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SKELETAL MARKERS OF SEXUAL DIMORPHISM: AN ANATOMICAL ANALYSIS OF THE HUMAN SKELETON

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რუსუდან ვადაჭკორია, დია სარტაჯი, რიშიკეშ ასოკან სუდაკუმარი

სქესობრივი დიმორფიზმის ჩონჩხის მარკერები: ადამიანის ჩონჩხის ანატომიური ანალიზი

ბათუმის შოთა რუსთაველის სახელმწიფო უნივერსიტეტი; საბუნებისმეტყველო მეცნიერებათა და ჯანდაცვის ფაკულტეტი, საქართველო

რეზიუმე

მიზანი: მამაკაცისა და ქალის ძვლოვანი სისტემების ისეთი ანატომიური განსხვავებების სტრუქტურირებული მიმოხილვა, რომლებიც ადასტურებენ იდენტიფიკაციისთვის მნიშვნელოვან სქესობრივ დიმორფიზმს; ჩონჩხის სხვადასხვა ანატომიური ნაწილების (მენჯის, თავის ქალას და კიდურების ლულოვანი ძვლების) მორფოლოგიურ ვარიაციებზე ფოკუსირება, და მათი სქესობრივ განსხვავებებზე მსჯელობა.

მეთოდი: მამაკაცისა და ქალის ძვლოვანი სისტემების მიმოხილვითი ანალიზი.

შედეგი: მენჯი ავლენს დიმორფიზმის უმაღლეს დონეს, განსაკუთრებით თეძოს ძვლის ფორმაში, ბოქვენის კუთხესა და მენჯის საერთო პროპორციებში, რაც აქცევს მას სქესის შეფასების ყველაზე სანდო მიდგომად. თავის ქალას ძვლების განსხვავებები გამოიხატება სიმტკიცის, კუნთების მიმაგრების ზედაპირებისა და ქალა-სახის პროპორციების ვარიაციით, ხოლო კიდურების გრძელი ლულოვანი ძვლები ავლენენ განსხვავებებს სიგრძეში, ძვლოვანი კომპაქტური ნივთიერების სისქესა და სტრუქტურულ სიმტკიცეში. მიუხედავად იმისა, რომ ჩონჩხის ცალკეული ელემენტები განსხვავდებიან დიაგნოსტიკური სანდოობით, მათი კომბინირებული შეფასება აუმჯობესებს სქესის განსაზღვრის სიზუსტეს, რაც ძალზედ მნიშვნელოვანია სასამართლო ანთროპოლოგიაში; ჩონჩხის იდენტიფიკაცია გადამწყვეტ როლს ასრულებს სამედიცინო-სამართლებრივ გამოკვლევებში.

დასკვნა: წარმოდგენილი მიმოხილვა, ჩონჩხის მახასიათებლების ერთ სტრუქტურირებულ ჩარჩოში ინტეგრირებით, ხელს უწყობს სქესზე დაფუძნებული ანატომიური ვარიაციის უფრო მკაფიო გაგებას სამედიცინო და სასამართლო პრაქტიკაში.

Introduction. Sexual dimorphism in the human skeletal system refers to the anatomical differences observed between male and female skeletal structures. These variations are primarily expressed in bone size, shape, proportions, and structural robustness, producing characteristic differences in overall body framework and body proportions between the sexes (Moore et al., 2014). In general, males possess a broader shoulder girdle, narrower pelvis, longer and heavier long bones, and a more robust skeletal build, contributing to a taller and more angular body structure. Females, in contrast, typically exhibit a relatively broader pelvis, narrower shoulders, shorter and more gracile bones, and a wider distribution of body weight around the pelvic region. These skeletal differences influence overall body proportions and create distinct patterns in trunk width, limb proportions, and pelvic architecture [4,5].

Male skeletons are generally characterized by greater bone mass, thicker cortices, and more prominent muscular attachment sites, whereas female skeletons usually display lighter and smoother skeletal features. The pelvis demonstrates the highest degree of sexual dimorphism due to structural adaptations associated with childbirth, while the skull and long bones also exhibit consistent morphological differences useful in anatomical assessment [2,5].

Understanding skeletal dimorphism is important in anatomy, forensic anthropology, osteology, and medical education because these structural variations assist in the identification and differentiation of male and female skeletal remains [1,7]. Knowledge of these anatomical distinctions also contributes to the interpretation of human variation and skeletal morphology in academic and clinical contexts. This review aims to present a concise and organized overview of anatomical differences within the human skeletal system by focusing on major skeletal regions including the pelvis, skull, and long bones.

Main Body. Skeletal system

1.Pelvis. The human pelvis demonstrates the most significant degree of sexual dimorphism within the skeletal system due to its combined roles in bipedal locomotion and childbirth [4,5]. Although the basic pelvic framework is similar in both sexes, consistent structural differences are observed in size, shape, and proportional relationships. The male pelvis is generally heavier, narrower, and more robust, with a deeper pelvic cavity, larger acetabula, and a smaller subpubic angle. In contrast, the female pelvis is broader and shallower, with a wider pelvic inlet and outlet, a larger subpubic angle, a broader greater sciatic notch, and a shorter, less curved sacrum [5,6].

These modifications increase the dimensions of the birth canal and represent important adaptations for parturition. Studies further suggest that some pelvic differences are associated with overall body size and stature (allometric variation), whereas several obstetrically important features, including the subpubic angle and pelvic inlet shape, are independent of body size and are considered non-allometric characteristics [4]. Due to its distinct morphological characteristics, the pelvis is considered one of the most reliable skeletal regions for sex determination in forensic anthropology and skeletal identification (Table 1) [1].

Table 1. Male and Female Pelvis Comparison*

Feature	Male pelvis	Female pelvis
General Structure	Thick, heavy, and robust	Thin, light, and gracile
Greater (false) pelvis	Deep and narrow	Shallow and wide
Lesser (true) pelvis	Narrow, deep, funnel-shaped	Wide, shallow, and cylindrical
Pelvic inlet	Heart-shaped and narrow	Oval or round and wide
Pelvic outlet	Relatively small	Relatively large
Pubic arch/subpubic angle	Narrow (<70Â°)	Wide (>80Â°)
Obturator foramen	Round	Oval
Acetabulum	Large and deep	Smaller and shallow
Greater sciatic notch	Narrow (˜70Â°, V-shaped)	Wide (˜90Â°, U-shaped)

*Source: Adapted from Moore's Clinically Oriented Anatomy, 7th Edition [6].

The human pelvis may be classified into several morphological types according to the shape of the pelvic inlet. These variations are especially important in obstetrics because pelvic architecture can influence the course of labor and fetal passage during childbirth. Four major pelvic forms are commonly recognized: gynecoid, android, anthropoid, and platypelvic [6].

The gynecoid pelvis is considered the typical female configuration. It possesses a rounded pelvic inlet, broad transverse diameter, and spacious pelvic cavity, features that are generally favorable for vaginal delivery. In contrast, the android pelvis resembles the male pelvic pattern and is characterized by a heart-shaped inlet, narrower cavity, and prominent ischial spines, which may complicate labor [5,6].

The anthropoid pelvis has an oval inlet with a greater anteroposterior diameter than transverse diameter. This type is often associated with a relatively deep pelvic cavity. The platypelloid pelvis is distinguished by a flattened shape with a wide transverse diameter and shortened anteroposterior dimension. Because of this broad and shallow structure, engagement of the fetal head may be more difficult during childbirth [6].

Considerable anatomical variation exists within both sexes, and not all pelvic features strictly conform to the typical male or female pattern. Certain traits commonly associated with one sex may occasionally appear in the opposite sex. Furthermore, the expression of pelvic sexual dimorphism differs among populations and ethnic groups due to the combined influence of genetic, environmental, cultural, and developmental factors. Thus, the morphology of the pelvis cannot be explained solely by sex differences, but also by population-specific variation and individual adaptation [5].

2. Skull. The human skull exhibits marked sexual dimorphism, which can be identified through characteristic differences in cranial morphology and anthropometric features. In general, male skulls are larger, heavier, and more robust, whereas female skulls tend to be smaller, lighter, and more gracile. Male crania typically show pronounced supraorbital ridges, a more prominent glabellar region, larger mastoid processes, broader zygomatic arches, and stronger muscular attachment sites, collectively producing a more angular and rugged facial profile. In contrast, female skulls are characterized by smoother contours, reduced supraorbital development, narrower facial proportions, and more rounded orbital margins [2,7].

Female cranial morphology is typically associated with a smoother nuchal region, with poorly developed nuchal lines and a minimal or absent external occipital protuberance. In contrast, male cranial features show a more pronounced nuchal area, with well-defined nuchal lines and a clearly developed external occipital protuberance [2].

The mandible is the largest and strongest bone of the face and is frequently preserved in forensic contexts, making it an important structure for sex determination when other skeletal elements are not available. It shows clear sexual dimorphism in both size and shape. In general, male mandibles are more robust, with greater overall dimensions, thicker cortical bone, and stronger muscular attachment sites, whereas female mandibles are comparatively gracile with smoother contours and reduced bony prominence. Key morphometric parameters of the mandible also show consistent sexual differences. The gonial angle is typically more obtuse in females and relatively more acute or less flared in males depending on population variation. Bicondylar breadth and mandibular length are generally greater in males, reflecting increased overall skeletal size. Ramus height and coronoid height are also higher in males due to stronger masticatory muscle development, while females show reduced values. Body thickness and symphyseal height are similarly greater in males, indicating increased mandibular robustness. Collectively, these morphometric differences contribute significantly to sex estimation and make the mandible a reliable skeletal element in forensic identification and anthropological analysis [1].

3. Long Bones. The long bones exhibit clear sexual dimorphism in both size and structural robustness. In general, male long bones are longer, thicker, and heavier due to greater overall body size and muscle mass, whereas female long bones are relatively shorter, lighter, and more gracile. Males typically demonstrate more pronounced muscle attachment markings, such as the deltoid tuberosity of the humerus and the linea aspera of the femur, reflecting increased mechanical loading and muscular development. In contrast, females usually display smoother bone surfaces and less prominent muscular ridges. Differences are also evident in cortical thickness and overall shaft robustness, with males showing relatively stronger and more developed long bone architecture, while females possess slenderer diaphysis. These variations arise from the combined effects of genetic factors, hormonal influences during growth and puberty, and biomechanical adaptation to functional stress. Although long bones are generally less reliable than the pelvis for sex determination, they remain valuable in forensic anthropology when pelvic remains are absent or incomplete [6].

Classical anthropological research has demonstrated that long bone dimensions also show sexual variation, particularly in the size of articular surfaces. Dwight (1905) reported that the articular surfaces of long bones tend to be larger in males compared to females, reflecting overall skeletal robustness. However, overlap between male and female measurements limits the accuracy of long bones when used in isolation. Therefore, long bone characteristics are best interpreted in combination with pelvic and cranial features to improve the reliability of forensic sex estimation [3,6].

Conclusion. Sexual dimorphism in the human skeleton is a fundamental concept in anatomy and forensic anthropology, reflecting biological and functional differences between males and females. The present analysis demonstrates that the pelvis, skull, and long bones all exhibit distinguishable morphological variations, although they differ in diagnostic reliability.

Among these skeletal regions, the pelvis provides the most accurate indicators of biological sex due to its direct adaptation to reproductive function. Features such as the subpubic angle, and the greater sciatic notch show consistent and functionally driven differences between sexes. The skull provides additional supportive evidence through variations in cranial robustness, facial structure, and mandibular morphology, although these traits are more variable and therefore less definitive than pelvic characteristics.

Long bones contribute supplementary information through differences in length, robusticity, and articular dimensions, which are influenced by overall body size, hormonal effects, and biomechanical loading. However, their higher degree of overlap between sexes limits their standalone reliability in sex estimation.

Overall, skeletal sex determination is most accurate when multiple anatomical regions are assessed in combination rather than in isolation. This integrated approach enhances diagnostic accuracy and reduces error in forensic identification, particularly in cases where skeletal remains are incomplete or fragmented. Nonetheless, population variation and biological overlap remain important limitations that must be considered in practical applications.

Recommendations. This paper may be recommended for teachers of Biology and Basic Medical Subjects, as well as for the students of Medical and Biological specialties.

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SUMMARY

Objective: structured review of anatomical differences between male and female human skeletal systems, with a focused emphasis on sexual dimorphism relevant to identification. It consolidates key morphological variations across major skeletal regions including the pelvis, skull, and long bones, highlighting consistent structural patterns that distinguish the two sexes.

Method: The review emphasizes the importance of the anatomical differences in forensic anthropology, where skeletal identification plays a crucial role in medico-legal investigations.

Result: The pelvis demonstrates the highest degree of dimorphism, particularly in pelvic inlet shape, subpubic angle, and overall pelvic proportions, making it the most reliable skeletal region for sex estimation. Cranial differences are expressed through variation in robusticity, muscle attachment development, and craniofacial proportions, while long bones show differences in length, cortical thickness, and structural robustness. Although individual skeletal elements vary in diagnostic reliability, their combined assessment improves accuracy in sex determination.

Conclusion: By integrating skeletal features into a single structured framework, this paper supports a clearer understanding of sex-based anatomical variation for medical and forensic applications.

Keywords: Sexual dimorphism; morphometric analysis; pelvic morphology; craniofacial dimorphism