Morphometric Maturity Norms of Albanian High-School Graduates

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I dedicate this book to my father,
Muharrem (Ruhan, Azize) Rexhepi (1912–1982),
who taught me to be independent and determined,

and to my mother,
Maliqe (Musli, Zyhrije Makolli) Rexhepi (1930–2011),
who nurtured and raised me to believe that anything is possible.

"Recite in the Name of your Lord who created –
Created man from a clinging clot.
Recite! And your Lord is the Most Generous –
Who taught by the pen,
Taught man what he did not know."

(Qur'an 96:1-5)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS USED IN THE MONOGRAPH

The following are the most frequently used abbreviations in this monograph, along with their corresponding meanings:

Abbreviation	Meaning
BMI	Body Mass Index
HCI	Horizontal Cephalic Index
VCI	Vertical Cephalic Index
TCI	Transverse Cephalic Index
TFI	Total Facial Index
KMO	Kaiser–Meyer–Olkin
SD	Standard Deviation
N	Number of individuals in the group
df	Degrees of freedom
p	Probability value
χ^2	Chi-square – Statistical test
λ	Wilks' Lambda – for evaluating discriminant functions
Rc	Canonical correlation
Op	Opisthocranion – most posterior point of the skull
G	Glabella – most prominent point on the forehead
Po	Porion – lowest point on the ear opening
V	Vertex – highest point of the skull
G–Op	Head length
V–Po	Head height
h^2	Communality of variables in factor analysis
Bartlett	Bartlett's Test of Sphericity – test for suitability of factor analysis

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First and foremost, I extend my deepest gratitude to Almighty God — All-Knowing, All-Powerful, and Most Merciful — for the light, strength, and perseverance He has granted me throughout my scientific journey. At every stage of this project, His guidance and mercy have been the unwavering source of strength that sustained my dedication and resolve.

I am profoundly indebted to my family, whose steadfast support, immeasurable patience, and unwavering understanding have been a constant source of encouragement. Their devotion has formed the very foundation upon which every accomplishment in my life has been built.

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Finally, I am deeply grateful to the teaching staff and students of schools across all Albanian-inhabited territories. Their readiness to participate and their dedication to ensuring accurate and reliable data collection have been crucial to the scientific integrity of this work.

FOREWORD

Anthropology, in its connection with biology, sociology, medicine and physical education, offers a distinctive lens for understanding physical development and biological maturity. During adolescence, particularly around school graduation, fundamental changes occur in morphological structure that are closely tied to hereditary, hormonal and environmental factors. It is at this stage of biological maturity that the adult form consolidates; assessing this phase is therefore of high importance for preventive medicine, physical education, nutrition, and fields concerned with voice, speech therapy and musical performance.

This work provides a comprehensive and up-to-date account of the morphometric dimensions of Albanian youth at the age of biological maturity, with a focus on the Balkan territories inhabited by Albanians. Its principal aim is to establish reliable reference norms and a clear interpretative framework for researchers and professionals in health, sport and physical anthropology, bringing together descriptive analysis and contemporary inferential methods.

The study is based on a large and representative sample of **2622** Albanian high-school graduates (**1272** boys and **1350** girls), randomly selected from general education schools in the Western Balkans. All measurements were carried out under standardised protocols with strict attention to data quality. For the first time in this population and age group, advanced statistical techniques have been applied in concert: exploratory latent factor analysis and canonical discriminant analysis, as well as Gaussian Mixture Models evaluated with the Bayesian Information Criterion. This multidimensional approach permits rigorous evaluation of distributional structure, including potential bimodality in weight and height, and the extraction of latent dimensions that organise morphometric traits into biologically meaningful forms.

The contribution of the work is threefold. First, it delivers sex- and region-specific reference norms and profiles that can inform clinical assessment, physical education, sport selection, ergonomics and population research. Second, it sets out a transparent methodological framework for interpreting distributions that appear unimodal yet may contain important

substructures relevant to health and education policy. Third, it offers a structured analysis of latent somatic and craniofacial dimensions, clarifying the integration of skeletal architecture, body composition and head morphology.

This monograph forms part of a broader scientific project comprising three interrelated units:

1. **Norms of Morphometric Maturity in Albanian High-School Graduates**, which establishes reference standards for this pivotal developmental period;
2. **Norms of Vocal Maturity in Albanian High-School Graduates**, which examines vocal change in the context of hormonal development;
3. **Analysis of Relationships between Anthropometric and Vocal Variables**, which explores links between body and acoustic measures at both manifest and latent levels.

The present volume lays the foundation for the subsequent analyses and is intended to contribute to sports medicine, speech therapy, music education, developmental anthropology and the wider humanities.

Interpretations and comparisons with the international literature have been undertaken with methodological care, maintaining scientific integrity and avoiding conclusions not supported by evidence. Updated terminology is used where appropriate to ensure coherence and readability.

The intended audience includes physicians, public health and nutrition specialists, sports scientists, physical anthropologists, biostatisticians and curriculum designers. It is hoped that the materials, summary tables and figures will serve as a durable reference and a starting point for further studies on Albanian populations and for international comparisons.

We thank the students and their families for their cooperation, the teachers and school administrators for facilitating fieldwork, and colleagues whose suggestions improved this manuscript. Special appreciation is due to academic collaborators and reviewers for their constructive remarks, which strengthened the scientific and stylistic quality of the text. Any remaining errors are the author's responsibility.

Pristina, August 2025
Agron M. Rexhepi

CHAPTER I

PREVIOUS RESEARCH, AIMS, HYPOTHESES AND METHODOLOGY

1.1 Previous research in the field of anthropology

Contemporary anthropology relies on a multidisciplinary approach that integrates data from morphology, physiology, biochemistry, and other health sciences to better understand the body's structure and biological functions (Little & Haas, 2022). In recent decades, authors such as Bogin (2012, 2023), Öberg & Collin (2017), Pawson & Huicho (2007), and Prosser (1964) have emphasised the importance of incorporating biological, ecological, psychological, and physical education perspectives to explain the relationship between body structure and biological functions. This interdisciplinary orientation not only enhances the interpretation of anthropometric results but also enables cross-cultural comparisons and the identification of developmental traits in populations under diverse socio-ecological conditions.

In this context, previous research has consistently highlighted the interplay between endogenous (hereditary) and exogenous (environmental and socio-cultural) factors in shaping human growth and development. Classic works by Howells (1966) stressed the significance of genetic variability, while Boas (1911) provided early evidence of environmental influences on phenotype, particularly in migrant populations. Later, Proser's (1964) concept of "adaptive capacity" explained how organisms respond to ecological pressures through phenotypic adjustments. More recent findings in evolutionary anthropology (Ulijaszek, 2006; Leonard, 2012) have shown that nutritional transitions, physical activity patterns, and climate adaptations play equally decisive roles in shaping morphological outcomes.

Among the most important parameters analysed in human morphology are linear dimensions (length, breadth, and circumferences), which, when combined with physiological measures and adipose tissue indices, offer a comprehensive picture of biological status. Schreider (1967) warned

against superficial interpretation of somatotype, while Twisselman (1949) distinguished between meso-stable and meso-labile traits depending on their sensitivity to external conditions. Modern approaches have expanded these ideas through multivariate statistics, using factor analysis and principal component analysis to uncover latent dimensions such as longitudinal growth, muscularity, adiposity, and transversal robustness (Carter & Heath, 1990; Malina et al., 2004). These dimensions are crucial for understanding biological maturity and for modelling developmental processes.

Longitudinal investigations have also identified **secular trends**—notably the increase in average height and changes in body composition across generations—largely attributed to improvements in nutrition, health care, and living conditions (Cole, 2003; Hatton & Bray, 2008). Extensive evidence from the Nordic countries, especially Sweden, has documented continuous increases in average height throughout the twentieth century, based on military conscription records (Öberg, 2014; Öberg & Collin, 2017; Holmgren et al., 2019). These studies also revealed regional disparities and socio-economic gradients in height, reflecting the impact of environmental and social determinants despite a generally favourable welfare context. The Swedish experience has become a reference point for anthropometric research worldwide, demonstrating the value of large-scale longitudinal databases.

In the Balkan context, populations exposed to rapid socio-economic transitions have shown measurable shifts in height, weight, and adiposity patterns (Padez, 2007). In the **Albanian context**, anthropological research has historically been limited and fragmentary. The earliest studies include descriptive accounts by Pukëvil (1805), Glück (1895), Coon (1950), Dhima (1985), as well as craniofacial and somatic measurements by Weissbach (1897), and Luschan (1922). While informative, these works were often descriptive and did not conform to standardised anthropometric methodology. More recent efforts in Albania and Kosovo have provided more systematic data, but there remains a need for updated, large-scale reference studies that reflect contemporary biological and socio-ecological conditions.

Recent anthropological research has also incorporated advanced statistical and modelling approaches. Gaussian Mixture Models (GMM), Bayesian Information Criterion (BIC), and discriminant analyses have been increasingly applied to detect latent structures, multimodality in growth distributions, and inter-population differentiation (Schilling et al., 2002;

Healy, 2014). These methodological innovations are particularly relevant for identifying population-specific developmental norms and for addressing questions of variability within and between groups.

The present study builds on this tradition by systematically measuring body dimensions of Albanian high-school graduates between 2016 and 2019. Its purpose is to establish robust morphometric reference norms for this age group, thereby filling a long-standing gap in anthropological knowledge of the Albanian population and positioning it within the broader European and Nordic literature.

1.2 Study Objectives and Hypotheses

1.2.1 Study Objectives

The aim of this study is to evaluate the morphometric maturity of Albanian high-school graduates by analysing linear body measurements, perimeters, and combined body variables. This will help establish a reference baseline for this age group, reflecting the norms of physical development within the Albanian geographical and socio-cultural context.

Specifically, the research aims to:

- determine normative orienting values of morphometric maturity (head-body) in Albanian high-school graduates of both sexes,
- investigate the correlations between the measured group variables (head/body) to understand the patterns of physical development at this stage of life,
- examine gender and regional differences in the body structure of high-school graduates,
- analyse the latent structure of body development using factor analysis,
- evaluate the discriminatory power of the variables in differentiating groups by gender and altitude of residence,
- provide an integrated interpretation of body maturity as an indicator of biological status at the end of adolescence,
- and utilise mixture models (GMM) and BIC-based selection to assess the structure of height and body weight distribution in both sexes to determine if internal bimodality is present.

1.2.2 Research Hypotheses

Based on these objectives, the following research hypotheses have been developed:

- **Hypothesis 1 (H1):** There are statistically significant differences in body morphometric characteristics between high-school graduates from the northern and southern regions of Albanian-populated areas**.**
- **Hypothesis 2 (H2):** High-school graduates from coastal areas and those from mountainous areas exhibit distinct morphometric profiles, consistent with differences in environmental influences and living conditions**.**
- **Hypothesis 3 (H3):** Head morphometric parameters, including length, width, circumference and cephalic indices, are expected to show distinct variation consistent with ecological influences, living conditions, and phenotypic expression within a shared hereditary background.
- **Hypothesis 4 (H4):** The mean values of body mass index (BMI) for both sexes will stay within the acceptable range of the health standard for 17–18-year-olds (BMI=18.5–24.9 kg/m²), indicating a balanced overall anthropometric status**.**
- **Hypothesis 5 (H5):** Factor analysis will identify an organised latent structure of body dimensions, including distinct aspects such as longitudinal, transverse dimensions, body mass, and fat content.
- **Hypothesis 6 (H6)**: Compared to global standards for 17–18-year-olds, it is expected that Albanian high-school graduates will have a body height towards the upper end of the average, particularly in regions with positive socio-economic influences, which likely reflects the cumulative impact of improved living conditions**.**
- **Hypothesis 7 (H7):** The distribution of height and body weight among Albanian high-school graduates of biological matura age will tend to be bimodal within each gender, as confirmed by the best fit of models with two Gaussian components based on Bayes Information Criterion (BIC) estimates, particularly for body weight**.**

The formulation of these hypotheses aligns fully with the scientific aims of this study and provides the foundation for the comparative, exploratory, and interpretative analyses outlined in the following chapters. They are designed to reflect the anthropological reality of the Albanian space, to be statistically supportable and theoretically interpreted with scientific

coherence, serving as a bridge between the data collected and the analyses in both the manifest and latent space.

1.3 Methodology

The research presented in this monograph has an anthropological character, with a multidisciplinary and interdisciplinary approach. Data collection was carried out during the implementation of the project:

"Morphometric and acoustic characteristics of the voice of Albanian boys and girls aged 18."

This project was carried out by the Institute of Sports Anthropology in Pristina from 2016 to 2019. The research involved systematically collecting, measuring, and analysing morphometric parameters, with a special focus on evaluating the developmental maturity level of high-school graduates (aged 17–18). The methodological framework was designed to ensure the reliability, validity, and objectivity of the results, allowing for intergroup comparisons and the development of normative reference values.

Data were collected following standardized anthropometric protocols, with the sample comprising high-school graduates from all regions of the Western Balkans inhabited by Albanians. This ensures a broad ethnic and geographical representation. The procedures, instruments, and analytical methods used adhere to current standards in anthropological and biometric research, providing a solid scientific foundation for the findings, which are relevant to educational, medical, and sports contexts.

1.3.1 Sample of Test Subjects

The research sample consisted of 2,622 high-school graduates aged 17–18 years, chosen from all Albanian-inhabited regions in the Balkans, including Kosovo, Albania, North Macedonia, the Presevo Valley (Serbia), and Montenegro. This sample includes 1,272 males and 1,350 females, ensuring a balanced gender distribution. The data presented in Table 1 offer a comprehensive overview of the gender and geographical distribution of the graduates measured in this study, reflecting balanced representation of Albanian-inhabited regions across the Balkans.

Male High-School Graduate Sample

The group of male high-school graduates includes 1,272 males distributed across various cities in five Balkan regions inhabited by Albanians.

- **Kosovo:** 394 males (Pristina/Prishtina, Podujevo, Gjakova, Peja, Mitrovica, Kamenica, Dragash);
- **Albania:** 423 males (Kukës, Shkodër, Tirana, Korçë, Sarandë, Vlorë);
- **North Macedonia:** 314 males (Kicevo/Kërçova, Struga, Dibra, Skopje/Shkup, Tetovo/Tetova);
- **Presevo Valley:** 76 males (Presevo/Presheva, Bujanovac/Bujanoc);
- **Montenegro:** 71 males (Ulcinj/Ulqin, Tuz).

Sample of female high-school graduates

The group of girls includes a total of 1,350 high-school graduates, representing the same regions and cities as the previous group boys:

- **Kosovo:** 427 girls;
- **Albania:** 534 girls;
- **North Macedonia:** 241 girls;
- **Presevo Valley:** 94 girls;
- **Montenegro:** 57 girls.

This gender and regional distribution offers a solid foundation for comparative analyses, as well as for deriving indicative values of the growth and development of Albanian youth in the final stage of adolescence.

The distribution of participants presented in Table 1 confirms the methodological soundness of the sampling process. The representation from 23 cities across five Balkan regions inhabited by Albanians ensures that no single geographical area disproportionately dominates the dataset, while maintaining a near-equal gender balance (1,272 males and 1,350 females).

The proportional spread across both densely populated urban centres (e.g., Tirana, Pristina and Skopje) and smaller municipalities (e.g., Tuz, Bujanoc, Presheva) strengthens the representativeness of the sample. This balanced geographical coverage minimises potential bias and allows for robust inter-regional comparisons.

Table 1. Distribution of High-School Graduates by City and Sex, with Frequency, Percentage, and Cumulative Percentage

City	Freq. (M)	% (M)	Cumul. % (M)	Freq. (F)	% (F)	Cumul. % (F)
Kukës	76	6.0	6.0	87	6.4	6.4
Shkodër	64	5.0	11.0	88	6.5	13.0
Tirana	78	6.1	17.1	82	6.1	19.0
Korçë	71	5.6	22.7	96	7.1	26.1
Saranda	71	5.6	28.3	100	7.4	33.6
Vlora	67	5.3	33.6	85	6.3	39.9
Kicevo (Kërçova)	66	5.2	38.8	60	4.4	44.3
Struga	54	4.2	43.0	45	3.3	47.6
Dibra	56	4.4	47.4	49	3.6	51.3
Skopje (Shkupi)	73	5.7	53.1	43	3.2	54.4
Tetovo (Tetova)	55	4.3	57.5	44	3.3	57.7
Bujanovac (Bujanoc)	38	3.0	60.5	44	3.3	61.0
Presevo (Presheva)	38	3.0	63.4	50	3.7	64.7
Ulcinj (Ulqin)	41	3.2	66.7	45	3.3	68.0
Tuz	30	2.4	69.0	12	0.9	68.9
Pristina (Prishtina)	45	3.5	72.6	66	4.9	73.8
Podujeva	52	4.1	76.7	57	4.2	78.0
Gjakova	66	5.2	81.8	62	4.6	82.6
Peja	59	4.6	86.5	58	4.3	86.9
Mitrovica	55	4.3	90.8	71	5.3	92.1
Kamenica	53	4.2	95.0	63	4.7	96.8
Dragashi	64	5.0	100.0	43	3.2	100.0
Mean	**58**	**4.55**	**x**	**61**	**4.5**	**x**
Total	**1272**	**100.0**	**x**	**1350**	**100.0**	**x**

From an anthropological perspective, such diversity in sampling captures potential morphological variations arising from regional differences in lifestyle, socio-economic conditions, and environmental factors such as climate and altitude. As a result, the normative values derived from this study can be generalised with a high degree of confidence to the broader population of Albanian youth in their final stage of adolescence.

Representation of High-School Graduates from Albanian Capitals

Although the number of participants from each capital city was not among the highest in the dataset, the inclusion of Tirana (78 males, 82 females), Pristina (45 males, 66 females), and Skopje (73 males, 43 females) is of considerable representational and symbolic importance to the study.

Tirana and Pristina, as the respective capitals of Albania and Kosovo, reflect the full demographic and institutional realities of the two states

with an Albanian majority. Skopje, while not the administrative centre of an Albanian state, is included because of its substantial Albanian population and to represent an important part of the Albanian community in North Macedonia.

This threefold representation from the main urban centres helps create a balanced and diverse geospatial picture of Albanian youth's development across the Balkan region.

1.3.2 Geographical Characteristics of the Study Locations

In designing this study, particular attention was given to ensuring that the research reflected the full geographical breadth and diversity of Albanian-inhabited territories across the Western Balkans. The selection of locations was not merely a methodological requirement, but also a deliberate effort to capture the rich interplay of cultural, environmental, and demographic factors that shape the lives of Albanian youth. Conducting measurements in 22 cities across five countries provided a variety of settings which, taken together, offer a comprehensive and nuanced framework for anthropological analysis.

The division by administrative location is as follows:

- Albania: Kukës, Shkodër, Tirana, Korçë, Vlora, Saranda (6 cities);
- Kosovo: Pristina, Podujeva, Mitrovica, Gjakova, Peja, Dragash, Kamenica (7 cities);
- North Macedonia: Skopje, Tetova, Dibra, Kërçova, Struga (5 cities);
- Presevo Valley (Serbia): Bujanovac, Presheva (2 cities);
- Montenegro: Ulcinj, Tuz (2 cities).

The aim of including such a broad sample was to build a solid and representative foundation that reflects the geographical, environmental, and ethno-cultural realities of Albanian youth. Furthermore, the selection was focused on 17–18-year-old graduates, as this stage of life is particularly suitable for studying morphometric maturity, marking the transition from late puberty to full biological maturity.

All measurements were carried out under standardised conditions and in accordance with internationally recognised protocols in scientific anthropometry

Criteria for geographical and altitudinal grouping

To evaluate the influence of environmental and natural factors on participants' physical development, cities were categorised based on two primary criteria:

(1) Altitude of residence, and

(2) Geographical position (north–south).

This classification enables comparison of anthropometric traits across environments with differing natural and geographical conditions, particularly to examine the effect of altitude on physical development.

Altitude Above Sea Level

For the purpose of geographical analysis, the cities were categorised into two groups based on their altitude above sea level:

- Low-altitude cities (≤ 50 m): Shkodër (10 m), Vlorë (8 m), Saranda (22 m), Ulcinj (36 m), Tuz (48 m);
- High-altitude cities (≥ 650 m): Korçë (874 m), Dragash (1,030 m), Podujeva (670 m), Dibra (660 m), Struga (696 m).

Cities that do not fall into either of these altitude categories (neither ≤ 50 m nor ≥ 650 m) were excluded from analyses requiring a clear altitudinal division into two comparative levels.

Geographical Position: North and South

Unlike traditional boundaries defined by geographical coordinates, this study employs the Shkumbin River as the natural dividing line, which has historically separated the Albanian lands into two major regions: North and South.

- **The northern zone** includes the cities of Kukës, Shkodër, Gjakova, Mitrovica, Dragash, Peja, Podujeva, Pristina, Kamenica, Tetova, Bujanovac, Presheva, Tuz, and Ulcinj. For this study, efforts were made to gather data from the northernmost locations possible while maintaining a balance between entities from different sub-regions. The locations chosen as representatives of the northern region are Podujeva, Mitrovica, Peja, Kukës, Shkodër, and Tuz.

- **The Central (intermediate) zone,** regarded as a cultural transition area between the Gheg and Tosk regions, includes Tirana, Dibra, Kërçova, and Struga.
- **The southern zone** includes the cities of Korçë, Vlorë, and Saranda.

Basic geographical information for each city, including latitude, longitude, and altitude, is shown in Table 2.

Table 2. Geographical Position and Altitude Above Sea Level of the Cities Where Measurements Were Conducted

City	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)
Kukës	42°04'36"	20°25'18"	350
Shkodër	42°04'10"	19°30'11"	10
Tirana	41°19'43"	19°49'12"	130
Korçë	40°36'50"	20°46'41"	874
Vlora	40°27'58"	19°29'29"	8
Saranda	39°52'29"	20°00'36"	22
Gjakova	42°23'04"	20°25'42"	366
Mitrovica	42°53'29"	20°51'57"	508
Dragash	42°02'65"	20°65'33"	1030
Peja	42°39'34"	20°17'19"	515
Podujeva	42°54'37"	21°11'28"	670
Pristina (Prishtina)	42°39'47"	21°09'56"	601
Kamenica	42° 35'02"	21°34'30"	470
Dibra	41°31'36"	20°31'26"	660
Skopje (Shkupi)	41°54'51"	21°25'41"	249
Tetovo (Tetova)	42°00'25"	20°58'17"	468
Kicevo (Kërçova)	41°30'46"	20°57'09"	624
Struga	41°10'41"	20°40'42"	696
Bujanovac (Bujanoc)	42°27'38"	21°45'52"	402
Presevo (Presheva)	42°18'31"	21°39'02"	507
Ulcinj (Ulqini)	41°55'51"	19°12'50"	36
Tuz	42°21'55"	19°19'51"	48

Since some cities in the central zone are situated near the dividing line, methodological consistency was maintained for statistical purposes by excluding them from direct North/South comparisons.

The following map illustrates the geographic distribution of cities across Kosovo, Albania, North Macedonia, the Presevo Valley (Serbia), and Montenegro where anthropometric measurements of Albanian high-school graduates were conducted.

Figure 1. Geographic distribution of cities where measurements of Albanian high-school graduates were conducted

Source: Ikonact, *Geographic map of the Balkan Peninsula*, Wikimedia Commons, CC BY-SA 4.0. Modified by the author.

1.3.3 Measured Body Parameters (Variables) and Their Importance in the Analysis

In keeping with the objectives of this study, a carefully structured set of morphometric variables was selected, covering both body and head dimensions. All morphometric measurements were carried out using validated instruments (Figure 2) in accordance with Martin's methodology, ensuring high measurement precision, ranging from 0.2 mm for subcutaneous fat thickness to 1 mm for linear dimensions, and 100 g for body weight.

The instruments used for morphometric measurements included:

- Anthropometric scale (precision: 100 g);
- Anthropometer and short anthropometer (precision: 1 mm);
- Pelvimeter (precision: 1 mm);
- Cephalometer (precision: 1 mm);
- Sliding caliper (precision: 1 mm);
- Measuring tape (precision: 1 mm);
- Caliper for measuring subcutaneous fat tissue (precision: 0.2 mm).

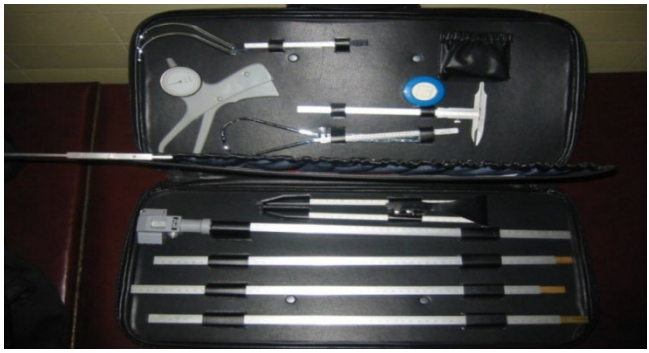

Figure 2. Instruments used for morphometric measurements, according to Martin's methodology

Description of the Measured Body Dimensions

Body morphometry was assessed through a set of 12 directly measurable variables, selected in accordance with the guidelines of the International Biological Programme (IBP) (Weiner 1965). All measurements were