

Accuracy of Age Estimation from Right Fourth Rib in Male Libyan Population

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Abstract

Age estimation is an important component of forensic identification, particularly in unidentified skeletal remains and living individuals of undocumented age. The sternal end of the right fourth rib has been widely used for adult age estimation because it undergoes progressive age-related morphological changes involving pit depth and shape, rim configuration, wall thickness, and bone quality. This review summarizes the anatomical basis of fourth-rib age estimation, the İşcan and Loth morphological methods, factors affecting their accuracy, and the influence of population variation, with relevance to validation in the male Libyan population. It also reviews the application of computed tomography and three-dimensional reconstruction for assessment of the sternal rib end. Previous studies have demonstrated good intra-observer and inter-observer reliability for fourth-rib assessment; however, accuracy may vary according to age group, sex, and population, supporting the importance of population-specific validation, particularly in male populations. Studies using multislice and post-mortem CT have shown good agreement with direct skeletal assessment, supporting the use of virtual evaluation of fourth-rib morphology. Population-specific validation remains important because established standards may underestimate or overestimate age when applied to different populations, including male populations from different geographic and ethnic backgrounds.

Conclusion : Three-dimensional CT assessment of the sternal end of the right fourth rib is a reliable and valid method for age estimation, showing good comparability with direct skeletal assessment. Its non-invasive nature also supports its application in living individuals.

Keywords: Age estimation; Right fourth rib; Sternal rib end; İşcan method; Loth method; Forensic anthropology; 3D-CT; Morphological assessment; Population variation.

Introduction

When human remains are found, the first priority of the investigation is to ascertain the identity of the deceased. The first step in the identification process is to build up a biological profile, which is a general description of the individual's ancestry, sex, age-at-death, and stature [1].

Age estimation of unidentified adult human remains relies on standards that have used reference populations of known age, sex, and ancestry to correlate various signs of skeletal degeneration and remodeling with different life stages and their associated chronological age ranges. Skeletal growth and degeneration are non-uniform across time and regions due to complex relationships with genetics, environment, socioeconomics, and behavioral influences.

The fourth rib approach is one of the suitable methods used to estimate age-at-death from adult skeletal remains [2,3].

İşcan and colleagues based their method on McCormick's observation of age-related costal cartilage ossification. They developed an eight-phase system focused on age-related changes to the sternal rib ends of the fourth rib. Their method has been widely tested and is generally accepted as a reliable, replicable, uni-modal indicator for estimating age [4-6].

Hartnett [7] revised the İşcan et al. methods by combining the male- and female-specific approaches and reducing the number of phases from eight to seven by truncating the younger phases. This method has been found to be reliable for modern populations.

The aim of the study was to determine the accuracy of age estimation of the male Libyan population (both skeletal remains and living individuals) using right fourth rib via direct morphological assessment and 3D-CT scan applying the İscan and Loth method.

Thoracic Cage

The thoracic cavity consists of 12 pairs of ribs, the sternum, the clavicles, and the thoracic segment of the spine. The ribs are flat, elastic bones that articulate anteriorly with the sternum and posteriorly with the vertebral bodies. They can be classified as true, false, or floating according to their sternal articulation, or as typical or atypical according to their morphology [8].

Ribs are classified according to their anterior attachment as true, false, and floating ribs. The first seven ribs are true ribs because they attach directly to the sternum through their costal cartilages, whereas ribs 8–10 are false ribs because they attach indirectly through the cartilage of the rib above. The eleventh and twelfth ribs are floating ribs because they lack an anterior costal attachment. Morphologically, the third to tenth ribs are considered typical and are characterized by a body, neck, head, and tubercle that form the costovertebral and costotransverse joints [9].

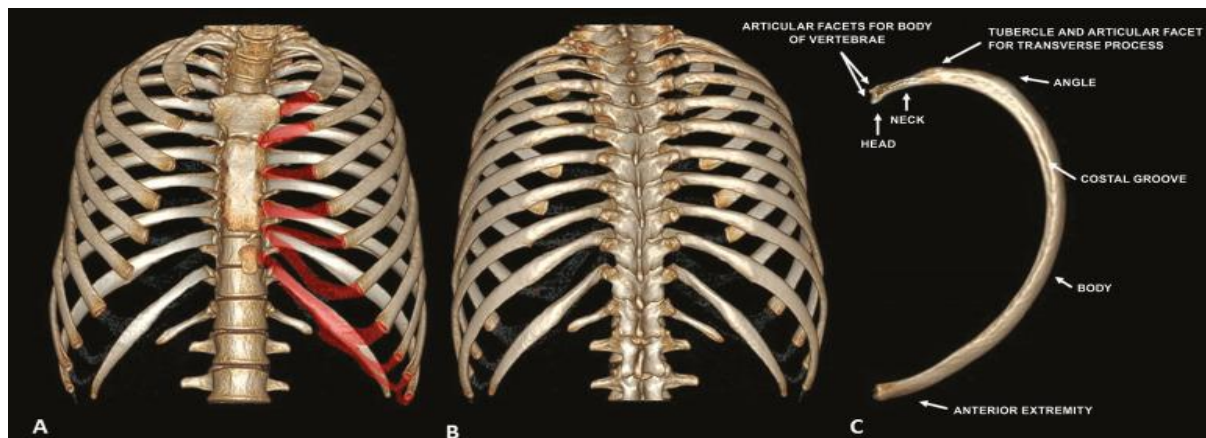


Figure (1): Anatomy of the ribs. Three-dimensional reconstructions showing the usual anatomy of the ribs in a young adult [10].

Fourth Rib

On the posterior thorax, the fourth rib can be found at the level of the medial end of the spine of the scapula [11]. On the anterior thorax, the fourth rib is located superior to the fifth rib, inferior to the third rib, and lateral to the fourth costal cartilage. It articulates with the fourth costal cartilage at the fourth costochondral joint and with the third and fourth thoracic vertebrae at the fourth costovertebral joint [12].

The fourth rib is one of the seven true ribs of the thoracic cage. It is considered a typical rib because it consists of a head with two articular facets, a neck, a tubercle, and a body. The fourth rib is classified as a flat bone and includes the following bony features [9]:

- **Parts:** head, neck, tubercle, body, and costal end.
- **Surfaces:** internal and external surfaces, with superior and inferior borders.
- **Landmarks:** angle, costal groove, crests on the head and neck, and articular facets on the head and tubercle.

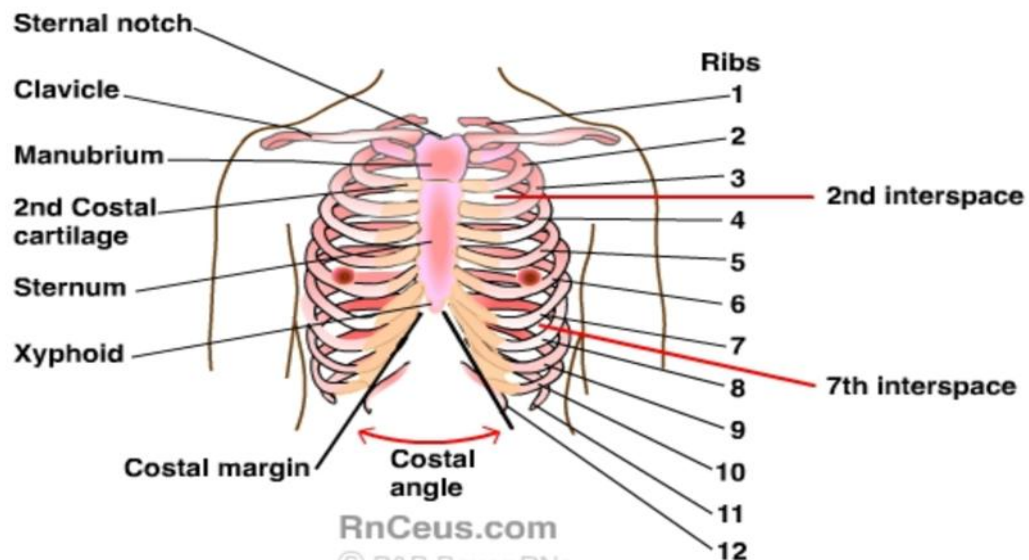


Figure (2): Landmarks of the bony thoracic cavity anatomy [13].

Development and Ossification of the Fourth Rib

The fourth rib, like the other ribs, develops embryologically from the differentiation of somites. Somite formation starts when the paraxial mesoderm begins to form somitomeres, which subsequently aggregate and form somites [13].

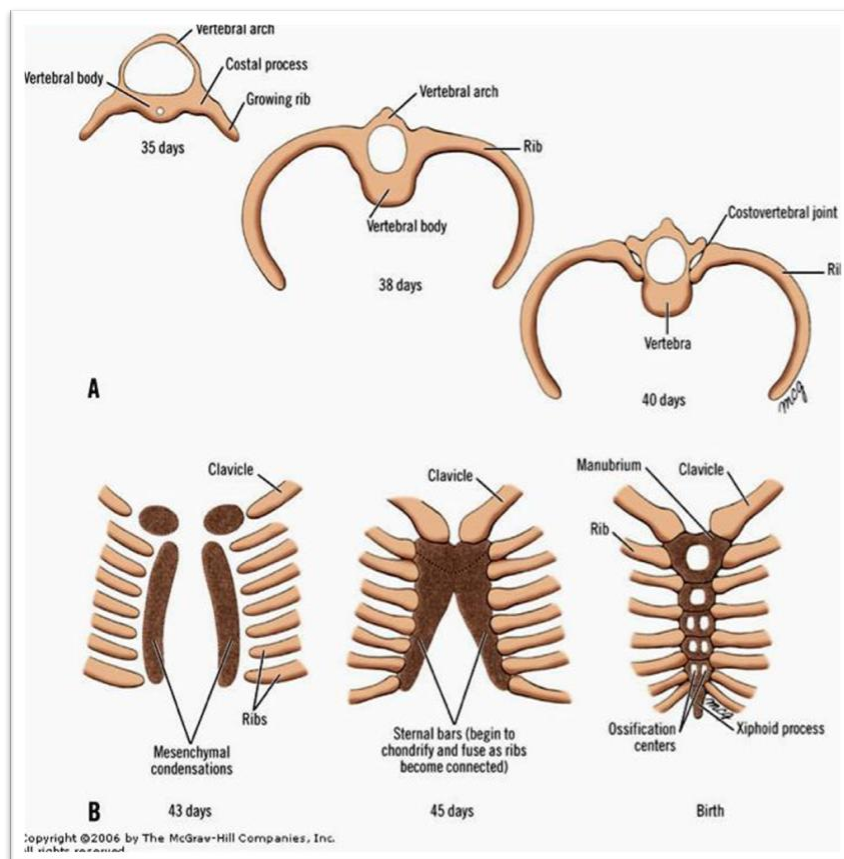


Figure (3): Development of ribs and sternum [14].

Ossification of the fourth rib occurs at several ossification centers [15]:

- The body, which appears in utero during the second month.
- The head, which appears during puberty.
- The tubercle, which appears during puberty.

The ossification centers of the head and tubercle fuse with the body of the fourth rib between the fourteenth and twentieth years [16].

Variations of the Fourth Rib

Variation in rib morphology may occur between individuals and between males and females. The volume of the rib cage is smaller in females than in males, whereas the cranio-caudal inclination of the ribs is greater in females. The ribs of females also grow longer relative to the axial skeleton. Other variations include developmental deformities and cervical or short ribs [17].

Regarding the fourth rib specifically, it may occasionally be fused with adjacent ribs, while its costal end may have a bifid appearance [17].

Age Estimation

Identification of human remains almost always involves assessment of the age at death of the individual. Although aging phenomena occur in non-bony tissues, osseous tissues and teeth have traditionally been at the core of most age-estimation methods because of their persistence after decomposition [18].

In forensic cases, determining age at death and year of birth are two sides of the same issue [19]. A fundamental assumption of most forensic anthropological methods is that biological age more or less follows chronological age. Chronological age is the calendar age expressed in years, whereas biological age refers to how aging affects the body and how these effects can be observed [20].

Generally, most age-assessment methods rely on identifying age-related skeletal characteristics and assigning these characteristics to a system of stages or scores, resulting in an estimated age interval [19].

Methods used to estimate age in adults have changed considerably throughout the development of forensic anthropology. Increasing attention has been directed toward the observation that age-estimation techniques developed using one study sample may not necessarily be applied to other samples with the same level of confidence.

Adult age estimation is generally more complex than age assessment in subadults because adult methods depend primarily on progressive degenerative and remodeling changes rather than predictable developmental events. The expression and timing of these changes may show considerable biological variability.

Macroscopic Morphological Age Estimation

Macroscopic morphological methods are commonly used in adult skeletal age assessment. These methods rely on visible age-related alterations in skeletal structures and classify these changes into phases or stages corresponding to particular chronological age ranges.

Several skeletal structures have been used in morphological age estimation. Among these, the sternal rib end represents an important site because the bony rib articulates with the costal cartilage in this region.

The sternal rib-end method described by İşcan et al. has a practical advantage in forensic anthropology because this region is readily accessible during autopsy. The rib cage is usually opened as part of routine examination, allowing the fourth rib end to be recovered and prepared relatively easily [21].

Age-related changes in the joint surface are tabulated and related to broad age categories, allowing the investigator to compare the morphology of the rib end with established phase descriptions [22].

A major issue with morphological methods is whether the characteristics used for classification are sufficiently well defined to avoid excessive intra-observer or inter-observer variation. Quantification of observer variability is particularly important in forensic anthropology. Continued assessment of method validity, including intra-observer and inter-observer evaluation, is therefore necessary [23].

Radiological and CT-Based Age Estimation

Radiological assessment has also been applied to forensic age estimation. Imaging techniques permit skeletal structures to be evaluated when direct removal or preparation of bone is not feasible.

Several established morphological age-estimation methods have been investigated using computed tomography scans and three-dimensional visualizations. Early investigations compared CT images and 3D reconstructions directly with established morphological phases, including phases used for assessment of the sternal rib end [24].

The increasing application of CT provides the possibility of visualizing skeletal structures without direct destruction or preparation of the bone. Three-dimensional reconstructions may permit morphological features to be examined from different orientations, while stored digital images can be reassessed by the same or different observers.

The application of CT to conventional skeletal age-estimation methods is particularly relevant when the same anatomical structures are to be assessed in both skeletal remains and living individuals. However, CT-based assessment requires evaluation of whether the morphological characteristics observed in reconstructed images can be interpreted with adequate reliability.

Population Variation

Forensic anthropologists must consider the influence of population variation on skeletal aging. Such variation may reflect genetic differences as well as socioeconomic, environmental, and nutritional influences. Research has therefore increasingly focused on testing methods developed from one skeletal collection or geographic region in other populations.

Age-estimation standards developed using one reference population may demonstrate different levels of accuracy when applied to another population. Population-specific validation is therefore an important part of assessing the performance of established forensic age-estimation methods.

Muñoz et al. tested published standards for estimating age from the sternal end of the fourth rib in a contemporary Mexican sample. The study included 444 males and 60 females of known age at death ranging from 17 to 92 years. Application of the published standards resulted in underestimation of age [25].

These results demonstrate that variation between reference populations may affect the relationship between a particular morphological phase and chronological age.

Estimating Age in Living Individuals

Some forensic situations require age estimation in living individuals. These cases may relate to migration, juvenile or adult legal status, undocumented age, and other circumstances in which reliable chronological-age documentation is unavailable [26].

Methods used for living individuals differ from those applied to skeletal remains because direct examination of skeletal structures is not possible. Imaging techniques therefore have an important role in evaluating age-related skeletal characteristics in living persons.

Radiological approaches, including conventional radiography, CT, and magnetic resonance imaging, have been investigated for age assessment using different skeletal structures.

Age estimation in living individuals remains challenging because of the limited skeletal information directly available, ethical issues associated with radiographic and invasive procedures, and the complexity introduced by population variation [19].

Rib-Based Age Estimation

The human skeleton provides valuable information regarding an individual's age, and the ribs are among the skeletal elements examined for this purpose. Rib bones undergo age-related changes that can provide information for age estimation [27].

Several methods have been developed to estimate age based on rib morphology and histology. Features evaluated by these methods include rib length, sternal rib-end morphology, changes in rib-shaft curvature, and the presence of primary and secondary ossification centers [28].

The accuracy of rib-based age-estimation methods has been evaluated in several studies. Although these approaches can provide useful age estimates within certain age ranges, no age-estimation method is completely

accurate, and limitations related to biological variation and methodological application should be considered [29].

Effect of Age on Rib Morphology

Age-related changes occur not only at the sternal end of the rib but also in the overall shape and orientation of the ribs.

Kent et al. described an age-related effect on rib angulation in an adult male population. Ribs were found to become more horizontally oriented in the sagittal plane with increasing age [30].

Holcombe et al. examined landmarks obtained from adult male rib cages and described progressive rounding of the rib cage with increasing age [27].

Other investigations have similarly reported changes in rib angle and overall thoracic morphology with advancing age. These findings demonstrate that aging produces progressive alterations in rib morphology, although fourth-rib age-estimation methods primarily focus on changes occurring at the sternal rib end.

İşcan Method

İşcan et al. established a standard technique for age estimation based on morphological changes occurring at the sternal end of the right fourth rib [21].

The technique divides progressive age-related changes into nine phases numbered from phase 0 through phase 8. The right fourth rib was selected because of its accessibility during medical and forensic examination.

The method evaluates several characteristics of the sternal rib end, including its form, shape, texture, and general bone quality [21].

In younger individuals, the medial surface of the sternal rib end is relatively flat and billowy. As age increases, a pit develops in the central portion of the rib end and progressively becomes deeper and wider.

The rim also changes progressively with increasing age. It initially has a relatively rounded appearance, subsequently becomes scalloped, and eventually develops an increasingly irregular configuration.

Bone quality also changes. In younger individuals, the bone is generally solid and dense, whereas progressive aging is associated with thinning of the bone and increasing porosity [21].

Morphological changes at the medial end of the fourth rib result from progressive remodeling. Increasing age is associated with gradual deepening of the sternal joint and thinning of its walls [21].

İşcan et al. initially examined right fourth ribs from 118 Caucasian males between 17 and 85 years of age. Subsequent work examined female specimens and developed corresponding sex-specific standards [21,5].

The descriptive system consists of nine phases from 0 to 8. Phase assignment is fundamentally based on characteristics including the depth and shape of the rib articulation, configuration of the rib edge, thickness of the rib walls, and general condition of the rib [21].

Because sex and ancestry may influence rib aging, separate standards were originally developed for males and females. The phase system has subsequently been tested and applied to other populations [31].

İşcan and Loth Method

The technique proposed by İşcan et al. and İşcan and Loth estimates age at death on the basis of degenerative changes occurring at the sternal end of the fourth rib [21,32].

The method consists of nine phases of degenerative progression graded from phase 0 to phase 8. Morphological changes occurring in the osseous portion of the rib were found to be related to age at death.

The precision of phase assignment was evaluated in the original investigations, with relatively limited interobserver error. Estimated phase assignments generally differed from the expected phase by no more than one phase [21].

Morphological features involved in phase assessment include pit morphology, rim configuration, wall thickness, and the general condition and quality of the rib.

İşcan et al. also reported that several factors may affect the normal aging pattern of rib ends. These include physical activity, heavy labor, endocrine disorders, chronic lung disease, drug use, sex differences, diet, and intercostal variation [21].

Correct identification of the fourth rib, intercostal variation, and sex differences were considered particularly important when applying this method [21].

Applicability of the Right Fourth Rib

The right fourth rib represents the standard rib used in the İscan technique. Investigators have therefore evaluated whether age-estimation standards developed for the right fourth rib can be applied to other ribs.

Yoder et al. examined right and left ribs II through IX to determine whether the aging technique developed for the right fourth rib could be applied to other rib levels. A total of 249 samples from three skeletal collections were examined [33].

The study included both males and females aged 10 years and older. Left ribs IV–IX did not differ considerably from the right fourth rib. However, significant differences were observed between the right fourth rib and some other rib levels [33].

The right second rib and left third rib showed differences from the right fourth rib. The left third rib was also reported to differ significantly from the right fourth rib in males but not in females [33].

These findings demonstrate that intercostal variation must be considered when applying standards developed specifically for the right fourth rib.

Accuracy and Reliability of Fourth-Rib Age Estimation

Previous work has suggested that the sternal end of the fourth rib exhibits less variation than the pubic symphysis and may be associated with less inter-observer error. The fourth rib has also been considered useful in older adults, in whom some other skeletal age indicators may become less accurate.

However, the fourth-rib method has been questioned regarding population variability, bias, and reproducibility [34].

Saunders et al. tested the validity of techniques developed by İscan et al. and İscan and Loth and supported their usefulness for estimating age at death [35].

However, they found that age was generally underestimated as chronological age increased. Bias and inaccuracy also increased among older individuals [35].

Fanton et al. reported problems related to reproducibility and repeatability during assessment of the sternal rib end. Difficulties included imprecision in the assessment of pit depth and inadequate consideration of pit shape, rim configuration, and wall morphology [36].

Hartnett also investigated the accuracy of age-at-death estimation from the sternal end of the fourth rib. Differences were reported between observed and actual ages together with inter-observer variation [7].

Hartnett emphasized the importance of bone quality and density in phase assignment and in revisions of the original fourth-rib aging method [7].

Fourth-Rib Age Estimation in a Tunisian Male Population

Haj Salem et al. evaluated the validity of the İscan method in a Tunisian male population [37].

The study included 108 sternal ends of fourth ribs obtained during forensic autopsies. Two observers independently assigned each specimen to an İscan phase.

A good correlation was reported between the estimated İscan phase and the phase corresponding to chronological age. Correlation coefficients of 0.758 and 0.717 were reported for the two observers [37].

Intra-observer agreement was also good. Agreement was better for phases below phase 5, and the method showed better performance in individuals younger than 39 years [37].

Two-Dimensional and Three-Dimensional CT Assessment of the Right Fourth Rib

Dedouit et al. evaluated the application of the İscan method to two-dimensional and three-dimensional multislice computed tomography imaging of the sternal end of the right fourth rib [38].

Morphological characteristics of the rib ends were assessed both directly and using reconstructed CT images.

Good intra-observer and inter-observer reliability were reported for CT-based assessment. Agreement between phases obtained through direct examination of bone specimens and those obtained using multislice CT reconstructions was also good [38].

Morphological features of the sternal rib end could therefore be evaluated using reconstructed CT images.

The study demonstrated reproducibility between the results obtained from MSCT reconstructions and those obtained from direct examination of dry fourth-rib specimens [38].

Post-Mortem CT Assessment of the Fourth Rib

Richard et al. evaluated a post-mortem CT method for age estimation based on degenerative changes occurring at the sternal end of the fourth rib in a French population [39].

The study included 250 post-mortem CT examinations from individuals aged 18 to 98 years [39].

The sternal end of the right fourth rib was evaluated by two radiologists using an approach adapted from the İscan method.

Both intra-observer and inter-observer reliability were high, and fourth-rib scores demonstrated a strong relationship with chronological age [39].

Despite the high reproducibility of the scoring system, individual age-prediction intervals remained relatively wide [39].

Conclusions

Three-dimensional CT assessment of the sternal end of the right fourth rib has shown good reliability and validity for age estimation. CT-based morphological evaluation can provide results that are highly comparable with direct skeletal assessment, while offering the additional advantage of being non-invasive and applicable to living individuals. This supports the use of 3D-CT as a practical alternative for evaluating age-related morphological changes of the fourth rib.

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