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PHD THESIS

MORPHOMETRIC AND MORPHOLOGICAL CONSIDERATIONS IN FACIAL RECONSTRUCTIONS

A B S T R A C T

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A B S T R A C T

This thesis focuses on facial reconstructions (FR) and aims to give a detailed description of the process of FR in general, on the methodologies and techniques used, as well as provide examples of FR in the special part of the thesis.

Facial reconstruction is the process by which the face of an individual (often unknown) is rebuilt based on the cranial structure. This process requires a detailed knowledge of Anatomy and Anthropology. It is widely used in Forensics, with the aim of positively identifying unknown victims, in historical-archaeological cases, where the skeletal remains are considered of historical value or for the reconstruction of hominid faces.

General Part

The general part of the thesis begins with providing information on the historical background of FR, where and how has it all started and what is the purpose of FR.

The first references of facial reconstructions in the scientific literature are linked to reconstructions of Johann Sebastian Bach and Dante Alighieri. Wilhelm His (1831-1904) started to measure tissue depths in cadavers to reconstruct the face of Johann Sebastian Bach onto the cast of his skull [1]. Similar to His, Arthur Kollmann (1859-1941) used the same principle to rebuild the face of Dante after his famous “death mask”. Several other attempts for the reconstruction of Dante’s face have been made since, one in 1921, by the famous anthropologist Fabio Frasetto, one in 2006 and the last one in 2022, while celebrating 700 years since the poet’s death [2].

First, we discuss terminology, as there are several partly similar, partly overlapping terms describing similar processes, and we make the distinction between facial superimposition and facial reconstruction, in particular. The terms facial reconstruction, facial estimation or facial approximation are synonyms. The distinction must be made between facial reconstruction and facial superimposition; the latter describes the process of comparing an antemortem photo of an individual to a cranium, to see if the two match and a positive identification can be made. This is a more cost-efficient method to identify a victim and is used in Forensics.

Facial Reconstruction Methods

The facial reconstruction methods are primarily divided into 2D and 3D. The 2D method can be, very basically, described as “drawing a face” onto a skull. There are specific steps that are taken to ensure a realistic face rendering, but essentially, the drawing is made according to the skull and by making sure the traits of the skull are expressed in the drawing. Karen Taylor is one of the main authorities in this field and she even recommends always using the 2D method prior to using the 3D method ,for more accuracy [3].

The 3D method relies on estimating the muscles and anatomical structures of the face onto the skull and layering them according to the true anatomy of the face. We describe the various 3D methods used, their benefits and their limitations. The most commonly used method is called the “British” method and is a combination of other previously used methods. This one relies on both the layering of the anatomical structures onto the skull, as well as on facial soft tissue thickness guides (FSTT). These FSTT’s are based on measurements of facial thickness depth gathered in collection databases from ethnically, age and sex diverse populations. Many studies have focused on bringing data regarding FSTT for various populations and all these efforts have culminated in an open-source data repository. This is a collection of FSTT from living, as well as dead individuals. The value of data collected from living individuals is clearly higher, due to the inherent degradation and desiccation of the tissues in embalmed cadavers; also there is more data collected from adults than there is from children, but it is a great leap forward into standardizing the FSTT data [4][5].

The 3D FR can be performed either manually, by adding clay on a skull (usually a 3D printed copy) or virtually, by computer aided methods, by digitizing the skull through scanning and then following the same protocol as the manual method with the help of various software, like ZBrush® for instance.

Other techniques, like photo mapping or age progression/regression are also discussed.

The accuracy of FR benefits greatly from the progress made in genetic sequencing, a method which attempts to generate a facial description of an individual based on his or her genes. Specific physical traits can be determined through genetic analysis; this type of research has mostly been undertaken within the last 20 years and is based on the fact that different DNA sequences are encoding specific physical traits like: eye color, skin color, hair color, genetic ancestry, sex, etc.[6] [7].

However, it is important to note, that given the early emerging stages of this type of research, limited testing and validation has occurred so far and also, there are warnings that because of the high complexity of the genetic processes involved in physical appearance, molecular photofitting “may be too aspirational to ever be sufficiently achieved” [8]. At the same time, ethical considerations, and debates around using DNA sequencing for forensic identification are also taking place.

Further, we discuss the form and heritability of the face and again, we touch on the subject of gene expression of specific traits, but we point out that genes associated with facial patterns have often proven inconsistent among different population groups. There are genes that seem to affect only one population, or even have different expressions depending on the population [8].

Face Recognition

Face recognition is very relevant for the process of FR, as it is important to acknowledge the importance of certain facial features in the face recognition process, especially in the Forensic field, where the identification of the individual is the ultimate goal of the process. We, therefore, discuss the eyes and the mouth in particular, as being the main features that are involved in the process of face recognition. Fox and Damjanovic analyze the eye region in particular and conclude that the eye region has the ability to activate the amygdala system of the brain (involved in face recognition) and also that the eyes provide enough information for someone to judge another person’s state of mind [9]. However, a different view regarding facial features is taken by Blais et al., in their paper called “The eyes are not the window to basic emotions”, who consider the mouth as being the most important feature in estimating both static and dynamic facial expressions [10].

Lee and Wilkinson raise another important issue regarding the FR, namely the importance of the FR performer and how their ability is dependent on how familiar a face is, i.e., the “cross-race” effect, where faces of familiar ancestry are more easily recognized than faces of an unfamiliar ancestry [11]. This is highly relevant to facial reconstructions, as the rendering of an accurate FR depends also on this effect on the practitioner performing it. Lee and Wilkinson have tested out this hypothesis and have proven that, indeed, this is a factor to take into consideration, as the practitioners produced better FR in cases of familiar ancestry [11].

Morphology of the face, facial proportions, and landmarks

The next part of the thesis is dedicated to discussing the face form and morphology of the face in general.

We describe the facial proportions based on anthropometric landmarks, as well as the neo-classical beauty canons and their applicability for various ethnic groups. These are Greek neo-classical canons of beauty, from ca. 450 BC but they are still relevant today in the anthropological, plastic surgery or orthodontic practice. Based on these canons, the nose would fit perfectly within the middle fifth and the lateral fifth extends from the lateral canthus to the lateral most visible point of the ear helix, on frontal view.

Since the 1970’s and 1980’s Leslie Farkas has published, probably the largest and most widely used, cranio-facial anthropometrical collection using 132 traditional direct measurements [12] and his contribution to this field is invaluable. Farkas’ collection is comprised out of 2326 individuals of European ancestry, men, and women, aged 0-25 years.

A more recent collection, using 3D photogrammetry is the 3DFN (3D Facial Norms) database, which was created as part of the FaceBase, an NIH funded Consortium in an effort to provide data for the scientific community.

Both collections focus on the same type of population, namely North American Whites, both men and women. The age groups of the two databases does vary, but there is enough overlap to be able to compare the efficacy and accuracy of the measurement methods [13]. The database features an interactive interface, so users can search and download 3D measurements, appropriate statistics and calculate Z scores; also, for every individual in the database there is demographic description and genomic data available. Thus, this extensive data repository can be used for anything from anthropological, morphometric and all the way to genomic studies.

Since facial features vary greatly among different ethnic groups, a large number of studies have focused on this topic. Especially the orbital, nasal and oral regions have been explored, in Caucasian, Black, Asian populations etc. [14] [15]. The methods used to assess these differences range anywhere between two-dimensional imaging techniques, like simple photography, to radiographic images like lateral cephalograms or computer tomography all the way to three-dimensional surface imaging.

Fang et al. argue that the most variation between the different ethnic groups exists in the forehead height, followed by interocular distance and nasal width while the least amount of variability is found in the ear height and facial width. The midface widths zygion-zygion, exocanthion-exocanthion and gonion-gonion show the least amount of variation amongst different ethnic groups. No great differences were found among sexes in the neoclassical facial proportions [16].

Consistent with Fang's et al. study, Farkas et al. studied anthropometrical differences in Caucasians, Middle-Easterners, Asians and Africans and found that the values of forehead height, mouth width and ear height were identical to North America Whites (NAW) in both sexes, while the orbital regions presented the most variation compared to NAW and nose heights and widths also varied greatly [17].

We then go on to explore the inter-ethnical differences in eyes, nose, and mouth morphology, as well as discuss face morphology in children compared to adults, healthy versus syndromic individuals, why certain faces are perceived as being more attractive than others, and how this all relates to FR.

Quite predictably, all inter-ethnic studies regarding the Golden Ratio and the neo-classical proportions found significant differences in terms of these measurements in between populations and among genders, but a recent study of Zacharopoulos et al. found that even for most present-day Greeks, the neoclassical canons were not valid. So, not only are these old beauty canons not applicable to different ethnicities, but they are not even relevant to the modern Greek population, which is significant for corrective surgery and for facial approximation techniques [18].

Facial Imaging

The next chapter begins with the exploration of the anthropometric imaging instruments, from direct anthropometry to computerized anthropometry and the exploration of the types of landmarks, which form the basis of any anthropometric endeavor.

The instruments used can be divided into two main categories:

- Optical, non-contact - like 3D range cameras, Moire topography, stereophotogrammetry, laser scanners
- Contact – like the electromagnetic or electromechanical digitizers, ultrasound probes, etc.

None of the instruments described are invasive, while the optical scanners are preferred for the rapidity of data accumulation and for the high amount of data being processed. Nowadays, they are more frequently used in both clinical, as well as in research facilities and are becoming more affordable.

The electromechanical and electromagnetic digitizers also have their benefits and are mainly related to their cost-efficiency. They are, however, more prone to artifacts.

Facial scanners are quickly becoming indispensable in clinical and research units and are used in a vast array of domains; especially in dentistry, facial scanners are becoming more affordable and widely used, as clinicians get accustomed with their potential benefits.

There are four types of scanners: photogrammetry, stereophotogrammetry, structured light and laser scanning. The first two types are based on passive methods (based on two or more photographs taken of the subject), while the last two types are active methods (meaning that 3D sensors capture light via triangulation) [19].

The main advantages that facial scanners have are that they are non-invasive, accurate, easy to use and reproducible. The main disadvantage is probably related to the high cost.

More recently, scanners have been incorporated into mobile devices, like smartphones, tablets, etc. and numerous studies have investigated their capacity to produce accurate images.

Mai and Lee, Kuhlman et al. and Andrews et al. have all reported similar findings regarding mobile device scanners, that is that they are less accurate than the professional ones but that they are appropriate for clinical use [20] [21] [22].

Smartphones have recently been upgraded with infrared structured light depth-sensing cameras which have increased their scanning accuracy; this system is similar to professional scanners and is based on the so called “time of flight” technique. On the other hand, professional scanners have more sensitive-to-depth sensors. Some of the studies reviewed reported better results for smartphones compared to professional scanners, like the iPhoneX that managed to achieve a shorter scan time, but it performed worse in terms of depth accuracy of over 2mm.

The conclusion drawn by the authors is that all analyzed scanners are clinically acceptable, with the following ranking: stationary stereophotogrammetric scanners, followed by portable ones and then followed by smartphones. The main challenge of the smartphones seemed to be the acquisition of irregular surface images and the main advantages consisted in their low cost and their portability.

Computed Tomography, Cone Beam Computed Tomography and Magnetic Resonance Imaging

CT, CBCT and MRI are all relevant FR research related imaging techniques. An essential part of FR is the validation of estimating equations. There are several estimating equations (that are extensively explored in the thesis, in Chapter 6) for estimating the position, dimension, angulation, etc. of the mouth, the nose, the ears, positioning of the eyeballs, etc., essentially all soft tissue facial features that leave little or no impression on the skull. Therefore, a great part of the FR relies on the age, sex and ethnically specific research that has been carried out before. This type of research explores the relationship between the skull and soft tissue (in a way similar to our study described in Chapter 7), such as: positioning of the eyeball relative to the orbital margins, protrusion of the eyeball beyond the orbit, position of Pronasale point depending on the piriform aperture, inclination and aspect of the tip of the nose depending on the nasal spine, height of lips based on the dimension of the teeth, width of the mouth depending on the upper anterior teeth, position and inclination of the ear based on the mastoid and the list can go on. Also, valuable FSTT data can be acquired, especially from CBCT scans, where the orthostatic position of the patient is beneficial in terms of precision of measurement, as lying down (like for CT or MRI scans) can cause the compression and deformation of the soft tissue.

CT, CBCT and MRI form a chapter of the thesis because these are technologies that allow the visualization of both the hard and soft tissue at the same time, making them extremely efficient for this kind of research. The thesis explores in more depth their specific applications, benefits, and limitations.

Automatic Facial Recognition

The next part of the thesis explores the automatic facial recognition systems, also known as deep-learning or computer-based systems, which are all subcategories of artificial intelligence (AI). Their main applications, relevant to our topic, would be in the medical and forensic field but the versatility of the face recognition systems goes way beyond these domains. In fact, the applications of emotion reading based on the face could form a thesis on its own; our focus, however, is only to shed light on technologies associated with the face, most of them recently emerged and potentially impacting research and our society.

In the medical field, AI based facial recognition has been found to be helpful in diagnostics; this hypothesis is based on the observation that many of the metabolic, genetic or neuromuscular disorders have a specific facial appearance or a facial phenotype that could potentially be recognized by a computer, hence optimizing and facilitating the screening and diagnosis of specific disease, and at the same time ensuring a cost efficient process and an easier decision making. Automated machine diagnosis has started to be used since the early years 2000 and one of the first applications in AI medicine was for children diagnosis, mainly for genetic and neuromuscular disease [23].

Since then, facial recognition-based AI medicine has evolved and has become an integral part of radiology, dermatology, endocrinology, etc.

The automated emotion recognition systems based on the face form part of research for very diverse domains, like monitoring the mental health of patients, interpreting the ratings of pleasantness in music concerts based on the audience's facial expressions, for enhancing human-robot interactions, for kinship verification based on AI etc. [24] [25] [26] [27].

The relationship between these technologies and the FR is that all this is based on deep knowledge of the face, on large morphometric datasets from healthy as well as diseased individuals and made possible through advancement in the imaging and computer field. Therefore, the anthropometrical data acquired from the FR research is essential to developing further technology based on the study of the face.

All these techniques share common ground with facial reconstruction techniques and benefit from publicly available soft tissue depth datasets and anthropometrical studies from various populational groups. The advancement in computer technology has made the readily available data easily accessible for worldwide research, thereby further advancing scientific progress.

Special Part

Facial Reconstruction on Virtual Skull

This next chapter forms the largest part of the thesis and is based on the step-by-step description of a facial reconstruction. The whole process is analyzed from the scientific literature perspective and reproduced in detail. We start with the facial development, beginning with pre-birth development, all the way to the aging process of the face, as this is highly relevant to FR. Knowledge of the developmental stages of the growing and aging face has great impact on the accuracy of the FR. Also, variations of the facial features depending on age, sex and ethnicity are discussed at large in this chapter (Chapter 6), as are the identification of a person's age, sex and ethnicity based on the skull alone. Each part of the skull (like the occipital bone, the orbital ridges, shape and dimension of the piriform aperture, position, and dimension of the mastoid bone, etc.) bears sexual dimorphism, age, and ethnical related variations. Attributing the skull a correct anthropological identity is key to a successful FR and details around this topic are being presented in the first part of Chapter 6.

The most used estimation methods and regression formulas for the soft tissue are being described in the introductory part of chapter 6.

Prediction of the nose

Revealing the shape of the nose and creating nasal projection guidelines has been a research focus for decades. Generally, these guidelines focus on predicting the Pronasale (the most anterior part of the nose) and predicting if it is upturned, downturned or level. Some of these methods are famous, such as Krogman and Iscan's "threefold ANS method [28], Gerasimov's "two tangent method" [29], the method described by Prokopec and Ubelaker [30], Macho's method [31], the method described by Stephan et al [32] or the one described by Rynn and Wilkinson [33].

The "threefold ANS" method is quite popular in the United States and consists of tripling the length of the anterior nasal spine (anterior nasal spine) and then adding the mean tissue depth at Subnasale in the direction projected by the ANS [28]. A variation of this method was tested on lateral cephalograms and found to be unreliable because the VMJ (vomer maxillary junction) was often indistinct, so the length of the ANS was taken from lateral border of the piriform aperture to the Acanthion, which gave rise to inaccuracies, especially since the method requires the threefold multiplication, therefore multiplying the error as well [34].

Macho's method was based on seven cranial landmarks: the height of the piriform aperture, from Rhinion to the ANS, height of nose, from Nasion to ANS, distance from the Sella-Nasion plane to the most prominent point of the nasal bones, height of the nose from Nasion point, height of Rhinion and the angle between ANS- Nasion plane and ANS plane- Rhinion plane. She also mentioned that the nasal thickness and depth were correlated with age [35].

The "two tangent method" created by Gerasimov seems to be relevant from an anatomical and developmental point of view; he suggested that "the soft part of the nose is an organic continuation of the nasal bones" and therefore, the line following the direction of the ANS, when intersecting the projection of the second line, tangent to the most distal part of the nasal bone, should predict the tip of the nose [34]. The Rhinion and Acanthion variabilities have been incorporated in different versions of this method for nasal estimation. The angle of the Rhinion, the Nasion and Acanthion have also been incorporated into a multivariate statistical analysis. They found that the direction of the nasal bridge is highly correlated with the direction of the nasal septum, but the nasal tip seemed to be independent and possible exogenous factors were suggested to be the cause for that, such as nutrition for instance. A notable comment on Macho's study is also the fact that she demonstrated that the profile line of the external nose does not always follow the underlying structure [35].

In 2006, Rynn and Wilkinson also tested out six nasal prediction techniques: Gerasimov, Krogman, George, Prokopec and Ubelaker, Macho and Stephan's. They found Gerasimov's method to be quite accurate, and the best performing out of all methods tested. Krogman technique was found inaccurate, as it was underestimating the nasal projection by a significant amount; Macho's method also performed poorly, as it was underestimating the depth and height of the nose for both males and females and just height for males. Prokopec and Ublaker's method was also unreliable, as it wasn't taking into account the asymmetry of the nasal lateral borders. Regarding Stephan's method, they found it accurate in predicting the nose for females but not for males in Caucasoid individuals; the problem with Stephan's et al. method was that it involved taking complex measurements and was found to be complicated and time consuming [36] .

Prediction of the mouth

Reconstructing the mouth from a dry skull is notoriously difficult, because it consists of soft tissue entirely and leaves almost no marks on the skull.

Krogman and Iscan stated that the face is just the cover of the bony structure and that a close relationship exists between the two [28], however, the soft tissue, especially the mobile parts of the face are more difficult to approximate.

The skull does act like a matrix for the face, however, the muscles and soft tissue forming the outer face carry great individual variability, depending on habits, lifestyle, parafunctions, ageing process, etc.

It is acknowledged that the individual body mass index (BMI) plays an important role in face recognition, but there is no way to estimate this from the skull. Likewise, other habits, like smoking, alcohol consumption, certain medication can affect the aspect of the face.

There are several aspects of the mouth that must be considered when reconstructing this region: the mouth width, the height of the lips, the protrusion of the lips and the philtrum of the upper lip.

The morphology of the mouth is most commonly related to the anterior teeth but interpupillary distance or the medial borders of the iris have also been considered to estimate mouth width. In the sagittal plane, the morphology of the lips and the protrusion of the lips was found to be closely related to the anterior teeth and more precisely to the incisor occlusion. This is especially important in orthodontic treatment because the retraction or proclination of the maxillary anterior teeth will induce profile changes for the patient. A strong correlation was found between the position of the upper central incisors and the position of the upper lip in the saggital plane. It is generally accepted that the dental occlusion will strongly influence the aspect of the oral region, the peri-oral succusses, the mouth width and the height of the lips.

The topic of morphological changes relative to age and sex have been explored in depth by many researchers, as it is a highly relevant to the Anthropological field, as well as to the Orthodontic, Maxillofacial and Esthetic Surgery fields. They concluded that the mouth width, philtrum width, total lip height and lip volume were significantly larger in men, increased with age and had age-sex interactions. The vermilion area and height of lips parameters increased with age until late adolescence and then decreased with ageing while the vermilion height-to - mouth width ratio was larger in women and also decreased with age [37].

The decrease in lip volume has been a stigmata of face ageing and therefore a lot of research has been undertaken regarding this topic, especially within the Esthetic Surgery departments.

Raschke et al. have performed a study on 346 males, between the ages of 20 to 60 and have found a few changes in lip morphology that occur with ageing: a decrease in height of the upper and lower vermilion and an increase of the cutaneous part of the lips [38].

Another interesting, longitudinal study, performed on a cohort of patients evaluated over a period of 10 years found a retrusion of the upper lips in females and a decrease of upper lip thickness in both males and females [39].

Wilkinson et al. studied the position of the corners of the mouth relative to the eyes and the thickness of the upper lip relative to the upper incisors. She found positive correlations between the interlimbus (the distance between the medial borders of the iris) distance, the interpupillary distances and the width of the mouth, with the interlimbus distance being the most reliable method for mouth width approximation.

Regarding the lip height, they reported positive correlation between the upper lip height and the height of the upper incisors, between the lower lip height and the height of the lower lip and between the total lip height and the height of upper and lower teeth. The correlations were present in both the women and the male samples, for both White and Indian individuals; however, for lip thickness there were differences between the White and the Asian sample, with Asian individuals displaying thicker lips. This study suggests that individual, gender and ethnic variations need to be acknowledged.

Another frequently used guideline belongs to Stephan and Henneberg, stating that the inter-canine distance represents 75% of the total mouth width [40].

All these factors were carefully assessed in our study and are described in detail in chapter 6.

Prediction of the eyes

Traditionally, the eyeball was placed in the middle of the orbit for FR, other theories, like Wolff's from 1976, postulated that the cornea is tangential to the line uniting the superior with the inferior orbital borders [41]. More recent studies, however, have found that the position of the eyeball is not in the middle of the orbit, but it is placed 1.4 mm superior and 2.3 mm lateral to the center of the orbit [42].

The position of the inner and outer canthi is dictated by the nasolacrimal duct on the medial side and by the malar tubercle on the lateral side. The inner canthus is positioned 2 mm inside of the nasolacrimal duct, while the outer canthus is positioned 3-4 mm from the malar tubercle. In the sagittal view, research has found that the lateral canthis is approximately 5mm posterior of the corneal apex; at the same time, the lateral canthi is usually higher than the medial canthi [43].

The upper eyelid overlaps and extends lateral to the lower eyelid at the lateral canthus. Ageing causes sagging of the lower eyelid and a higher skinfold. The position of the epicanthic fold can be approximated from the shape of the supraorbital margin.

Deep-set eyes are usually found when the orbital rim is greatly thickened and is protrusive relative to the lower one.

As a rule, the eye fissure represents 60-80% of the width of the orbit.

Regarding the eyeball protrusion, research found the following regression formula:

Eyeball protrusion=18.3-(0.4 x orbit depth)

All measurements undertaken in our study, as well as the screenshots saved during the reconstruction process can be found in the Annexes section of our thesis. It shows the correct placement of the eyeball relative to the orbit in the horizontal, vertical, and sagittal plane.

Then, we go on to describe the methodology used for our FR; we give details regarding the software used and, on the method applied. The FR process began by placing the virtual FSTT (facial soft tissue thickness) pegs, followed by application of each individual facial muscle (one by one), based on their anatomical position and their dimension. The eyeball is the next soft tissue element to be reconstructed, followed by the estimation of the nose, the mouth, and the ears, which are more difficult to reconstruct, because they leave little to no marks on the skull. The estimation of the mouth (thickness of the lips, width of the mouth, position of Cheilion landmark, depth, and contour of the upper lip philtrum, etc.) is notoriously difficult, therefore we explore this in depth in the next chapter, by analyzing the relation between hard and soft tissue of the mouth region.

Most of the reconstruction is based on a combination of Gerasimov's method and of the British method and the process of estimating each facial feature is described, measurements of our skull are presented, as well as estimation formulas that have been used. Photographs pertaining to screenshots taken during the reconstruction process are available in the Annexes, where every step of the process can be easily visualized and reproduced upon.

Specific issues regarding edentulous skulls, environmental factors, like sun exposure or smoking and their effects on the face and therefore on what the reconstruction process needs to consider have also been mentioned. Any information available on the person's environment, lifestyle and risk factors must be considered, as they will aid in rendering a realistic image of the individual.

Populational data study: A morphometrical Anthropometrical Analysis of the Upper Lip in Adult Romanian Population

Chapter 7 of the thesis will describe the study undertaken on CT scan images that explores the relationship between hard and soft tissue in the mouth region. The CT scans belong to patients investigated in the Municipal Hospital of Timișoara and none of the patients were exposed to additional ionizing radiation, this study being a retrospective study. The relevant Ethics committee approval can be found in the Annexes section. As previously mentioned, the estimation of the mouth can often prove to be a difficult task to achieve, as there is little "information" visible on the skull, so the reconstruction of the mouth relies on a dose of artistic interpretation that can be detrimental to the reproducibility and accuracy of the FR.

The mouth has great ethnically, sex and age variance, therefore all this needs to be considered when attempting to reconstruct or predict the mouth.

It is generally accepted that ethnicity will also influence the morphology of the facial features and same applies to the lips and the oral region. Therefore, the need for studies to collect normative data from various ethnic groups is evident. So far, to the best of our knowledge, there is no data collection regarding lip morphology of Romanian population. The closest datasets that could be useful for this ethnic group would be the data collected from other Eastern European population, like Polish, Russian, Lithuanian, etc. [44]. However, there are variations of the facial features of populations that are obvious even among different regions within the same country, so data collections from different countries may lack accuracy.

We focused on bringing new normative data regarding the relationship between the upper lip and the upper anterior teeth, knowing that there is a strong relation between the upper lip and the maxillary anterior teeth in the sagittal, vertical, and transverse dimension. This has been largely explored, mostly in orthodontic studies, in different types of populations, as it is highly relevant in treatment planning, especially in cases where upper premolar extraction is considered. As previously mentioned, in craniofacial superimpositions it's important to acknowledge the fact that orthodontic pathologies, especially those of the anterior teeth, will affect the position of the lips.

Our study explores the direct relation between the upper anterior teeth and the position of the Cheilion and Cupid Bow points landmarks. All measurements were taken for right and left sides.

The study was performed on CT scans of 226 individuals, 119 men and 107 women, all adult patients from the database of the Emergency Municipal Hospital of Timisoara, Romania.

The patients' records were anonymized and were divided into subgroups depending on age and sex. There were three age groups: 18-25 years old, 25-35 years old and 35-43 years old. The study was limited to the age of 43 due to the very large number of patients above this age that had compromised upper anterior teeth and therefore could not be included in our study. There were a total of ten landmarks taken into consideration, eight of these in the frontal plane and the rest in the sagittal plane, five hard tissue and five soft tissue landmarks, as follows: upper central incisors - right and left (the midpoint of the buccal surface at the cervical limit of the anatomical crown), upper canines (the midpoint of the buccal surface at the cervical limit of the anatomical crown) - right and left, Cupid Bow points - right and left, Cheilion – right and left, soft tissue Point A and hard tissue Point A. The craniofacial complex was orientated on the Frankfurt Horizontal Plane (FHP). The landmark placement and all measurements were repeated for a number of 44 patients in order to assess the intra-operator error.

To test whether variations in different measurement distances predict other distances' dimensions, a series of linear models were calculated. Sufficient approximation of residual normality and variance homogeneity across the investigated ranges, linear relationships and the absence of influential outliers were visually confirmed.

There is positive correlation between all analyzed landmarks, with the most relevant one being the one between inter-canine distance and inter-cheilion distance, confirming existent data from the literature. The inter-canine distance was larger in men in all groups. The distance between hard and soft tissue Point A was found to be higher in men compared to women, in all age groups. This was intended to serve as normative data and as a guide for approximating the depth of the oral philtrum in CFS.

All inter-landmark distances were larger in men, compared to women, with one exception, that is the distance between the Central Incisor right and Central Incisor left.

Our main findings coincide with similar research of the field and found positive correlation between the soft tissue and hard tissue landmarks, especially for the inter-canine distance relative to inter-cheilion distance.

Orthodontic analysis of an ancient cranium aided by manual partial reconstruction of the mandible. Personal contribution.

As previously discussed, facial reconstruction techniques are often employed for archaeological specimens, where there is a research interest in either recreating the appearance of an important historical figure or for analyzing the facial features of previous civilizations in general, for investigating ancient pathologies or for assessing the frequency and changes of these pathologies over time. In all these circumstances FR has proven a valuable tool. Often, it has also brought public attention and media coverage of these topics through animated FR.

Our study is based on the partial reconstruction of an ancient cranium that was uncovered in an archaeological site, as part of an assessment regarding an orthodontic anomaly. This study is only a partial reconstruction of an ancient mandible and is intended as an example of reconstruction used with a very specific purpose in mind, that of analyzing the pathology of an ancient skull.

Without this minimal reconstruction, the analysis of the dental arches and of the occlusion would not have been possible, therefore the exploration of ancient pathology could not have been undertaken.

Chapter 8 gives more detail regarding the methods and results obtained, while photographs of the jaws are also presented.

Discussions

Finally, the last part of the thesis explores the topic of virtual surgical planning (VSP) and its relationship to FR, as well as the topic of automated facial reconstructions.

One of the challenges of reconstructive surgery lies in the reconstruction of cartilaginous surfaces, like the ear, nose, etc., for which the gold standard remains the autologous tissue donors, where grafts are usually harvested from the ear, septum, or costal cartilage. The main limitations of these reconstructive techniques are related to the associated risks of graft warping or long-term immunosuppression, therefore the need and desire for an alternative method is consistent. Tissue engineering and 3D printing of custom-made scaffolds for reconstructive surgery have been proposed to mitigate the requirements of donor sites and reduce morbidity; they can also improve position and design therefore enhancing the outcome. These techniques are totally dependent on computer design and 3D printing, which is very closely related to the facial reconstruction techniques employed in the forensic field.

Recent research in the computer field combined with larger and more diverse datasets, as well as more accurate prediction methods have taken facial reconstructions another step forward, into automated facial reconstructions, a predictable and probable path, judging by the other, so many applications of AI.

Automated tools are more frequently used in facial approximations and the more reliable the computer software becomes, the more accurately rendered faces we can expect.

Even though computer generated FR will most likely lack the “human touch” to begin with, the vast majority of the forensic FR do not actually require this finesse, since their prime purpose is only to achieve a positive identification of an individual. In the case of historical or museum FR, the personal touch will probably be more desirable.

Judging by the fast progress in the AI field, however, and by the enormous database that it can access, it is very likely that soon the AI will be able to render very accurate FR on its own. The database is essential, meaning that the FSTT’s and the morphometric measurements of large and diverse populational groups, together with estimation equations are the core of the computer-generated FR.

The advantages of the computer-generated FR are mainly related to time efficiency and easiness; the computer can generate several, repeatable and objective versions of FR in a short time frame, allowing the qualified practitioner to choose the most appropriate version. Most computer- generated FR to date rely on a combination of input data for hard tissue (CT, CBCT, MRI), soft tissue depth markers from diverse populations and statistical analysis to generate a probable outcome.

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