SYSTEMATIC REVIEW

Anthropometric Measurements Analysis for Sex Determination in Human Ribs: A Systematic Review

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ABSTRACT

Introduction: Sex estimation is one of the primary aspects in determining the biological characteristics of an unknown adult skeleton. The variations between male and female skeletons can be attributed to a complex interplay of genetics, hormonal factors, culture, and environment. However, skeletal remains frequently found are often incomplete, with most sexually dimorphic bone like the pelvis and skull potentially absent. Hence, it is essential to conduct a comprehensive evaluation of multiple skeletal elements to attain a high degree of precision in sex estimation within forensic anthropology context. Ribs have been utilized in forensic anthropology for sex estimation since the 1980s, a comprehensive review of their sexual dimorphism is yet to be conducted. In this study, we examined various anthropological methods applied to ribs for sex estimation. **Method:** A systematic search was performed using PubMed, Science Direct, and Google Scholar from 2000 to 2020, retrieving a total of 10 articles that met the inclusive criteria. The search followed the main points outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. **Results:** This systematic review provides a comprehensive summary of the analytical approaches employed to estimate sex using human ribs. **Conclusion:** The findings revealed that different part of human ribs can be reliably used for sex estimation via metric method.
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INTRODUCTION

Sex estimation is an essential component of biological profiling in forensic anthropology (1). It serves as a critical initial step, enabling investigators to make accurate assessments regarding other aspects of the individual's profile, including age, race, and stature. Once the sex of the deceased is established, it eliminates a vast number of other possible counterparts and significantly narrows down the pool of potential matches.

While the pelvis and skull are commonly employed for sex estimation in forensic cases due to their reliability and displayed most sexually dimorphic features (2–5), it is essential to acknowledge that these bones may be absent or incomplete in the remains under examination. This is particularly important in cases involving large-scale civilian disasters, severely decomposed or mutilated bodies, those concealed in unusual locations, and situations where deliberate attempts have been undertaken to obscure the identification of the deceased (6,7). In such complex scenarios, the utilization of ribs and other available skeletal elements becomes imperative for accurate sex determination.

The focus of research on ribs has emerged as a growing field within forensic anthropology. Ribs has shown to have high accuracy rate for sex estimation due to its dimorphic features (8–10). Continuous research on ribs helps validate and refine sex estimation methods. New techniques and measurements can be tested and

compared to existing ones, leading to more reliable and accurate results.

Two main approaches are utilized for sex estimation using ribs: metric/morphometric and non-metric/ morphologic methods. In the morphologic approach, the outcome of sex estimation heavily depends on the qualitative assessment of variations in the shape and visual characteristics of the examined bone. Notably, the Iscan method is a frequently utilized technique for sex estimation from ribs (11,12). This method involves the examination of features at the sternal end, particularly the presence of pits, as indicators for sex determination. Nonetheless, this method has certain disadvantages. It is operator-dependent, meaning that the accuracy of measurements can vary depending on the individual conducting the assessment (13). Additionally, it may be deficient in providing critical information pertaining to the shape characteristics of the bone, which is an essential aspect that the morphometric method excels at delivering (10).

Morphometric approach entails the quantitative measurement of distances between specific anatomical landmarks on the bone or even a virtual representation of the sample(14). For instance, calipers are employed to directly measure the width and length of the rib bone, generating linear measurements and ratios that are subsequently used for sex estimation. With advancements in technology, the morphometric method has evolved beyond the use of calipers. Measurements can now be obtained from radiographs or CT scans, eliminating the need to measure directly on the bone (14,15). Geometric morphometric techniques take advantage of these advancements and provide an objective way to measure differences in skeletal shape (16). This approach involves converting identified landmarks into precise coordinates, allowing for a detailed representation of position, orientation, size, and shape (17,18).

This review discusses demographic information, methods and part of the ribs that has been used to estimate sex via various anthropometric approaches. The data collected from this review might assist forensic anthropologists in choosing the right method and anatomical structures such as landmarks when it comes to sex identification using ribs from skeletal remains.

METHOD

A systematic literature review was undertaken to identify relevant studies on various anthropometry methods for sex determination using human ribs in anthropological investigations. A comprehensive search was conducted on PubMed, Google Scholar, and Science Direct, spanning the period from 2000 to 2020. The search employed a combination of keywords to retrieve pertinent literature. Specifically, the keywords used in the search included: (i) anthropometric OR anthropometry, combined with (ii) sex OR gender, and (iii) human ribs OR chest OR ribs OR thorax OR thoracic cage OR ribcage. This search strategy was applied consistently across all three databases.

Research articles selection

The inclusion criteria for the selection of studies were as follows: (i) studies that provided a detailed description of the anthropometry method employed, (ii) studies focusing on the use of human ribs for sex determination, (iii) publication in English language, (iv) studies directly related to human ribs, and (v) studies involving the utilization of anthropological tools such as callipers, computed tomography (CT) scans, or X-rays. Conversely, the following criteria were used for exclusion: news articles, review articles, editorials, letters, case studies, and research that did not involve experimental methods or were not specifically associated with human ribs.

Data extraction and management

The literature review process followed three phases in accordance with the PRISMA guidelines(19). During the first phase, studies that did not meet the inclusion criteria based on the title were excluded. In the second phase, the abstracts of the remaining papers were assessed, and any studies that did not fulfil the inclusive criteria were also excluded. In the final phase, the full-text articles of the selected papers were obtained and thoroughly examined to ensure they met the inclusion criteria. Duplicate articles were identified and removed during these phases. To ensure reliability and accuracy, the eligibility of articles was assessed by at least two reviewers (NHZ and CKW). The title and abstracts were reviewed and if there is any disagreement, third reviewer will be appointed to review and decide.

For consistent data collection, independent extraction of data was conducted using a standardized data collection form. The following information was gathered from each selected study: (1) name and year of the author, (2) participant characteristics summarized briefly, (3) a concise description of the study's approach, (4) a summary of the research outcomes, and (5) study type.

RESULTS

Search results

During the literature search, a total of 1306 publications were initially identified as potentially relevant to the study. Through the evaluation of titles and abstracts, 1,287 articles were excluded as they did not meet the inclusion criteria. Subsequently, the remaining 19 articles underwent further evaluation and data extraction. Ultimately, only 10 articles met all the inclusion criteria and were selected for the final analysis. The rejected studies are mainly due to 1) sex estimation using ribs are not its one of study objectives 2) The studies measure kinematic function instead of morphology of the ribs 3)

the studies are not related to the forensic anthropological studies. The flowchart in Figure 1 provides a visual representation of the identification and screening processes, including the application of inclusion and exclusion criteria.

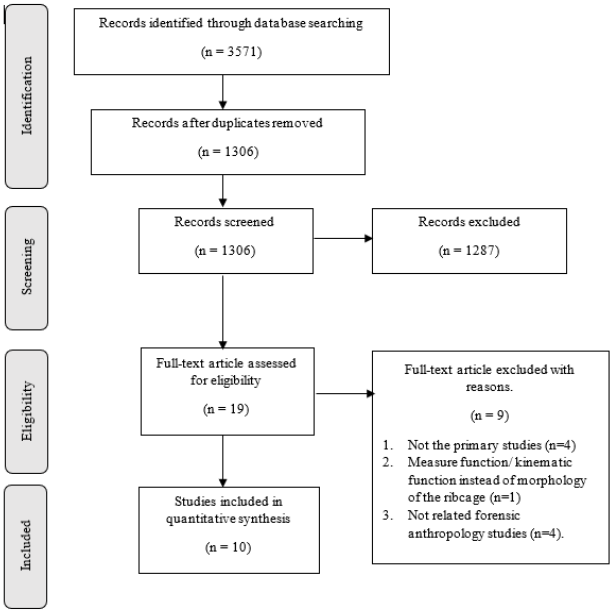

Figure 1: The PRISMA flow chart showing the selection process for systematic review

Study characteristics

The characteristics of studies published between 2000 and 2020 on sex estimation using human ribs are summarized in Table I. Among the included studies, eight utilized the conventional morphometric method, while two employed the geometric morphometric method. Table II provides information on the specific rib levels and parts used in these studies as well as its association with other part of the skeleton if available.

Data analysis

The extracted data from the selected articles were analyzed and organized into two categories: conventional metric method and geometric morphometric method. These two methods represent the main approaches utilized in the studies reviewed.

The conventional metric method involves the use of direct measurements, such as length and width, to assess sexual dimorphism in ribs. This method relies on traditional anthropometric tools and techniques. On the other hand, the geometric morphometric method utilizes advanced techniques to analyze the shape and form of ribs. This approach involves the use of landmark-based coordinates to quantitatively assess and compare rib shape variations between males and females.

The data extracted from the selected articles were presented and discussed based on these two methods, providing insights into the findings and outcomes related to sex estimation using ribs in forensic anthropology.

Conventional metric method

Bellemare et al. (2006)(20) explored the 3rd, 6th, and 9th ribs for sex dimorphism among Caucasians. The length and its ratio to the thoracic spine of the investigated ribs were studied and compared between sexes. The study showed the length of 3rd, 6th, and 9th ribs between males and females was not significant, thus not exhibiting any sexual dimorphism features. However, the ratio of 3rd, 6th and 9th rib length to body length and thoracic spine was significantly increased in female group compared to male group.

Kocaka et al. (2003) (21) investigated the viability of sternal end of the 4th rib to establish sex among Turkish population. Parts of the ribs which are the superior-inferior height (SIH), anterior-posterior breadth (APB) and medial pit depth (MPD) were measured. The study established SIH to be effective markers for sex estimation followed by APB. In the younger age group, the accuracy rate for sex determination using SIH is more effective than APB. Sex determination was possible in 86.1% for males, 91.7% for females and 88.6% on average. For the older age group, both SIH and APD were found to be effective for sex determination. The accuracy rate in this group was 85.1% for males, 90.5% for females and 86.5% on average. For the total group, sex estimation was possible in 85.5% of males, 87.2% of females and 86.1% for average. MPD was not effective for sex determination in both males and females.

Kubicka & Janusz (2015) (22) used 1st rib to estimate sex among Polish population. They used constructed 3D images from CT scan and measured the linear skeletal dimensions using landmarks placed in the rib body and sternal end. The parameters measured were stated in Table I. As a results, the average accuracy for the original group for rib body and sternal end was 80.9 % and 67.9 %, respectively. The percentages of correctly assigned individuals for the functions based on the rib body and sternal end in the cross-validated group were 76.6 % and 85.0 %, respectively. Higher average accuracies were obtained for stepwise discriminant analysis: 83.1 % for the original group and 91.2 % for the cross-validated group. The exterior edge, anterior-posterior of the sternal end, and depth of the arc were the most reliable parameter.

Darwish et al. (2017) (7) assessed sexual dimorphism of both right and left 4th rib among Egyptians. They used 3D images constructed from multi-slice CT scan to measure the distance between the most superior and most inferior edge of the rib just lateral to costochondral junction on the right and left 4th rib. The research concluded that both width of 4th rib revealed significant sex differences with the use of Multislice Computed Tomography 3D images.

Peleg et al. (2020) (10) estimated sex using 5th to 9th ribs among European-African-American population via

Table I: Summary of the studies that used human ribs to determine sex

Study title	Author and year	Participants	Intervention/ method	Comparison	Outcome	Study type
Sexual Dimorphism of Human Ribs.	Francois Bellemare, Tambwe Fuambaa,& Andre Bourgeault, [2006] (20)	• 46 fresh cadavers (23 males, 23 females). • Below 60 years old. • All were Caucasians (42 were from French-Canadian descendent).	• Conventional morphometric method. • The length of the 3rd, 6th and 9th was measured from the head of each rib to the end of the costal cartilage. • Body lengths were obtained from the pathological report. • Thoracic spine was measured.	• Length of ribs in 3rd, 6th and 9th ribs were compared between male and female. • The ratio between the 3rd, 6th and 9th ribs length to body length and thoracic spine is compared between male and female.	• The lengths of the 3rd, 6th and 9th ribs between male and female were not significant. • The ratio of 3rd, 6th and 9th rib length to body length and thoracic spine was significantly increased in female	Retro-spective.
Sex Determination from the Sternal End of the Rib by Osteometric Analysis	Aytac Kocak, Ekin Ozgur Aktasa, Suheyla Erturka, Safiye Aktasb & Ali Yemiscigila, [2003] (21)	• Autopsied subject • Turkish population • 78 females and 173 males of known age, sex, and race between 1994–1997 • Age group: 15–89-year-old	• Conventional morphometric method. • The sternal end of the right 4th rib • The parameters are defined as: i) Superior–inferior height (SIH) ii) Anterior-posterior breadth (APB) iii) Medial pit depth (MPD) • The sample was separated into 3 groups: 1. Young group (15–32-year-old) 2. Old group (33–89 years). 3. Total group (15–89 years). • The ideal function to determine sex was done using stepwise discriminant function analysis.	• Sternal end of 4th rib of young, old and total group was compared between male and female	• In the young group, the accuracy rate for sex determination using SIH is more effective than APB. Sex determination was possible in 86.1% for males, 91.7% for females and 88.6% on average. • For the old group, both SIH and APD are found to be effective for sex determination. The accuracy rate in this group was 85.1% for males, 90.5% for females and 86.5% on average. • For the total group, sex estimation was possible in 85.5% of males, 87.2% of females and 86.1% for average. • MPD was not effective for sex determination in both males and females.	Retro-spective
Sex Estimation from Measurements of the First Rib in a Contemporary Polish Population.	Kubicka Anna Maria & Piontek Janusz [2015] (22)	• CT images of the first right ribs • 223 Polish patients (108 females, 115 males) • Age group: 20-75 years old	• Conventional morphometric method. • The sample was divided into 2 • Group 1- for discriminant function development • Group 2- to test the accuracy of group A • A 3D reconstruction of the first rib was done via 3D Slicer software (version 4.4) • Linear skeletal dimensions were measured using GOM Inspect software (version V8) • Measurements collected from the right 1st rib: Length of the exterior edge (EE), Length of the interior edge (IE), Chord (C), Thickness (T), Depth of the arc (DA), Distance A (A): length of the chord to DA inferiorly, Distance B (B): length of the chord superiorly, Superior-inferior (SI), Anterior-posterior (AP). • The parameters were grouped into 3 groups: (1) all parameters (2) rib body (3) sternal end	• Each measurement was compared between males and females by: 1. Demarcation point 2. Direct discrimination function analysis 3. Stepwise discriminant function analysis	• Descriptive analysis: Significant differences were noted in all measurements except for B when compared between male and female A) Demarcation point: ➢ Group 1: ▪ The depth of the arc has the highest accuracy rate for females at 83.5% ▪ The thickness variable produced sex estimation at a high accuracy of 89.0%. ➢ Group 2: ▪ The depth of the arc obtained the highest accuracy rate for females at 87.0%. ▪ Sex estimation by distance A and anterior-posterior for males produce 100% accuracy. B) Direct discriminant analysis: ▪ All 8 measurements except B showed 87.1% accuracy for sex estimation for females and 75.8% for males. ▪ Cross-validation in Group 2 showed greater accuracy where sex estimation for females was 91.3% and 91.7% for males. ▪ The accuracy on sex estimation when 6 parameters were used (except SI and AP) showed 83.6 % for females and 78.1% for males. ▪ Cross-validation showed lower accuracy for both sexes, where 73.9% for females and 79.2 % for males. ▪ The accuracy rate for sex estimation when only 2 variables were used (sternal variable) showed 65.9 % for females and 69.2 % for males ▪ The accuracy rate was greater in the second group during cross-validation, where sex estimation was accurate at 78.3 % for females and 91.7 % for males. C) Stepwise discriminant function analysis: ▪ First discriminant analysis showed that EE, AP, and DA possess the greatest influence on correct assessment. ▪ 2nd discriminant analysis showed EE, DA, and T to have the strongest dimorphic features. ▪ 3rd discriminant analysis showed AP was stronger than SI.	Retro-spective

Table I: Summary of the studies that used human ribs to determine sex (continued)

Study title	Author and year	Participants	Intervention/ method	Comparison	Outcome	Study type
Sex Determination from Chest Measurements in a Sample of Egyptian adults using Multislice Computed Tomography	Ragaa T. Darwish, Manal H. Abdel-Aziz, Abdel-Aziz M. El Nekiedy & Zahraa K. Sobh [2017] (7)	• 60 adult Egyptian patients (30 males, 30 females) • Age range: 21-74 years old	• Conventional morphometric method. • Multi-Slice Computerised Tomography scans of the chest • 3D images were constructed and measured from the anterior view for 4th rib width (FRW). • Sex determination accuracy was compared using 1) student t-test 2) multiple regression analysis.	• The 4th rib was compared between males and females. • The right and left 4th rib was compared in each sex, respectively • The 4th rib was used for sex estimation using multiple regression analysis.	• There was a significant difference in the right and left width between both male and female sexes. • No significant difference between the right and left 4th rib width within the same sex • For sex estimation via multiple regression analysis, the accuracy for sex estimation using the width of the right and left rib was 72.68%	Prospective cross-sectional
New methods for sex estimation using sternum and rib morphology	Smadar Peleg, Pelleg Kallevag, Gali Dar, Nili Steinberg, Youssef Masharawi & Hila May [2020] (10)	The sample was divided into three samples: • The first sample was obtained from Hamann-Todd Human osteological collection with a total sample of 413. • The second sample was obtained from a CT scan from Israel with a total sample of 33. • The third sample was obtained from Anthropological Collection at Tel Aviv University with a total sample of 15.	• Conventional morphometric method. • Identification of ribs in the skeletal sample was performed using traditional tools like calliper and osteometric board. • The ribs were identified through side identification and ribs sequencing: • The ribs were measured by the Rib length (RL), Rib depth (RD), Rib tubercle to angle length (RTA). • Reconstruction of the ribs from CT stacks via a 3D surface mesh of the ribs from each. • Image samples from the second and third groups were constructed via Amira 6.3 software. • The landmarks were placed using Evan Toolbox software 1.72.	• The outcome for sex estimation using a complete set of ribs (5th-9th) was compared. • The method for sex estimation, either traditional (skeletal sample) or virtual (CT scan), was compared • The outcome using a complete set of ribs (5th-9th) and an incomplete set (single rib) was compared. • The outcome for sex estimation is compared when the ancestry is known or unknown	• Significant effect of size with 64% variance was observed on rib characteristic • Male has significantly larger ribs compared with females with $p < 0.05$ • In the skeletal sample, in a complete set of ribs, the success rate for sex estimation was >85% in both male and female • In the skeletal sample, with incomplete ribs with unknown ancestry, the sex estimation was at >80% for males and females. • In the skeletal sample with incomplete and known ancestry, the sex estimation was at >81% • During cross-validation (using equation created from the skeletal sample), a high success rate (>80%) were obtained for sex prediction for 8th right ribs for both male and female in an unknown ancestry condition • In cross-validation in known ancestry conditions, sex prediction for males and females was similar (at ~85%) based on the left 6th, 8th, and 9th rib.	Restro-spective
Sex and Age at Death Estimation from the Sternal End of the Fourth Rib. Does Iscan's method really work?	Alexandra Mucoz, Nuvia Maestro, Marna Benito, Josй Antonio Sбnchez, Nicholas Mбrquez-Grant, Daniel Trejo & Luis Rнos [2018] (12)	• 504 ribs with known sex and age from a morgue sample (444 males, 60 females) • Age range: 17 to 92-year-old • Mexican population	• Conventional morphometric method. • All the corpses underwent an autopsy procedure for sex and age identification prior to anthropological examination. • The relatives then provide official documentation to reveal the sex and age of death of the deceased. • Discriminant analysis functions were created for sex determination. • The ribs were measured by vernier calliper for: • Superior-Inferior Height (SIH) • Anterior- Posterior Breadth (APB) • To verify the Iscan method, the sample was divided into Iscan classification: • Male: • Iscan's Phase 1–4: n=40, Iscan's Phase 5–8:n=40 • Females • Iscan's Phase 1–4: n=40, Iscan's Phase 5–8:n=40	• The height and breadth of the sternal end of the 4th rib were compared between female and male	• Through univariate analysis, sex estimation in the total sample using APB and SIH was 73.6% and 79.3%, respectively. • Through multivariate analysis, using APB and SIH, correct sex estimation was at 80.6%. • Upon dividing the sample into the Iscan phase, sex estimation by univariate using SIH was at 82.8% for phase 5-8 and 83.4% for phase 1–4, and by multivariate analysis reached 81.7% and 84% for both groups of phases. • Cross-validation by univariate in SIH reached 78.7% for phase 1-4 and 90.0% for phase 5-8, while in APB, the sex estimation reached 73.7% in phase 1-4 and 78.7% in phase 5–8. • Correct sex assignment was obtained in 73.3% to 84% of the cases.	Retro-scpective
Morphometric analysis of variation in the ribs with age and sex	Ashley A. Weaver, Samantha L. Schoell & Joel D. Stitzel [2014] (23)	• 339 chest CT scans (168 males, 171 female) • Age range: 0–100 years.	• Geometric morphometric method. • Landmark was done via 3 methods • image segmentation • atlas development • image registration • Rib landmarks were analysed by Procrustes superimposition • A rib cage atlas was developed from the existing computer-aided design (CAD) geometry of a 50th percentile male thorax. • Grids of homologous landmarks were placed on each atlas rib at an even spacing of 1.7 mm.	• The shape and size of ribs in male and female were analysed at different age group • The changes of the shape (isolated shape) were analysed in male and female at different age group	• Significant changes in the size and shape variation in male and female. • Significant changes in shape variation only in male and female • A similar trend for males and females was observed on the ribcage's size increment from age 6 months to 20, 20 to 30 and 30-100 years old.	Retrospective

Table I: Summary of the studies that used human ribs to determine sex (continued)

Study title	Author and year	Participants	Intervention/ method	Comparison	Outcome	Study type
Sex Determination based on a Thoracic Vertebra and Ribs Evaluation using Clinical Chest Radiography	Shun Tsubaki, Junji Morishitab, Yosuke Usumotoc, Kyoko Sakaguchie, Yusuke Matsunobua, Yusuke Kawazoef, Miki Okumurad & Noriaki Ikeda [2017] (24)	• 600 chest radiograph (300 males, 300 females) of Japanese population. • Age range from the 20s to 70s and divided into six groups (20s, 30s, 40s, 50s, 60s, and 70s)	• Conventional morphometric method. • The widths of the 6th and 7th rib on a chest image were measured. • The 10th thoracic vertebrae were measured by the average of diagonal, horizontal and vertical length. • Sex determination was done via student t-test, linear discriminant analysis and stepwise discriminant analysis.	• The width of 6th and 7th ribs were compared between males and females. • The combined parameter (thoracic vertebrae and ribs) between males and females were compared.	• The accuracy rate for sex estimation using 6th rib is 81.7% and 82% for male and females, respectively and 81.8% in total. • The accuracy rate for sex estimation using 7th rib is 76.7% and 82% for males and females, respectively and 79.3% in total. • The combination between 10th vertebrae and 6th&7th ribs, the accuracy rate for sex estimation in male, female and total was at 87.3%, 90.3% and 88.8%, respectively. • Among the age group, the 20s age group showed the highest accuracy rate for sex estimation using the combined parameter (10th thoracic vertebrae, 6th, and 7th ribs), i.e. 96% for all categories (male, female, and total sample).	Retrospective
Morphological and functional implications of sexual dimorphism in the human skeletal thorax	Daniel García-Martínez, Nicole Torres-Tamayo, Isabel Torres-Sanchez, Francisco García-Río Markus Bastir [2016] (25)	• CT scan of the ribcage • 42 adults (18 males, 24 females) • Spanish population	• Geometric morphometric method. • Each thorax was segmented using the Mimics 8.0 software program. • The post-processing of the 3D surface models was carried out with Artec Studio software, and the final 3D thorax models were imported into Viewbox4 software. • 402 landmarks and sliding landmarks were mapped on each thorax.	• The size of the thorax between males and females was compared by calculating the distribution of the thoracic size in a neutral kinematic state • The shape of the thorax between males and females was compared. • The change of thoracic size during inspiration between males and females was compared.	• Male has a significant larger neutral kinematic state and functional size compared to female. • The male thoraces were wider, and the ribs were more horizontal than the female. • There was a significant difference in the shape change as a more horizontal disposition of ribs was observed in males than females. The shape changes in a different direction for males and females as the ribs shift caudally in males and cranially in females	Prospective
Analysis of Quantitative Methods for Rib Seriation Using the Spitalfields Documented Skeletal Collection	Sonya K. Owers & Robert F. Pastor [2005] (26)	• 133 adults from Crypt of Christ Church Spitalfields, London (59 females, 71 males, 3 indeterminate)	• Conventional morphometric method. • The ribs were measured for the following parameters: ➢ superior (anterior) costo-transverse crest height (SCTCH). ➢ The articular facet of the tubercle-to-angle length (AFTAL). ➢ Head-to-articular facet length (HAFL).	• The parameters (SCTCH, AFTAL, HAFL) were compared between male and female	• There was a significant difference in the SCTCH and AFTAL between males and females with p<0.001 as SCTCH and AFTAL were larger in males than females. • No significant difference was observed in HAFL between the male and female sample	Retrospective

Table II: Summary of the accuracy rate for sex estimation at different level of rib and its association with other bone

Author and Year	Rib Level	Part of Ribs	Method	Accuracy Rate (if available)	Association with other bone
Kubicka & Janusz (2015) (22)	1	Body and sternal end	Conventional morphometric	Rib body: 80.9% Sternal end: 67.9%	N/A
Bellemare et al. (2006) (20)	3,6,9	Length of the whole ribs	Conventional Morphometric	Not significant in length	Ratio is significantly increased in females.
Kocak et al. (2003) (21)	4	Body: Superior-inferior height (SIH), anterior-posterior breadth (APB), medial pit depth (MPD)	Conventional Morphometric	• Young group: 88.6% • Older group: 86.5% • SIH of the rib is the most reliable parameter; APB follows it.	N/A
Munoz et al. (2018) (12)	4	Height and breadth of sternal end	Conventional Morphometric	73.6%-79.3%	N/A
Darwish et al. (2017) (7)	4	Width of the sternal end	Conventional Morphometric	72.68%	N/A
Peleg et al. (2020) (10)	5-9	General shape, length, height	Conventional Morphometric	>85% accuracy rate when all parameters used	
Tsubaki et al. (2017) (24)	6	Width	Conventional Morphometric	81.7% accuracy (males), 82% accuracy (females)	Accuracy rate increased to 88.8% in combination with T10.
Shun Tsubaki et al. (2017) (24)	7	Width	Conventional Morphometric	76.7% accuracy (males), 82% accuracy (females)	N/A
Owers et al. (2005)(26)	1-12	Crest height (SCTCH), tubercle-to-angle length of the articular facet (AFTAL), head-to-articular facet length (HAFL)	Conventional Morphometric	Significant increases in SCTCH and AFTAL between sexes	N/A
Daniel García-Martínez et al. (2016) (25)	Various	Size and shape	Geometric Morphometric	Significant differences in size and morphology between males and females	N/A
Weaver et al. (2014) (23)	1-12	Size and shape	Geometric Morphometric	Significant differences in shape and size between males and females	N/A

Hamman Todd Human osteological collection. Results from the studies were cross-validated from the Israel population via virtual sample from CT scan. The general shape, length and height of the ribs were analysed and used. The rib's parameter used were as followed: 1) Rib length; 2) Rib depth; 3) Rib tubercle to angle length. When all the parameters used to estimate sex, the accuracy rate reached >85% in both males and females. However, when only part of parameters was used, with or without the ancestry information, the accuracy level was reduced to at least 80%. Of all the skeletal elements tested, left 6th. 8th and 9th were found to be the most reliable skeletal elements for estimating the sex of an individual.

Munoz et al. (2018) (12) tested the Iscan method on the Mexican population for sex determination via conventional morphometric method using sternal of the 4th rib. The maximum distance from the most superior point to the most inferior point of the sternal end (SIH) and the maximum distance between the most anterior and posterior points of the sternal end (APB) were measured. The accuracy rate for sex estimation for using both SIH and APB was 73.6% and 79.3%, respectively. When using both APB and SIH, correct sex estimation was at 80.6%.

Tsubaki et al. (2017) (24) used 6th and 7th ribs from the chest radiograph to determine the sex. The width of the 6th and 7th ribs was measured at the proximal clavicle with the central and bottom region of the lungs as a reference point. The accuracy rate for sex estimation using the 6th rib was 81.7% and 82% for males and females, respectively. As for the 7th ribs, the accuracy rate for sex prediction was 76.7% for males and 82% for females. When all parameters were used for analysis, the accuracy rate for sex estimation in male, female and total was increased at 87.3%, 90.3% and 88.8%, respectively. Among the age group, the 20s age group showed the highest accuracy rate for sex estimation using the combined parameter i.e., 96% for all categories (male, female, and total sample).

Owers et al. (2005) (26) determined sexual dimorphism using ribs seriation from a complete set of rib. The study was based on three metric variables that measured the crest height (SCTCH), tubercle-to-angle length of the articular facet (AFTAL) and head-to-articular facet length (HAFL). The parameters between males and females show significant increases in the size of SCTCH and AFTAL between the sexes ($p<0.001$). However, no significant difference was noted in HAFL between male and female samples.

Geometric morphometric method

Weaver et al. (2014) (23) analysed the variation of the human ribs in terms of size and shape according to sex. Chest CT scan images (399) were used in the analysis by placing landmarks on the image through 3 methods: 1) image segmentation, 2) atlas development and, 3) image registration. The landmarks were then analysed by Procrustes superimposition. The variation of the shape and size in male and female parameters were compared at different age groups. Significant differences between males and females were observed when the parameters were combined (shape and size) with $p< 0.0001$. Similar findings were found when only one parameter was used (shape only) with $p < 0.0053$. These results were applicable in all 24 ribs as significant differences were found to occur with age in males and females. Similar trends were observed for the male and female sample when parameter of size was used, where the ribcage increases in size starting from 6 months to 20, 20 to 30, and 30-100-years old age group.

García-Martínez et al. (2016) (25) studied the sexual dimorphism of the ribcage thorax among Spanish using CT scan images. The fixed and sliding landmarks were mapped on each thoracic with a total of 402 landmarks and sliding semi-landmarks. The mean shape of each individual between inspiration and expiration (neutral kinematic state) were calculated. All the data with regards to the size and shape data were analysed by Generalized Procrustes Analysis. The results showed that male has a significant larger neutral kinematic state and functional size compared to female ($p<0.05$). The male thoraces were also wider and more prominent at the lower thorax than females. Significant differences were also seen in the morphology of the ribs as a more horizontal disposition of ribs was observed in males compared to females.

DISCUSSION

Over the past 35 years, numerous attempts have been made to develop a reliable method for sex estimation using human ribs. In this systematic review, we analyzed ten articles that focused on anthropometric measurements of human ribs for sex estimation. Our findings shed light on the approaches used in estimating sexual dimorphism in ribs, the anatomical landmarks used in the study and the factors that may contribute to such dimorphism.

Approaches in sexual dimorphism determination in ribs

Two main methods have been adapted for anthropometry measurement as mentioned in this review. All the research except Ashley et al (23) and Bastir et al (25) utilised conventional morphometric approach using instruments such as calliper for measurement, osteometric board or direct measurement on the radiographs. No qualitative approach was used as part of the research involving ribs to estimate sex from year 2000-2020. This trend indicated the preference of current research on the newer method that is more reliable with higher validity (27).

Only 2 studies used geometric morphometric method

23,25). This method complements the disadvantage of the conventional morphometric by providing additional information such as overall shape (using coordinates) in addition to distance measurements and angles between landmarks (28). Studies also have shown that geometric morphometrics demonstrates higher reliability and reproductivity than the conventional method (28). One of the disadvantages of conventional morphometric is lower accuracy rate for biological profile estimation. Research has shown that conventional morphometric tend to cause measurement discrepancies of more than 0.5 mm, resulting in 73% overestimating and 27% underestimating the measurement length (29). Geometric morphometric on the other hand are capable to analyse big data and evaluate the overall shape of the thorax, including individual ribs using only virtual samples from the radiographic images. The trend of using geometric morphometric method supports the idea of even incomplete and fragmented ribs can be analysed and its sex can be determined. This is especially important when the experts for forensics anthropologist is not available for direct visualisation to determine the biological profile of the human remains or the complete length or breadth cannot be determined via conventional morphometric method. Thus, there are many opportunities for other researchers to embark on the geometric morphometric method that can used robust data to estimate biological profile.

Regarding sample types, it is interesting to note that radiological samples, such as X-ray or CT scan images, were frequently employed instead of direct bone samples (7,10,22). This is advantageous as it offers a non-invasive approach that does not require physical manipulation of the original samples.

Anatomical parts used in ribs as landmark for sexual dimorphism estimation

Various parts of the ribs have been used in this review. Apart from the sternal end, which has been the most extensively researched part of the rib since its introduction by Iscan (11), other parts of the rib that have been measured include the tubercle (28), length (20), width (7), exterior and interior edges of the ribs (22). With the emergence of newer methods like geometric morphometry, these rib parts were translated into landmarks and coordinates. This method allows for the grouping of landmarks based on their respective rib parts, enabling the estimation of sex using available rib parts, even when the ribs are fragmented.

The most commonly utilized ribs for sex estimation are the typical ribs, specifically the 4th to 10th ribs (10, 20, 21). This preference is likely because typical ribs constitute the majority of human ribs compared to atypical ribs. However, one study focused on an atypical rib, the 1st rib, due to its unique and easily identifiable morphological features (22).

This review also highlights the importance of using multiple parts of the same rib for greater accuracy in sex estimation. For instance, combining the length and height measurements of the 4th rib resulted in a higher accuracy rate compared to using a single landmark of the 4th rib alone (12). A similar effect was observed in a study by Kubicka et al., where the combination of all the landmarks of the 1st rib led to a significant increase in correct sex assessment (22). Furthermore, combining other bones with ribs enhance the accuracy rate of sex estimation. For example, combining the 10th thoracic vertebrae with the 6th and 7th ribs resulted in a high accuracy rate in estimating sex from the sample, indicating that incorporating other bones with ribs can improve the accuracy of sex estimation (24).

Factors affecting sexual dimorphism on human ribs

Several factors can contribute to dimorphism in human ribs. For instance, studies have indicated that women tend to have higher lung volumes relative to lung capacity, potentially accommodating for the displacement of lung and abdominal volumes during pregnancy (30). Differences in breathing patterns between males and females, with males exhibiting greater chest expansion and relying more on abdominal muscles, may also impact rib morphology (31). Sex hormones, including androgen and estrogen, have been shown to influence bone activity and may contribute to variations in rib morphology (32). Additionally, variations in physical activity levels, particularly in response to upper body exercises, may cause changes in rib shape and size due to the activation of different muscle layers attached to the ribs (33). Smoking behavior is also more common in males, and studies suggest that smoking reduces chest expansion, lung capacity, and maximum expiratory pressure (34,35). While smoking may not directly impact female lung function, the higher likelihood of smoking among males could contribute to changes in rib morphology through changes in respiratory function.

CONCLUSION

In conclusion, different part of human ribs can be reliably used to determine sex through two main anthropological method i.e., Conventional, or geometric morphometric method. Studies have shown that high accuracy rate in sex estimation is achieved by using different level of rib at the same time, and the geometric morphometric method has emerged as the latest technique in this field. However, it's essential to recognize that anthropological measurements, while valuable, may not encompass all the visual aspects of sex differences that humans are skilled at noticing. With the demonstrated reliability of using ribs for sex estimation, future studies that incorporate rib data, along with sexual dimorphism information from other skeletal elements, chemical analysis, DNA analysis, or odontology, hold the potential to provide a more comprehensive and multi-faceted approach to sex estimation from skeletal remains. This holistic

approach can enhance the accuracy and reliability of sex estimation while considering the varied and detailed nature of sexual dimorphism.

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