CQ21: What postmortem imaging findings are useful for determining or estimating sex?

Recommendation Grade: C1

Sex determination, when morphological features of external or internal genitalia are identifiable, is facilitated through recognition of organs readily distinguishable on CT imaging-the penis and prostate in males, and the vagina and uterus in females. In contrast, when such visualization is not possible, sex estimation relies on the morphological characteristics and anthropological measurements of bones, with particularly high accuracy reported for the skull and pelvis. However, in individuals who have not yet completed secondary sexual development, sex estimation based on morphological differences remains challenging.

Explanation

● Background

In postmortem examinations, sex determination is generally based on the morphological characteristics of the external genitalia. When determination based on external genitalia is difficult, sex determination is established by confirming the presence of internal genital organs[1].

When visualization of the genital organs is not possible, sex estimation relies on the morphological characteristics and anthropometric measurements of hard tissues. When sex estimation is based on the morphological characteristics of bones, the pelvis and skull are commonly used due to their marked sexual dimorphism. However, in individuals who have not yet completed secondary sexual development, sex estimation based on these morphological features is difficult. When anthropometric methods are used for sex estimation, not only the pelvis and skull, but also the sternum, scapula, and long bones of the limbs may be involved[1 2].

Postmortem imaging can be used for both sex determination and estimation. In particular, CT-based skeletal analysis enables easy extraction of bone structures regardless of soft tissue condition, and allows for 3D rotation and non-invasive sectional viewing[3]. In recent years, there has been a growing number of studies suggesting the use of artificial intelligence (AI) for sex estimation[4–8]. Some of these studies do not explicitly state that AI was used, but terms such as machine learning, principal component analysis, support vector machines, and neural networks may indicate AI-based approaches.

● Imaging Findings

1) Sex Determination Based on Morphological Characteristics of External and Internal Genitalia Using Postmortem Imaging

In a report describing the use of CT screening for personal identification in a large-scale forest fire disaster, among 161 cases confirmed as deceased on postmortem CT, external or internal genitalia—or personal belongings relevant to sex estimation—were identified in 98 cases (61%). Despite significant burn damage, external or internal genitalia were clearly or partially detected in 81 cases (50%). In males, the penis and prostate were identifiable, while in females, features such as the breasts, vagina, labia, and uterus were distinguishable. However, one case involving partial pelvic organ damage resulted in misidentification; it was suggested that the rectum may have been misinterpreted as the uterus[9].

2) Sex Estimation Based on Bones Using Postmortem Imaging

(1) Estimation Based on Morphological Characteristics

There are few reports evaluating the accuracy of sex estimation based on morphological features of bones observed on rendered postmortem CT images used as substitutes for dry bones. In one study that estimated sex and age using a "virtual skeleton" created from postmortem CT, three anthropologists were able to correctly determine the sex of all individuals based on skull and pelvic morphology[10]. In another study, five cranial features (glabella, mastoid process, supraorbital margin, occipital protuberance, and mental eminence) were each scored from 1 to 5, and sex was estimated using discriminant analysis and decision tree methods. The reported accuracy was 88.1% using discriminant analysis and 90.4% using a decision tree[11].

Recently, methods have been proposed to objectively assess morphological features using 3D CT images by creating reference models and estimating sex based on deviations from these standards. A study using a homologous modeling approach to analyze the pelvis reported over 93% accuracy in sex estimation[4]. Other studies have used 3D image comparisons of the skull[5] and femur[6] to estimate sex based on their morphological differences. Furthermore, a study using 3D cranial images from postmortem CT employed supervised multi-instance learning, achieving an accuracy of 0.93, sensitivity of 0.92, and specificity of 0.95—surpassing the performance of forensic scientists[7].

(2) Estimation Based on Anthropometric Measurements

Sex estimation based on anthropometric measurements is often employed when bones are fragmented, when estimating younger individuals, or when objective data are needed to supplement morphological evaluations. In most cases, measurement values are applied to discriminant functions derived through statistical analysis. Because sexually dimorphic traits and discriminant formulas can vary depending on ancestry, the choice of method can affect the accuracy of estimation[1]. Therefore, selection of an appropriate method should be based on factors such as the preserved skeletal elements, estimated age, and estimated ancestry of the individual.

In studies involving Japanese populations, several methods using only postmortem CT measurements have been reported for the pelvis[12–14], femur[15], sternum[16], scapula[17], and mandible[18], with a wide range of measurement sites and discriminant formulas available. For example, in a study that measured 11 distances and angles of the pelvis, a discriminant function using only the subpubic angle achieved an accuracy of 98.1%, and a formula using the combination of the greater sciatic notch angle and the distance between the anterior superior iliac spine and the ischial tuberosity—both measurable from a single innominate bone—achieved an accuracy of 89.4%[12].

Additionally, non-linear models such as artificial neural networks have been applied. In one study, using measurements of the manubrium length, sternal body length, xiphoid process length, and sternal angle, the accuracy of sex estimation was reported as 0.906, with a sensitivity of 0.91 and a specificity of 0.90[8].

○ Literature Search Strategy and Selection

【PubMed】（#1～7：2023/8/31, #8, 9：2023/9/1）

#	Search formula	Number of articles
1	((postmortem) OR post-mortem) OR "post mortem"	157,132
2	(#1 AND imaging) OR (#1 AND CT) OR (#1 AND "computed tomography") OR (#1 AND MR) OR (#1 AND "magnetic resonance") OR (#1 AND MDCT) OR (#1 AND MSCT) OR (#1 AND X-ray) OR (#1 AND "X ray") OR (#1 AND Xray) OR (#1 AND roentgeno) OR (#1 AND radiograph) OR (#1 AND radiography)	34,362
3	((sex) OR gender) AND (((identification) OR estimation) OR dimorphism)	205,682
4	#2 AND #3	324
5	(victim) AND #3	2,470
6	(((((((((((imaging) OR CT) OR "computed tomography") OR MR) OR "magnetic resonance") OR MDCT) OR MSCT) OR X-ray) OR "X ray") OR Xray) OR roentgeno) OR radiograph) OR radiography	4,293,413
7	#5 AND #6	156
8	("Artificial intelligence" OR AI) OR "neural network"	1,205,093
9	#4 AND #8	4

【医中誌 Ichushi-Web (Japan Medical Abstracts Society Database)】（2023/9/1）

#	Search formula	Number of articles
1	((死後/AL) or (死亡時/AL)) and (((PT=会議録除く) and (FT=Y)) and (AB=Y))	4,805
2	((画像診断/TH or 画像診断/AL) or (X 線 CT/TH or CT/AL) or (MRI/TH or MRI/AL) or (X 線/TH or X 線/AL)) and ((FT=Y) and AB=Y and (PT=会議録除く))	533,250
3	(性因子/TH or 性別/AL) and ((FT=Y) and AB=Y and (PT=会議録除く))	27,818

4	#1 and #2 and #3	48

●Additional Sources Not Captured by the Search Strategy

References ［1］，［2］，［6］，［8］，［12］

■References

1） Saukko P et al：The establishment of identity of human remains. In：Saukko P, Knight B, eds. Knight’s Forensic Pathology 4th ed, p95-132, Boca Raton FL, CRC Press, 2016

2） Seta S et al : Danjosei no hanbetsu (Sex estimation). In: Seta S, Yoshino M, eds. Hakkotsu shitai no kantei (Analysis of skeletal remains), p108-152, Tokyo, Reibunsha, 1990 (in Japanese)

3） Dedouit F et al：Virtual anthropology and forensic identification using multidetector CT. Br J Radiol 2014；87：20130468（level 6）

4） Biwasaka H et al：A quantitative morphological analysis of three-dimensional CT coxal bone images of contemporary Japanese using homologous models for sex and age estimation. Leg Med 2019；36：1-8（level 4b）

5） Imaizumi K et al：Development of a sex estimation method for skulls using machine learning on three-dimensional shapes of skulls and skull parts. Forensic Imaging 2020；22 ： 200393（level 4b）

6） Fliss B et al：CT-based sex estimation on human femora using statistical shape modeling. Am J Phys Anthropol 2019；169：279-286（level 4b）

7） Kondou, H et al ： Artificial intelligence-based forensic sex determination of East Asian cadavers from skull morphology. Sci Rep 2023 ； 13 ： 21026（level 4b）

8） Oner Z et al：Sex estimation using sternum part lenghts by means of artificial neural networks. Forensic Sci Int 2019 ； 301 ： 6-11（level 4b）

9) O’Donnell C et al：Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster：experience gained from the 2009 Victorian bushfires. Forensic Sci Int 2011；205：15-28（level 5）

10) Grabherr S et al：Estimation of sex and age of "virtual skeletons"－a feasibility study. Eur Radiol 2009 ； 19 ： 419-429（level 4b）

11) Shim YT et al：Statistical classification methods for estimating sex based on five skull traits：A nonmetric assessment using 3D CT models. Homo 2023；74：45-54（level 4b）

12) Torimitsu S et al：Morphometric analysis of sex differences in contemporary Japanese pelves using multidetector computed tomography. Forensic Sci Int 2015；257：530.e1-530.e7（level 4b）

13）Biwasaka H et al：Analyses of sexual dimorphism of reconstructed pelvic computed tomography images of contemporary Japanese using curvature of the greater sciatic notch, pubic arch and

greater pelvis. Forensic Sci Int 2012；219：288.e1-288.e8（level 4b）
14) Hayashizaki Y et al：Sex determination of the pelvis using Fourier analysis of postmortem CT images. Forensic Sci Int 2015；246：122.e1-9（level 4b）
15) Chiba F et al：Sex estimation based on femoral measurements using multidetector computed tomography in cadavers in modern Japan. Forensic Sci Int 2018；292：262.e1-262.e6（level 4b）
16) Torimitsu S et al：Estimation of sex in Japanese cadavers based on sternal measurements using multidetector computed tomography. Leg Med 2015；17：226-231（level 4b）
17) Torimitsu S et al：Sex estimation based on scapula analysis in a Japanese population using multidetector computed tomography. Forensic Sci Int 2016；262：285.e1-285.e5（level 4b）
18) Kano T et al：Postmortem CT morphometry with a proposal of novel parameters for sex discrimination of the mandible using Japanese adult data. Leg Med 2015；17：167-171（level 4b）

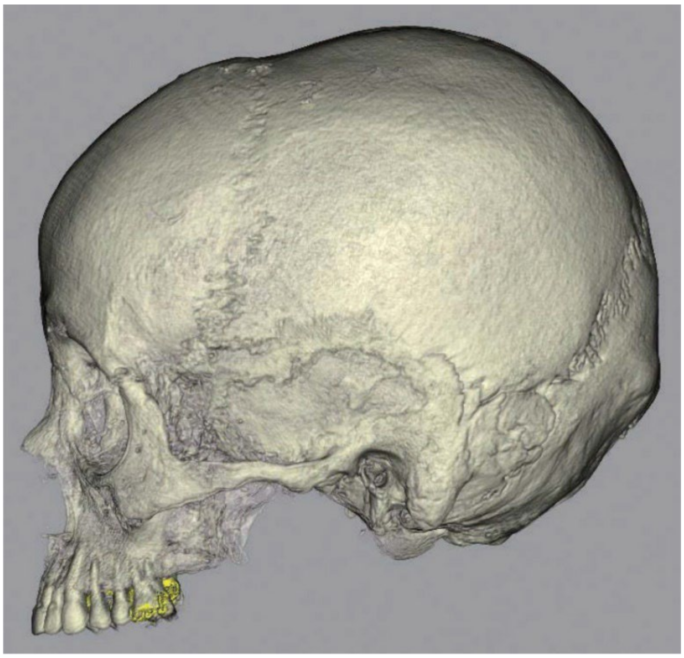

Figure. Woman in Her 80s Found in a Mountainous Area

Sex determination can be performed based on morphological features such as the frontal eminence and mastoid process. Dental restorations may assist in personal identification; therefore, imaging is conducted for all recovered remains.