

## PHOTOGRAMMETRY VS. ANTHROSCOPY

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### ABSTRACT:

Anthroposcopy means judging the body's built by inspection. Visual assessment, one of the oldest methods of examination, still used in medicine today, is not reliable because is highly subjective. Anthropometric studies are therefore needed for quantitative assessment. Traditional methods use an assortment of instruments (goniometers, rulers and tapes), which can cause varying measurement errors, depending on the region of interest and the examiner's experience and consequently may produce conflicting results, making the worth of scientific information doubtful. In this paper we discuss the use of photogrammetric techniques for craniofacial studies, explaining how this technique can be implemented and what are the comparative advantages to the commonly used methods that are still favored by the majority of medical doctors. Photogrammetry not only can minimize the above sources of errors, but it can also assist the doctor to perform and repeat the measurements in later time periods from that of the time of acquisition. We investigated 102 dissected facial halves and we used pins as markers of anatomic facial details in order to determine the *Modiolus* area relative to other stable, anatomic, osteal craniometrical points and measure details of the Zygomaticus Major muscle. The image acquisition and the photogrammetric processing including camera calibration, using a low cost software that supports maximum ease of use, are analyzed and results from the quantitative assessment are presented. Moreover, the paper demonstrates the feasibility that non-experts in photogrammetry can use commercial cameras and simple photogrammetric software tools to derive the required information.

## 1. INTRODUCTION

### 1.1 Anthroposcopy and Anthropometry

Anthroposcopy (from the Greek word anthropos, "human", and skopein, "examine") means judging the body's built by inspection. Visual assessment, one of the oldest methods of examination, still used in medicine today, is not reliable because the criteria for judgment are highly subjective. The examiner's judgment is predominant as it is influenced by his/her aesthetic perception and experience. For example a great value of experience is necessary in determining the approximate size of a feature, including the ability to discriminate taxonomy of small, medium and large features.

For the identification of craniofacial features the main problems are caused by the three-dimensional nature of the face and especially by the impulse to make estimates based on subconscious comparisons of the sizes of various facial features. With respect to this, visual evaluation alone does not provide enough information about the extent of a defect or morphology of anatomical structures. Errors apart from the examiner's failing may arise due to the method of the examination, the lighting conditions and therefore anthropometric confirmation is required.

Anthropometrically oriented studies are part of medical research and deal with measuring and analyzing absolute quantities and proportions of the human body, including the head. Face anthropometry has applications in clinical diagnostics as well as in

operation planning, forensics and The Arts. For clinical diagnosis based on Anthropometry, data are collected from a population of individuals and are further analyzed in order to extract a norm for facial features.

### 1.2 Current methods and tools in anthropometric craniofacial studies

Traditionally, facial measurements are taken by a medical doctor, using an different measuring devices such as rulers, tapes, and goniometers. The sliding caliper is used to measure the linear projective distances between two landmarks in the same or in neighboring planes. The spreading caliper is used to determine projective linear distance and the soft metric tape for tangential linear distances between landmarks.

Some measurements are of a rather qualitative nature, i.e., hard to define in numbers, such as the shape of the face is concave. These judgments depend to a large extent on the experience of the examiner, the latter is also important for deriving measurements with the sliding caliper (accuracy up to 3-4 mm). For more precise measurements, a standardized set of landmarks (Figure1) is defined on the head. Landmarks are prominent feature points, which can be found by visual examination or palpation or dissection, i.e. the latter in the case of human cadavers.

The individual measurements can be linear or angular. The linear measurements are divided into projective, where the shortest distance between two landmarks is determined and tangential, where the measurement is taken along the skin surface by the soft measuring tape between the two terminal landmarks. Lateral projective depth measurements of the face taken between

the tragion of the ear and the glabella, nasion, subnasale and gnathion in the facial midline provide certain information about the level difference between the parallel frontal planes and but do not define the true depth of the face.

However, even if the overall quality of the measurements can greatly improve with practice the use of improper instruments may produce conflicting results (Farkas, 1994), and the most common error sources in craniofacial anthropometry are in addition to the above the improper identifications of landmarks and the improper measuring technique.

### 1.3 Measuring the anatomy of the Zygomaticus Major muscle

Facial measurements are also used for investigations of the anatomy of facial muscles. The main interest is on the mimetic muscles as they display a high degree of variability and, as opposed to skeletal muscles, they exhibit variability among themselves (Pessa et al., 1998). The Zygomaticus Major is an important muscle for facial expression, originates at the lateral zygoma and inserts into the corner of the mouth and is usually depicted as a single unit or a muscular bundle. The muscle is responsible for pulling the lips upward and laterally to create a smile during facial animation. Its structure has great clinical importance among others in reconstructive and aesthetic surgery of the face, in facial movement in patients with Synkinesis, in the formation of the nasolabial fold and in dental surgery. Precise measurements are therefore required to analyze the morphology and structure of the muscle. In our study we derive the metric information from hemifacial dissections in cadavers utilizing images and photogrammetric techniques for the identification of craniofacial landmarks with an overall accuracy of less than 1 mm.

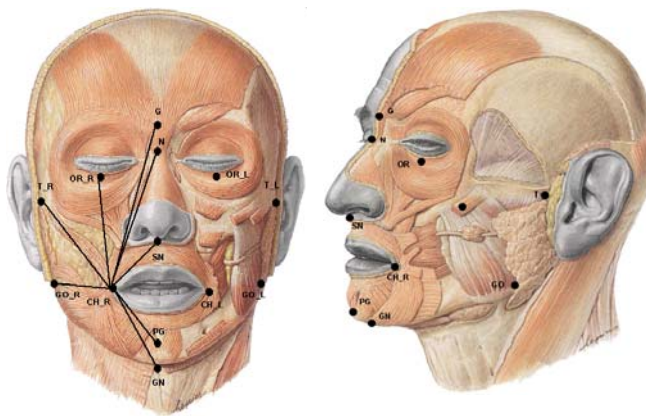


Figure 1. Craniofacial surface landmarks of the face in frontal (left) and lateral aspects (right). In our study the landmarks were marked on the skin using pins before taking the pictures (modified image from Sobotta (2001)).

## 2. THE ROLE OF PHOTOGRAMMETRY

In the quest for more accurate and reliable derivation of metric information, automation and repetition of the measurements at any time photogrammetry has a comparative advantage. In many respects the identification and measurement of craniofacial landmarks or other facial features including muscles, al-

though described as a medical problem it has similarities to usual photogrammetric problem and can be treated as one. Important to note that an amateur or a medical doctor, with minimal experience in photogrammetric techniques should be able to acquire and process the image data and to assess the results in a cost efficient, simple and effective way. The above is supported by the following trends that accounts for the use of close-range photogrammetry by non-photogrammetrists as noted by Fraser (2004): (a) the increasing availability and suitability of off-the-shelf, consumer grade digital cameras for photogrammetric applications (architectural, archaeological, forensic etc.), (b) the enhanced capabilities available in 3D modeling and visualization, processes which benefit from more comprehensive measurement and imagery data and (c) the developments in photogrammetric data processing, including improved computational models, and the development of automated image measurement and photogrammetric orientation software systems designed for use with low-cost digital cameras.

In generic terms the photogrammetric problem can be seen as the determination of the camera interior and exterior orientation parameters and the coordinates of object space points of interest and the fundamental mathematics remain the same (Patiás, 2004). With known camera internal geometry, as well as position and attitude we are able to compute a point in three dimensional space that is uniquely defined by the intersection of two or more corresponding rays (or alternatively of the “homologous” points on the two or more images). The determination of the interior orientation of the camera, defined by the geometric parameters of the camera itself and the distortions, is required in the first stage. The distortions depend on the distance from the object to the camera and the distance from the object to the plane on which the camera is focused. The determination of and correction for these systematic errors is significant for the current application, since their magnitudes can be many times the desired accuracy of the product and their presence leads to a bias in the results. The correction can be done through the calibration procedure of the camera (Section 3.3) or by including the distortion parameters in a simultaneous bundle adjustment, in which the camera and point parameters are determined. The second stage following camera calibration is the derivation of the sensor (camera) orientation. The two basic mathematical models used by photogrammetrists are the coplanarity equation for relative orientation, and the collinearity equations for spatial resection, intersection and multi-image bundle adjustment (exterior orientation), with or without camera self-calibration (Mikhail et al. 2001).

## 3. METHODOLOGY

### 3.1 Material

The material consisted of a series of 51 adult formalin fixed human cadavers, 34 female and 17 male, with age ranging from 53-97 years. The specimens were prepared by routine histological preparation technique in the Anatomical Department of the Medical School of the University of Cologne in Germany. The cadavers were in a recumbent position facing upwards. The skin and the thin subcutaneous fascia and fat were removed with attention not to damage the underlying muscles, especially the Zygomaticus Major, as well as the nerves and the blood vessels. The morphology and the dimensions of the Zygomaticus Major were examined in detailed and no differentiation in the dissection was made between male and female cadavers. 51 left and 51 right hemifacial dissections were performed with special fo-

cus in the histological preparation of the Zygomaticus Major muscle and in the *Modiolus*<sup>1</sup> at the angle of the mouth, defined by the craniometrical point CH\_R and CH\_L (*Cheilion*), where the facial muscles converge (Figure 1a).

In order to derive metric information by photogrammetric means, namely determine the *Modiolus* relative to other stable, anatomic, osteal craniometrical points, and measure details of the Zygomaticus Major, we used pins in different colors with diameter of 5 mm as markers of anatomic facial details (Figure 1). These points are commonly known as *Glabella* (G), *Nasion* (N), *Orbitale* (OR\_R, OR\_L), *Tragian* (T\_R, TR\_L), *Subnasale* (SN), *Pagonion* (PG), *Gnathion* (GN), *Gonion* (GO\_R, GO\_L) (Farkas, 1994). Additional markers were used to define the origin, insertion and the average width of the Zygomaticus Major muscle as well as observed muscle bundles of the Zygomaticus Major close to its insertion.

### 3.2 Image acquisition

Five consecutive color images have been acquired with the amateur digital camera Canon IXUS A400 (Figure 2), which has been calibrated beforehand (Section 3.3) and the camera parameters are listed in Figure 2. For each face the images were acquired at approximately vertical position and at 15 and 30 deg from both sides of the nadir position, all in approximate equal distances from the object (30 cm). This configuration was selected so that homologous points could be easily identified and measured in the images (large image overlap and scale), achieve an accuracy in the range of 1 mm or better, ensure a good distribution of points on the image, but also to avoid low convergent image configuration and though poor network geometry, less suitable for a reliable estimation of 3D coordinates. Simultaneous acquisition of images with more than one camera was not required, as the object was static. However this would be the case when performing the measurements on living humans.

The acquisition was performed twice for each cadaver in opposite directions and when alternative forms of the Zygomaticus Major close to its insertion were observed, additional images closer to the muscle area with high convergent angles were acquired. For additional control and scaling of the system a ruler was used, with circular planar white targets of 1 cm diameter in equal distances of 2.5 cm (between the centers of circles).



Sensor resol. [pix]	2048 x 1536
Pixel size [mm]	0.0021
Focal length [mm]	5.727
xo [mm]	-0.0726
yo[mm]	0.1096
K1	5.7359e-003
K2	-2.1114e-004
K3	6.4187e-006

Figure 2. The digital camera Canon IXUS A400 (left) and the camera parameters after calibration (right). The decentering distortions parameters (P1, P2) are omitted from the table.

<sup>1</sup> On each side of the face a number of muscles converge towards a focus just lateral to the buccal angle, where they interlace to form a dense, compact, fibromuscular mass: the *Modiolus* (Williams, 1995).

### 3.3 Camera calibration

The accuracy and stability of the camera calibration influences the accuracy and precision of the derived photogrammetric measurements. Though, the requirements when performing self calibration are a multi-image, convergent camera station geometry, which incorporates orthogonal roll angles, a good distribution of object points in each image, to assist accurate modeling of lens distortion, and initial starting values for the camera calibration parameters, with most important the initial value of the focal length.

We have performed the self-calibration using the low cost photogrammetric software *iWitness* (Photometrix), initially designed and developed for forensic measurement. *iWitness* incorporates user interfaces and interaction that are designed to support maximum ease of use. For the self-calibration the software derives fully automatic image coordinates of corresponding points by matching of circular color targets (red and green) and performs the bundle adjustment.

Twelve codes were placed on the floor, with one being out of plane, important, as noted by Fraser et al. (2005), for the precision of the recovered calibration and 8 images were acquired at the full unzoom mode. In Figure 3 a typical network for automatic calibration based on color codes is shown. Each code forms a bundle of rays and the broader the distribution of the codes a more robust photogrammetric network is achieved. However, it should be consider that consumer level cameras are usually affected by lack of stability and lack of robustness, because their design is not influenced by design constraints for metric use. Previous research (e.g. Shortis et al. 1998) has shown that the principal point location is prone to movement during normal handling of the camera, due to the mounting mechanism of the CCD array. In our tests we have repeated the self-calibration of the camera with an additional set of images and the changes in the principal point coordinates were of maximum absolute value of 0.02 mm. Self-calibration was also performed in the later stage of photogrammetric processing of the individual 51 image datasets of cadavers (Section 3.4). The changes in the principal point coordinates and the focal length did not have a large influence in the estimated accuracy of the 3D point measurements (RMS values in X, Y and Z). For the majority of the datasets the difference between the overall RMS derived with and without self-calibration was less than 0.2 mm and only in two datasets reached the value of 0.2 mm.

### 3.4 Photogrammetric processing with *iWitness*

The features of *iWitness* and the developed method for on-line camera orientation are described in detail in Fraser and Hanley (2004). The system was used for the measurements of the 51 image datasets successfully from non-photogrammetrists and with the minimum training effort.

The already calibrated camera exists in the database of the software with a unique id and is selected at image import. For the derivation of the initial exterior orientation of the images without the requirement of object space coordinates, the software uses the approach of relative orientation. At least six conjugate points are found and referenced manually in pairwise mode in the images, in order to solve for the unknown parameters.

With the completion of the initial pairwise orientation, a 3D set of measured object points within an arbitrary XYZ coordinate system is established. Additional object points can then be added to the point array, through both further referencing in the

initial two images and through extending the referencing to additional images. The spatial orientation of every image is computed when the referencing of four points is completed and from that point onwards remaining unreferenced points are indicated in the newly added image. Subsequent image point observations are integrated through an on-line bundle adjustment and the software gives indication on the quality of the network geometry. In order to assign a scale and an origin in the arbitrary XYZ coordinate system we set the distance of two circular targets attached to the ruler. The origin of the system can be assigned to any measured point (initially the origin is set to the projective center of the first image used in referencing). We have set the origin at the left or right most measured circular marker.

Two types of points were selected for the referencing of the images for a denser point distribution: a) points at the base of the markers and b) points on other features with good texture, e.g. corners of wrinkles, pores and nevus. The average overall estimated RMS from all datasets was 0.06 mm and the estimated accuracy of image referencing was in the range of 0.2 – 0.4 pixels. An example of the measured points on the five images from one cadaver and the recovered three dimensional geometry of the points and the camera stations are shown in Figure 4.

Considering the fact that the images were acquired by non photogrammetrists and were of large scale, the initially predefined imaging configuration was deviating in some datasets from the determined positions (larger rotations and varying distances from the face). This led in some cases in low convergence and therefore poorer network geometry and further in problems in the estimation of the relative orientation parameters within *iWitness*. With larger rotations the face did not cover the full format of the image. In these images apart from the area in which the face was imaged it was impossible to find and measure conjugate points to other images (lack of texture and smaller overlap to the other images). Hence, the point distribution was covering only a part of the image, plus it was more difficult to measure the same specific points from another image pair, due to occlusions. Also the software did not allow further measurements of points, if the convergent angle of an image pair was estimated in the range of 3 degrees or less. This problem could be resolved in future measurements by supporting the image acquisition with a round metallic bar, fixed at a certain distance from the object and with marked positions on which the camera can be attached.

#### 4. RESULTS

From the photogrammetric processing of the 51 image datasets of cadavers, we derived the 3D coordinates of the indicated landmarks, described in Section 3.1, and the distances with respect to *Cheilion* from each side of the face (CH\_R and CH\_L). Table 1 shows an example of these results and the estimated accuracy of the measured points in terms of RMS values in X, Y and Z in mm. As it can be seen the accuracy was significantly better compared to the accuracy derived by traditional methods used in anthropometrical facial studies. One important charac-

teristic of the dissected faces is that they exhibit good texture in the images, thus the measurements can be performed with high precision. Small details can be identified and measured and five images suffice for point localization. In most cases the 3D position of points at the sides of the face can be recovered from 2 or 3 images. Points in the frontal view, like SN, PG, G and N can be computed from almost all images rays. It should be noted that one of the major advantages of the method is that the measurements can be performed at any time, different of the time of acquisition. This is especially important when there are time restrictions in the acquisition of the information in situ.

For the medical investigations it was important to measure the superior and the inferior bundle of muscles of the Zygomaticus Major, identified in a number of dissected face halves. Three cases were identified as variations in the terminal anatomy of the muscle. The muscle may appear in three anatomical variants, namely as a single unit or bifurcated or divided in three parts at the subzygomatic fossa. The width and length of the muscular bundles in each identified case was measured. In Figure 5 the three variations of the Zygomaticus Major are shown and the width and length is defined by markers that were placed by the medical doctor. The conclusions to be derived from the quantitative assessment of the above measurements will be of interest for the medical science, especially for plastic surgery, as hitherto these anatomical variations are considered to be rare.

#### 5. SUMMARY AND CONCLUSIONS

The paper presented and justified the use of photogrammetric techniques in anthropometrically craniofacial studies, through the processing of image data from a large number of dissected faces of cadavers (51). The advantages of photogrammetry compared to other methods, traditionally used in anatomical studies for deriving metric information are seen in the much high accuracy of the measurements, the much higher quality of the results, robustness and reliability, plus the possibility to process the data in a different time period of the time of the image acquisition, in the ease of use of the method by non-photogrammetrists. Out of the results of the quantitative assessment, the derived conclusions will be of major interest for the medical research, as with other methods less objective and thus conflicting results appear.

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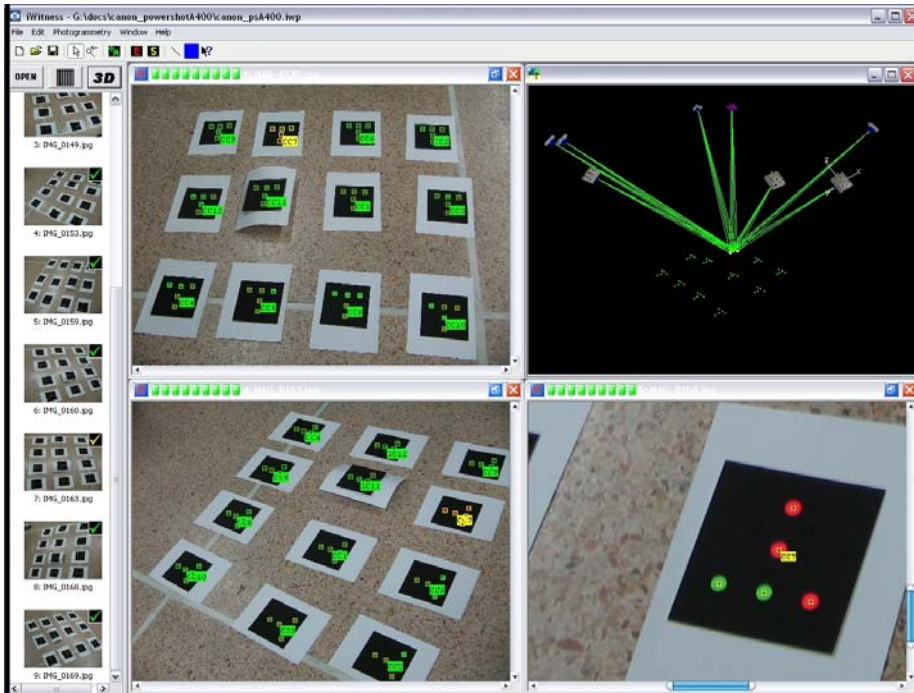


Figure 3. Automatic camera calibration in *iWitness* using color targets.

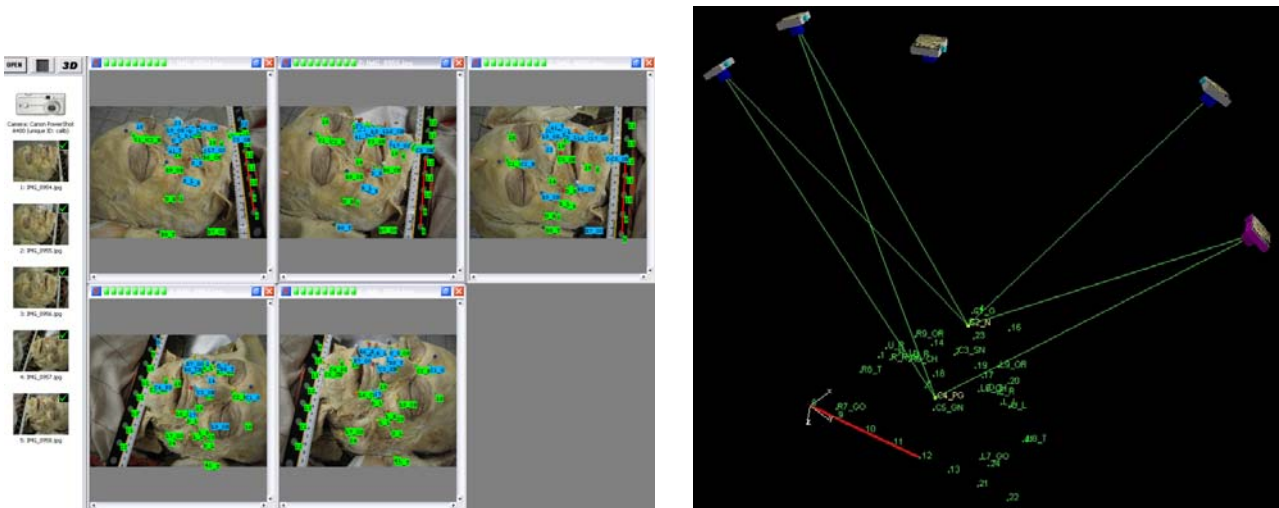


Figure 4. On the left the five images from one dataset with the measured points overlaid and on the right the points, the bundle of rays for two image points and positions of the camera stations are shown in 3D. The distance used for scaling is shown in red colour.

Description	ID	RMS X (mm)	RMS Y (mm)	RMS Z (mm)	Distance CH_R to (mm)
Cheilion (right)	CH_R	0.03	0.08	0.10	
Glabella	G	0.03	0.03	0.05	100.42
Nasion	N	0.02	0.02	0.03	89.20
Subnasale	SN	0.02	0.03	0.05	49.91
Pogonion	PG	0.02	0.03	0.03	50.71
Gnathion	GN	0.05	0.06	0.12	54.83
Gonion (right)	GO_R	0.03	0.08	0.16	54.94
Tragion (right)	T_R	0.04	0.05	0.09	96.49
Orbitale (right)	OR_R	0.02	0.02	0.03	52.96

Table 1. Example of measured landmarks for the right face half. Description, RMS values and measured distances.

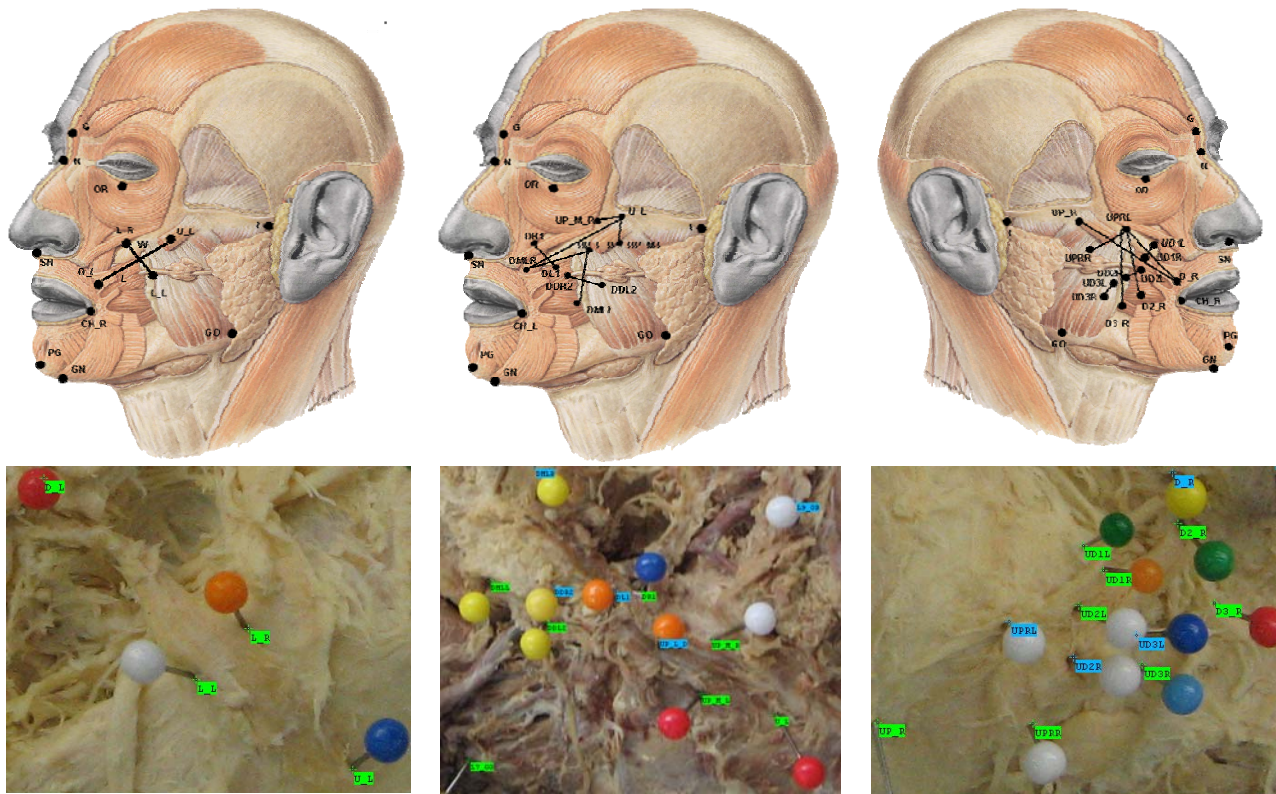


Figure 5. The three anatomical variations of the Zygomaticus Major. Forming a single (left), a double (middle) and a triple (right) bundle of muscles. In the lower row, the markers that were used to define the length and width of the each muscular bundle in each corresponding case.

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