skeletal remains. More importantly, due to a complex character of skeletal injuries forensic anthropologists are increasingly being asked to consult on skeletal trauma cases, even in instances, which are within the competence of a forensic pathologist.

An in-depth list of tasks in forensic skeletal trauma analysis includes determination and identification of present injuries, assessment of their extent and life threatening nature, recognition of their origin and timing, and identification of seminal agents responsible for the skeletal alterations. The occurrence of a skeletal injury almost exclusively presents itself as a fracture. A fracture occurs when the hard tissue (bone, tooth, calcified cartilage) cannot sustain external force. Occasionally, an infraction, bone loss or skeletal deformity may also suggest a traumatic event. A deep and complete understanding on how bones break and how they heal is paramount for interpreting skeletal trauma. The healing process is one of the few direct indicators of injury timeline. Timing sets skeletal lesions into one of three main categories. Antemortem trauma is a skeletal lesion that occurs prior to death and exhibits signs of the healing process (e.g., blunt edges, bony callus, remodeling). Perimortem trauma is a lesion that occurs at or around the person's time of death and postmortem trauma is any *ex vivo* damage, frequently presented in form of taphonomically or thermally induced fractures.

A key aspect in investigating traumatic events is to identify the mechanism that caused the injury. The known mechanism may reveal behavioral preferences of a perpetrator, classification of a crime or a sequence of events that had led to the injuries. Three main categories of skeletal trauma are generally recognized in regards to seminal weapons – gunshot, blunt force trauma and sharp force trauma. Blunt force trauma results from low-velocity mechanical force involving broad or blunt surfaces (e.g., blunt instrument, falls, energy waves or perpetrator's body parts). Sharp force trauma occurs from a low-velocity impact of an instrument with a cutting surface (e.g., knife, sword, machete, axe, but also saw). Gunshot trauma results from high-velocity interactions between a bone and a moving projectile. Appearance and patterns of skeletal injuries are relatively distinctive for each of the categories. Nevertheless, the number of endogenous and exogenous interfering factors (deceased person's age/sex, impact site, force, velocity, instrument size etc.) is nearly infinite and atypical, ambiguous or transitional characteristics may occur and eventually complicate the diagnosis. For gunshot trauma having resulted from a single fire, skeletal remains present typically one rounded entrance wound, a larger irregular exit wound, and radiating and concentric heaving fractures. Blunt force trauma is associated with linear, compressed or comminuted fractures. Occasionally, the causative instrument may leave a matching impression at the impact site. Sharp instruments produce weapon-specific injuries (stab wound, cut mark, chop marks, saw marks), which are reflective of blade characteristics (e.g., striations, kerf shape etc.).

Regardless of the type of trauma, the most attention has been given to injuries localized in human skull, most likely as a reflection of their severity and life-threatening nature. However, this does not exclude postcranial bones from being subject of skeletal injury analysis. Long bones of upper and lower limbs are particularly frequent in assessment of dismemberment trauma. Dismemberment, the intentional separation of body segments, is a specificity of forensic skeletal traumatology. Falling under the umbrella of postmortem injuries, these cases are mostly associated with perpetrator's attempts to obliterate evidence of the cause or manner of death and/or to prevent identification of the victim. Commonly, multiple sharp force trauma, such as saw or cut marks are evidence of dismemberment and subjects of a thorough analysis aimed at differentiating class and individual features of a causative tool. These cases may also include skeletal remains that were otherwise altered, for instance, boiled, burned or submerged in acid.

Alike the areas discussed in the previous chapters, skeletal trauma analysis is an ever-developing area of forensic anthropology whose existence is nowadays linked to advanced imaging and computation technologies. The virtual autopsy approach capable of displaying the spatial arrangement of fractured skeletal elements has made a great impact on diagnoses of violent events. High-resolution imaging technologies (e.g., microCT units, 3D stereomicroscopy, scanning electron microscopy) made it possible to examine patterns of osseous damage on a microscopic level. 3D computer modeling has been shown helpful in trauma-induced fragmentation of skeletal remains allowing to exploit various scenarios of a traumatic event without destroying the original evidence. And, matching 3D digital lesions with 3D digital copies of a suspected causative instrument has become more than a rarity.

Still, novel mechanisms of force that can damage human bones rapidly increase and experts are presented with less distinctive, even oddly looking skeletal injuries. Although for an anthropologist the descriptive aspect of trauma analysis will likely continue to prevail, the knowledge of dynamic and biomechanical principles of skeletal injuries are becoming more and more important to draw proper conclusions. Experimental and computation designs are critical in understanding how and why bone fractures occur. Advanced mathematical modeling, specifically using finite element analysis (FEA), has become a welcome aid for the validation of the bone‘s biomechanical behavior. The principal benefit of the computer modeling is that it allows working with human bones, albeit of virtual nature, varying in size and shape. The drawback is that bone is an anisotropic viscoelastic material, whose complex hierarchical structure with a wide range of intra- and inter-individual variations makes the mathematical simulations extremely computationally expensive unless a significant degree of simplification is involved. To this end, the majority of research remains focused on experimental modeling – ballistic and biomechanical experiments. Conducted typically on animal cadavers and artificial bones, experimental modeling analysis has been searching for alternative, more appropriate, model materials that would reproduce patterns of real-life injuries more authentically. The rapidly developing technology of 3D printing with the use of bioprinting materials combined with CT-generated digital models of victim's body segments is regarded as having the potential of substituting human bones in foreseeable future. There is little doubt that these new techniques bring a great improvement in the studies of skeletal trauma. Yet, similar to the other novelties with judicial consequences, not all of them have been proven admissible in courts. Although computer-aided approaches in skeletal traumatology can be considered extensions to the traditional analytical techniques, a valid argument against presenting such evidence in courts is that the non-materialistic nature of digital data makes them prone to careless, possibly untraceable modifications. As most of the skepticism derives from lacking standard procedure guidelines, which would fulfil the legal implications, only further research can fill these gaps.

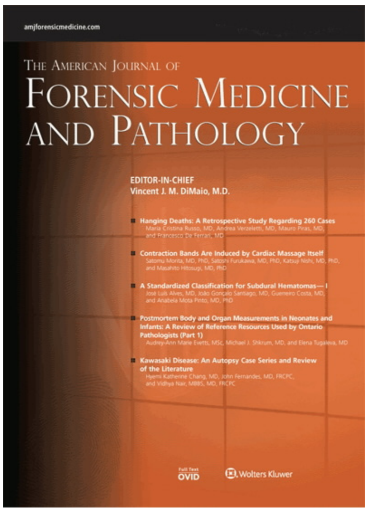
Two papers have been appended to this chapter, the first of them *"Agenesis of the Superior Cornua of the Thyroid Cartilage. A Rare Variant of Medicolegal Importance"* is a published case report, which raises awareness about rare anatomical variants occurring in the laryngohyoid complex. The paper falls in line with the triple studies on hyoid bone featured in Chapter 1. Specifically, it stresses the importance of neck elements from the diagnostic viewpoint. Human hyoid bones and cartilaginous laryngeal elements are highly variable, yet sometimes neglected, structures whose importance rises if evidence of trauma due to sustained neck injuries is implied. Isolated neck trauma may suggest both self-inflicted injuries (suicide by hanging) and trauma due to perpetrator's aggression (manual or ligature strangulation, compression with a blunt instrument). The knowledge of anatomical variants and morphological anomalies is imperative for a correct diagnosis at autopsy as well as in the process of anthropological examination.

The chapter closes with the last research paper in the volume entitled *"Virtual Approach to the Assessment of Skeletal Injuries in Human Skeletal Remains of Forensic Importance"*. It is a submitted manuscript draft (submitted on August 18th, 2016), whose objectives were drawn from three real forensic anthropology cases involving skeletal trauma. The case study, developed in collaboration with the Forensic Analysis Lab at North Carolina State University, outlines the first attempt to test a 3D virtual approach in the forensic context featuring the technology of 3D printing. The study examines two cases of gunshot wounds and dismembered skeletal remains with evidence of saw marks. One of the presented cases also demonstrates that the physical environment in which a body is deposited can largely alter the appearance of a skeletal injury.

4.1. Agenesis of the Superior Cornua of the Thyroid Cartilage A Rare Variant of Medicolegal Importance

by Petr Hejna, Martin Janík, Petra Urbanová

published in American Journal of Forensic Medicine and Pathology 36/1 (2015)



4.2. Virtual Approach to the Assessment of Skeletal Injuries in Human Skeletal Remains of Forensic Importance

by Petra Urbanová, Ann H. Ross, Mikoláš Jurda, Ivana Šplíchalová

submitted to Journal of Forensic and Legal Medicine, August 18th, 2016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